# LONGWOOD - integrating woodland history and ecology in a geodatabase through an interdisciplinary approach

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## ABSTRACT

Forests in Europe have been shaped considerably by human activities during most of the Holocene. Changes in forest structure, distribution of tree species and forest biodiversity are partly driven by management history, and many current forest types result from former management. The interdisciplinary project "Long-term woodland dynamics in Central Europe: from estimations to a realistic model" (LONGWOOD) aims to reconstruct long-term dynamics of woodland cover, structure and management in the eastern Czech Republic (Moravia, ca. 27,000 $km^2$), compare the historical and present state of forests, and analyze general patterns of changes and stability of woodlands as well as the role of humans in these processes. In the LONGWOOD project, palaeoecological, archaeological, historical and ecological sources of information on woodland cover, species composition, and human activities (management, settlement density) over the past 7500 years are collected and integrated in the form of a geodatabase. Combining data of different origin, scale, degree of spatial precision and detail into a single geodatabase is a challenging task. The level of detail, information content, and spatio-temporal distribution of data varies between layers as well as individual records according to the nature of the data source and the data itself. The limited and incomplete sources of information until ca. 1100 AD provide a coarser view on forest history while the historical period (especially the past ca. 250 years) is covered by large amounts of precisely located ecological and historical data enabling detailed spatial and temporal analyses. Data on forest structure, history and management will be related to environmental factors (soil type, climate, elevation and other topographic variables derived from DEM) and social historical data (settlement distribution, population density, landuse). A spatio-temporal forest landscape model will be built to assess the forest changes and the main drivers of change.

**Keywords**: geodatabase, interdisciplinary approach, forest history, spatio-temporal data analysis

## 1. INTRODUCTION

Although forest vegetation patterns are considered to be driven mainly by natural conditions, in European landscapes they were shaped by human activities for millennia. Humans influenced forest composition at various intensities and spatio-temporal scales (Peterken 1996[1]; Vitousek et al. 1997[2]; Sanderson et al. 2002[3]; Rackham 2003[4]). Throughout history, Central Europe has been transformed from a landscape of mixed deciduous forests into an agricultural area with islands of closely managed forests, many of them spruce plantations. Forest cover was gradually reduced and existing forests were managed under various regimes. Especially in lowlands, already in the Middle Ages forests were sparse and the need for wood considerable, which resulted in intensive management (coppicing). This profoundly altered forest structure and species composition. Long-term effects of human management modified forest species composition both directly by introducing new species and harvesting selected species and genotypes, and indirectly by favouring certain species by management practices (Gil et al. 2004[5]; Urbieta et al. 2008[6]). Today, only a small portion of forests approximates to what is regarded as natural species composition. Plantations of fast growing species are common even in the lowlands, and many

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new tree species were introduced, some of which became invasive (e.g. black locust, Eastern white pine, Carolina poplar or Northern red oak). These changes represent a threat to native flora and fauna.

Even if many studies on human induced historical landscape changes exist, significant gaps remain in the knowledge of forest dynamics. Early phases of deforestation (earlier than past ca. 200 years for which statistical historical sources are available) are usually inferred from changes in population density and are therefore only roughly assessed, without using data on past vegetation (Williams 2000[7], Olofsson & Hickler 2008[8], Kaplan et al. 2009[9]). Woodland management before modern forestry is often considered to be sporadic, and historical changes in tree species composition are usually interpreted as natural processes. Although there exist many local case studies, regional studies using large data sets of historical records or integrating several scientific disciplines are rare. Knowledge of forest history (composition, structure and management) helps us to understand the role of humans in shaping the forest environment and to explain general patterns behind the processes of change. History is crucial for the understanding and management of European natural heritage (Willis & Birks 2006[10]). To accomplish this task, we need to overcome the separation of natural and social sciences, and integrate geography, ecology and history to better describe landscape socioecological processes.

In the interdisciplinary project "Long-term woodland dynamics in Central Europe: from estimations to a realistic model" (LONGWOOD, funded by the European Research Council 2012-16 – www.longwood.cz) we aim to reconstruct long-term dynamics of forest changes focusing on human activities influencing the forests both directly and undirectly. The project integrates several disciplines (Table 1) in the fields of ecological (palaeoecology, vegetation ecology) and historical sciences (archaeology, history). Information on woodland cover, species composition and human activities (management, settlement density, land use) over the past 7500 years is integrated in the form of a geodatabase with high temporal and spatial resolution. This database serves as the basis for a spatio-temporal forest landscape model to assess changes in woodland and the main drivers of change.

| Fields of science | Precision of dating | Density of data through time | Time period covered | Distribution over the study area | Details on forests |
|---|---|---|---|---|---|
| Archaeology | low to medium | high | very long | good | very low |
| History | very high | low to medium | long | very good | low to high |
| Palynology | medium | very high | very long | poor | medium to high |
| Vegetation Ecology | very high | low to medium | short | very good | very high |

Table 1. Differences in resolution, coverage and detail among the disciplines involved.

In our research, we test several hypotheses, which among others include the following:

- Throughout history, the distribution of tree species is driven not only by the natural conditions but also by the management. Many current forest types result from former management.
- Historical changes in tree cover, composition and structure influence the herb understorey biodiversity.
- Forest cover, type and management intensity are correlated to population density and environmental conditions.

## 2. METHODOLOGY

The LONGWOOD project studies the eastern part of the Czech Republic (Moravia and the Czech parts of Silesia, ca. 27 000 km$^2$ with more than 3500 settlements, Figure 1). Moravia is a well-defined geographical unit, surrounded by mountains from three sides (Hercynian Mts and Carpathians), and by the rivers Morava and Dyje from the fourth side. The main vegetation types include thermophilous oak (south), oak-hornbeam (lower elevation), beech (higher elevation), and natural spruce forests (above 1000 m a.s.l.). This region was chosen because (i) it has existed in a relatively stable form since ca. the 11th century; and (ii) it includes a variety of natural conditions and forest types offering relevant comparative material for other parts of Central Europe.

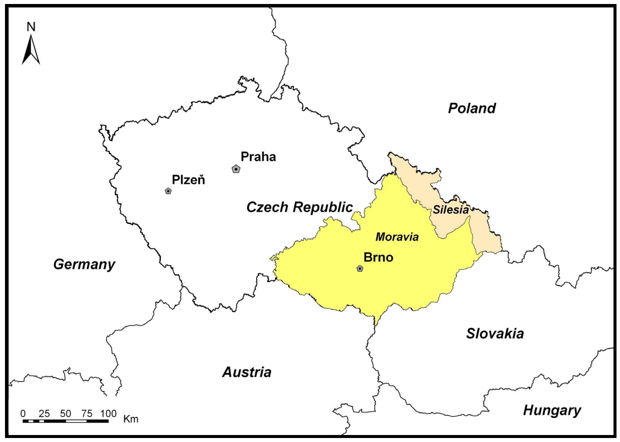

Figure 1. Location of the study area.

The LONGWOOD interdisciplinary project proceeds through the following phases:

1. the creation of historical, paleoecological and archaeological geodatabase of the past 7500 years (the time frame depends on the scientific discipline, see Table 1)
2. the analysis of information on forest cover, species and management in relation to environmental factors and archaeological and social historical data in order to establish the main drivers of stability and change, and to assess the role of humans in forest dynamics
3. the creation of a spatio-temporal forest landscape model
4. the comparison of the analytical results and the model to approaches currently employed in forestry and nature conservation and the preparation of guidelines for conservation and management.

Data of varying degrees of spatial precision, origin, accuracy and detail are collected. Because of these discrepancies, four separate coverages (archaeological, historical, palynological, ecological) were built in Microsoft Access to constitute the LONGWOOD geodatabase. Data is continuously fed into the geodatabase, and the database is planned to remain open after the termination of the project, making it a valuable resource for future research. Records are stored with metadata on data source and author to enable returning to the source in the future. The geodatabase contains information on woodland cover and species composition, as well as archaeological and social historical data on management and population. Its structure is flexible to include any new findings and relevant information found in archives. Coverages of the geodatabase include:

1. **Archaeological** coverage collects available records of human activities (living, burying, mining, etc.) in various forms of community areas (settlement, burial ground, quarry, pottery workshop, hillfort, etc) from the Mesolithic–Neolithic transition (ca. 7000 BC) until the 13th century AD. As there is no centralized robust database of archaeological records in the study region, specialized databases for archaeological heritage management (State Archaeological List[14], MEGALIT[15]) are combined with data from published papers and records of past archaeological research kept at the Archives of the Archaeological Institute of the Czech Academy of Sciences in Brno. In the LONGWOOD database, the records are geolocated using settlements and cadastral units (for the structure, see Figure 2). Although there is usually no direct information on forests in archaeological records, it is possible to reconstruct and model settlement and population density (Zimmermann et al. 2009[16]) and provide some evidence on agricultural activities to infer the progress of landscape deforestation.

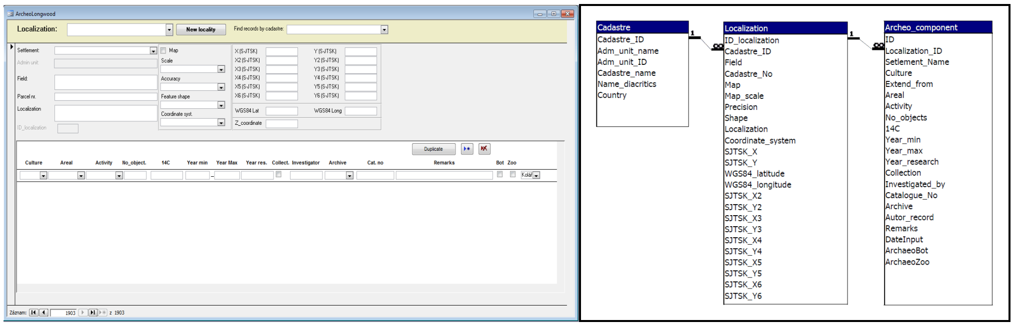

Figure 2. Structure of the archaeological database.

2. **Historical** coverage focuses on archival sources relevant for forest history (Figure 3). The localization of historical data is challenging, because its spatial precision varies from source to source. As they are usually mentioned in the context of the closest settlement, we decided to connect them to settlements (cadastral units). Sources available in larger quantities, such as urbaria, cadastral and other national surveys, and forest management plans are preferred. The earliest written records come from the 12th century AD. Closer to the present, sources become more abundant, detailed and precise. Especially in the last 150 years forests were regularly surveyed in forest management plans, providing details on the exact size and position of each woodlot as well as on forest structure, composition and management. Records on forest extent, type (broadleaved, coniferous or mixed), tree species composition and management (coppicing, coppicing with standards, high forest and pollarding) are gathered from the archives and linked to the cadastres. In addition, records on forest disturbances (both natural and anthropogenic) and human activities traditionally practiced in forests (burning, pasture, litter raking, hay cutting, wood pasture, pannage, charcoal burning, lime kilns, honey gathering, deer reserves, acorn, wildfruit, cone or leaf fodder gathering) are collected. Because the LONGWOOD geodatabase is designed to accommodate any archival information related to forests, flexibility is needed in its structure to allow for gradual modifications.

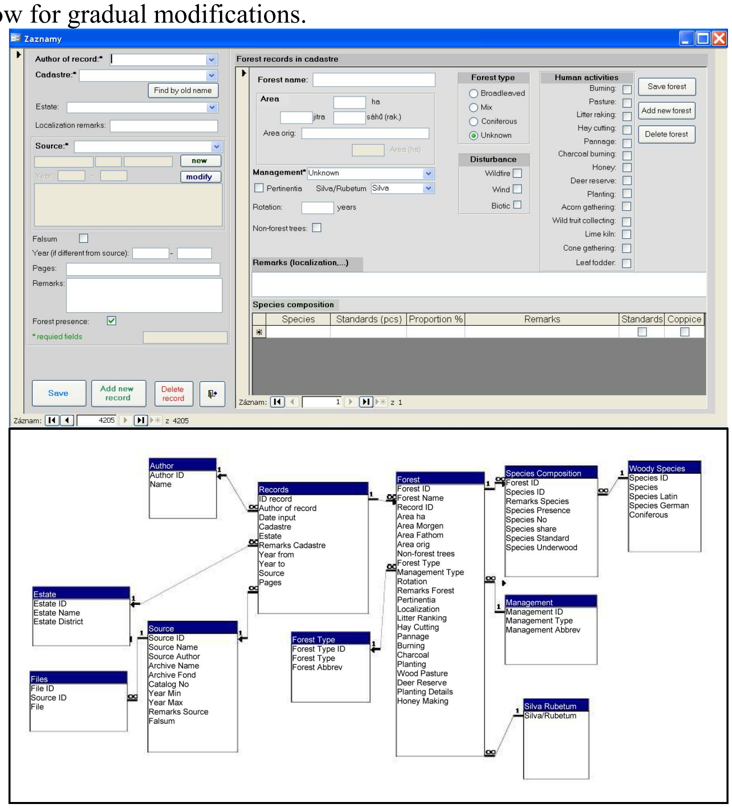

Figure 3. Structure of the historical database.

3. **Palynological** coverage deals with analyzes of the distribution of contemporary and fossil pollen grains contained in various deposits, especially peat bogs and lake sediments. After chronology is established, vegetation changes at the site are reconstructed. This method provides information on woodland cover and tree and herb species composition throughout the Holocene (the actual time span depends on the profile) but is limited spatially by the availability of preserved pollen sediments. Pollen curves are translated into regional landscape reconstruction through a modelling process, which compensates both for the ambiguous connection between pollen percentages and vegetation composition and the variable source area of pollen profiles (Sugita 2007[11], Sugita 2007[12]). In palynological coverage (point layer of the samples with the metadata attached as attributes), existing pollen stratigraphical data from the PALYCZ database (Kuneš et al. 2009[13]) are included, and we sample and analyze ca. 20 new sites to fill the gaps in existing knowledge.

4. **Ecological** coverage provides the highest level of detail (Table 1), including not only tree but also the herb species composition. It focuses on relating the spatio-temporal dynamics of the composition and structure of the tree canopy to understorey herbaceous vegetation. Patterns of forest vegetation are to be constructed through a combination of palaeoecological and historical data as well as knowledge about species co-occurrences and ecological requirements. As for historical sources of information on forest understorey vegetation, oldest sources of information on forest vegetation are available in herbaria, but they refer to individual occurrences rather than species assamblages and were therefore not considered. Precisely located and comprehensive forest vegetation records (stored in the database as point layer with the metadata as attributes) are available only since the 20$^{th}$ century. This youngest period of our interest is very dynamic, with many abrupt changes in forest management and composition. Comparing past vegetation of traditionally managed forests with their present state in modern landscapes gives valuable insights into the problematics of vegetation shifts and biodiversity losses. In scope of the LONGWOOD project, new permanent plots are being established to set up base for future research on vegetation dynamics.

Records gathered in Microsoft Access are exported to ArcGIS and analyzed in a GIS environment that allows various combinations according to the type of analysis. This data structure enables to work with different kinds of data. For example palynological and ecological data are connected to sampling points; environmental data (climate, soil types) are usually represented in the form of grids or polygons; and historical and archaeological data are located using cadastres. Historical data stored as a point layer can be easily connected with other data types (e.g. polygons representing cadastral units, environmental and socio-economic data, comparative sources) through standard GIS operations.

In our project, we will assess the causes for the patterns observed in terms of qualitative and quantitative factors, both natural and human-driven, and the role of human activities in structuring biotic communities within landscape mosaics. We will investigate the relationship of the information collected in the geodatabase, environmental factors (soil and climate conditions, elevation and other topographical functions derived from digital terrain model, such as slope, exposition, orientation, wetness index), and social-historical data on human population. The results of the project (reconstruction of past forest composition, observed patterns and driving forces) will be compared to concepts used in the forestry and nature protection.

## 3. PRELIMINARY RESULTS AND DISCUSSION

The archaeological and historical part of the LONGWOOD database is the most comprehensive - 3565 cadastres are being processed. Data are continuously fed into the database. As of March 2013 (that is, one year into the project), we have ca. 4000 records in more than 350 cadastres (archaeological coverage) and ca. 6000 records in more than 2000 cadastres (historical coverage). The average number of records per cadastre is 10 (maximum 150 records) for the archaeological and 3 (maximum 36 records) for the historical database. First results show high number of records on forest presence/absence and also some details on forest species composition and management coming mainly from the so-called Stable Cadastre (historical database, ca.1850 AD). Current palynological coverage contains 32 sites, some of them just outside the Moravian border (Figure 4). Ecological coverage so far includes 670 historical vegetation records in South Moravia (mostly from 1950s to 1960s), 260 of them were resurveyed last year (Figure 4).

The database is continuously fed and the number of records will rise considerably, although we do not expect even spatial distribution in the study area. In the first year of the project, we focused mainly on southern Moravia, which is a region of densely populated lowlands (Figure 4). This cultural landscape represents one of the oldest inhabited areas in the Czech Republic occupied since the Palaeolithic, and the number of records is therefore high. At higher elevations (mountaineous and hilly areas in the north and west) human occupation started later and forest exploitation has been less intensive, and we can therefore expect lower numbers of both archaeological and historical records. The distribution of pollen sites is limited by the availability of suitable sediments. In some parts of the study area we have not yet found any pollen deposits; such regions are systematically surveyed to locate possible sites.

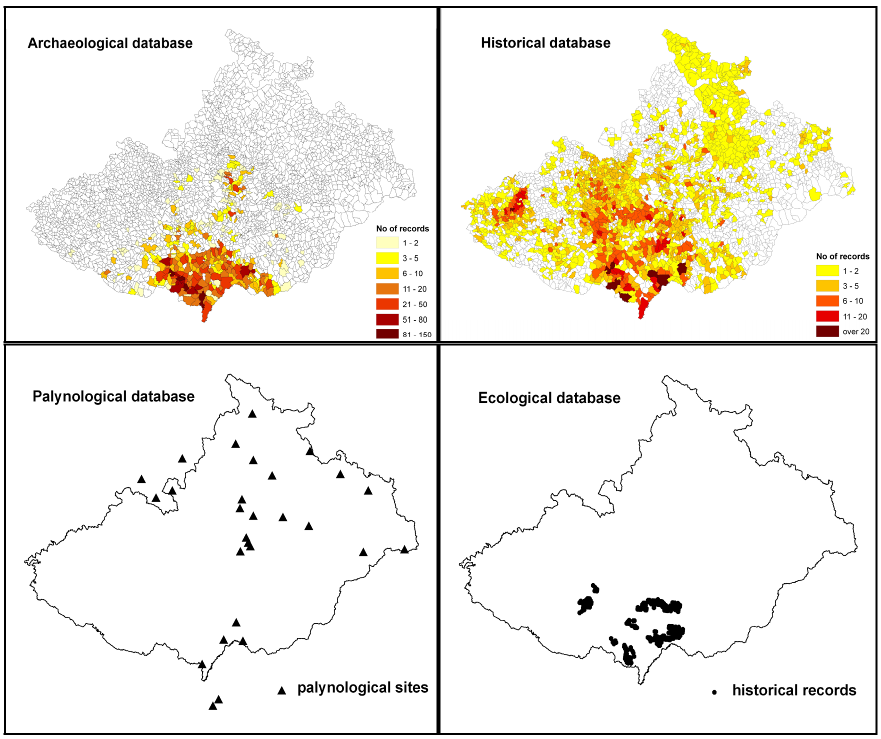

Figure 4. Distribution of records in the LONGWOOD geodatabase (archaeological, historical, palynological, and ecological coverages) after the first year of the project.

In the LONGWOOD geodatabase, different sources are joined to provide a basis for the analysis of forest changes. Large amounts of material are surveyed in archives and other databases. The most problematic issue of our research is the various spatial and temporal resolutions of the disciplines (Table 1). Palynology provides detailed information down to the species or species group level on both tree and herb species and goes far back into the history but its spatial coverage is relatively poor and dating coarse. Archaeological data cover long periods of time, are copious and spatially exact but temporally less well-defined and the content of information relevant for forest research is low. History (written sources) covers the last ca. eight centuries, but records older than ca. 500 years are sparse and not very detailed. However, for the last 200 years history provides large amounts of precisely dated and sometimes very detailed information on forest structure, tree composition and management. However, information on understorey vegetation is almost completely absent in archival sources. Vegetation ecology has fine spatial resolution, high level of detail on forest vegetation and well located data but it covers only the last century. Considering these constrains, the cadastre was chosen as the basic geographical unit that can be linked to all types of data involved. The settlement structure of the region has been relatively stable since ca. the 13th century and cadastres as administrative units work generally in the same structure for the last 200 years. They represent relatively small (750 ha on average), well defined and stable units. This decision limited the detail of historical and archaeological data in some cases but it was necessary to unify the level of spatial resolution to enable the comparability of the various data. The archaeological database includes optional higher spatial precision where data are available.

Interdisciplinarity is an important advantage of our project and individual disciplines are going to benefit from cooperation. For example, palynological findings on vegetation composition can be verified by and confronted with historical records on landscape changes in a given time period. Historical and archaeological records can help to identify and explain spatio-temporal patterns of landscape ecological processes. We hope to provide a platform for close cooperation among the disciplines as different views can bring new insights to the problematics and enrich all participating fields. In landscape ecological studies, social sciences are often undervalued even though humans are considered as the main driving factor behind landscape changes. Our project demonstrates the inevitable links between past human activity and present biodiversity in woodlands. By introducing forest management as an equal driving force into historical woodland dynamics, we would like to foster a paradigm shift in ecology towards construing humans as integral parts of ecosystems. Both ecological and social-scientific points of view are necessary to understand past and present changes in landscapes, and to undertake the right actions to preserve the last remnants of valuable forest environments.

## 4. ACKNOWLEDGEMENTS

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