

12 | RECONSTRUCTING ANCIENT LANDSCAPES AND VEGETATION

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When the Point Becomes the Area: Multivariate and Spatial Analysis of Pollen Data

Abstract: Almost every agricultural activity affects vegetation; these disturbances are recorded in the palynological record of natural archives, such as lakes and mires. A great number of data sets have been elaborated in recent decades, providing detailed and excellent information about vegetation and land use history since Neolithic times. Each of these datasets, however, is restricted to a particular point in the landscape. The project introduced here collects these data in a database and processes them for further spatial analysis. The aim of the project is to develop maps for the intensity of human impact in different landscapes: A diachronous index for the intensity of human impact is derived by canonical correspondence analysis, mapped and displayed spatially. Here the first results of the project for the Rhenish Loessboerde (Western Germany) and the Lake Constance region (Southern Germany) shall be introduced.

Introduction

The multivariate and spatial analysis of pollen analytical data is the task of the project introduced here which was conducted at the universities of Frankfurt and Cologne and funded by the German Research Council. It is part of the Rhine Lucifs bundle, a connection of five projects dealing with land use and climate impacts in the Rhine catchment in pre-historic and historic times (http://www.giub.uni-bonn.de/gidi/RL_Homepage/RL_welcome.html).

Pollen or palynological stratigraphies consist of counts of pollen grains per taxon in samples of stratigraphical order, which then form the pollen profile. These data are punctual data in the sense that the profile represents a certain point in the landscape and the single sample a point in time. The task of the project is to collect data from several neighbouring stratigraphies and analyse them spatially to obtain regional responses. The detailed information contained in pollen diagrams will be summarized to gain a more global proxy.

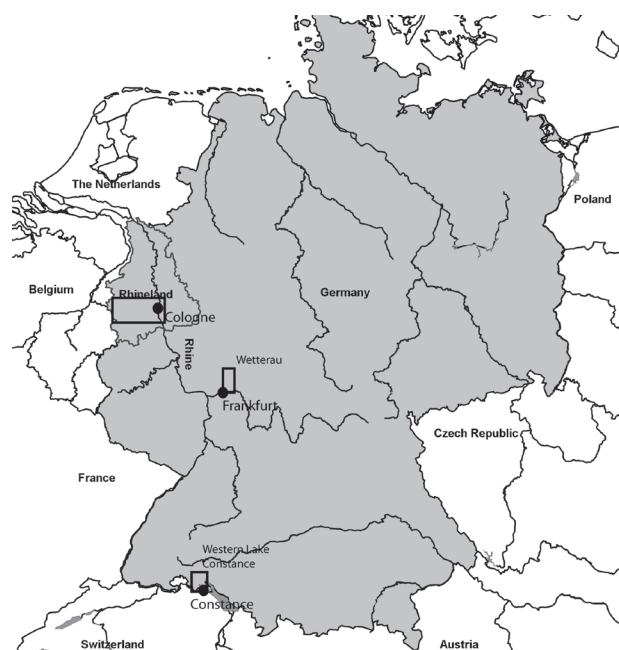


Fig. 1. Localisation of core regions.

In the first phase of the project methodological developments were the focus, so independently dated, high resolution pollen data were required. Three core regions were selected: the Rhenish Loessboerde, which is part of the Rhineland, the Wetterau in Hesse and the Western Lake Constance region (Fig. 1).

The palynological record in these areas is exceptionally good. For the Loessboerde and the Wetterau several independently dated pollen diagrams exist. The Western Lake Constance Region provides fewer profiles, but they have a very high resolution, are well dated and reach back to the late glacial practically without any hiatuses.

This paper presents results from the Rhineland and the Western Lake Constance Region.

Database

The pollen datasets are collected in a database together with metadata and datations. The structure of the database is very simple. It consists mainly of four separate tables; all profiles can be identified by a three letter code. Metadata, such as geographical coordinates, data provider, and references, are collected in one table.

A second table contains the datation for every horizon in every profile. A third table contains raw data and is linked by the sample name and the three letter code with the datations. A fourth table contains the taxa names used in the pollen data together with some ecological information. There is a separate taxalist for each region because the use of different pollen keys and descriptions leads to differences in the nomenclature of pollen grains. Superregional analyses however call out for unified taxa lists. This problem has often been addressed in palynological research (e.g. JOOSTEN / DE KLERK 2002), but up until now no satisfactory solution has been found. In the course of this project a unified taxa list will be developed.

At the moment the database contains 22 pollen datasets from the Rhenish Loessboerde, the Wetterau, the Lake Constance area, Upper Swabia and the Vosges mountains. More profiles are still to be added from the core regions as well as from other regions of the Rhine catchment. The database allows queries for certain time slices, ecotypes, regions or pollen components. The query results are exported to spreadsheet calculation for further processing.

Statistical Methods

The data are analysed by multivariate, ecological standard methods, mainly correspondence analysis, in its canonical form (cf. BIRKS / PEGLAR / AUSTIN 1996). The proven ordination method offers the opportunity to display high-dimensional data in a lower-dimensioned space, while maintaining most of the original information. Thus CA is suited for recognizing ecological or sociological connections (GREENACRE 1984; GREENACRE / BLASIUS 1994) as well as for finding transfer functions (e.g. FACHER / SCHMIDT 1996) or as a step in seriation, especially in archaeology (MADSEN 1988a; SHENNAN 1997; MÜLLER / ZIMMERMANN 1997) and has also been successfully applied to pollen data (BIRKS 1988; KALIS / ZIMMERMANN 1997; KERIG / LECHTERBECK 2000; 2004).

Correspondence analysis is a method to display high-dimensional data in a lower-dimensioned space. An example of high-dimensional data would be species by sample pollen data, where every species and every sample is a dimension.

The first step in correspondence analysis is the conversion of the data into a matrix of chi squared distances (SHENNAN 1997, 313–315). For the species, as well as for the samples, the same principal component space will be calculated. In contrast to other multivariate techniques, correspondence analysis can be applied directly to rectangular contingency tables. As a result, the correspondence analysis calculates axes which are called eigenvectors (for the method see GREENACRE 1984, 37–41; MADSEN 1988a, 11–13). There are as many eigenvectors calculated as there are variables minus 1. Every variable can be located by allocation of coordinates on all axes. However the scores on the first eigenvector are of higher explanatory value than all scores on the following eigenvectors, because the first eigenvector,



Fig. 2. Localities of pollen profiles in the Western Lake Constance Area.

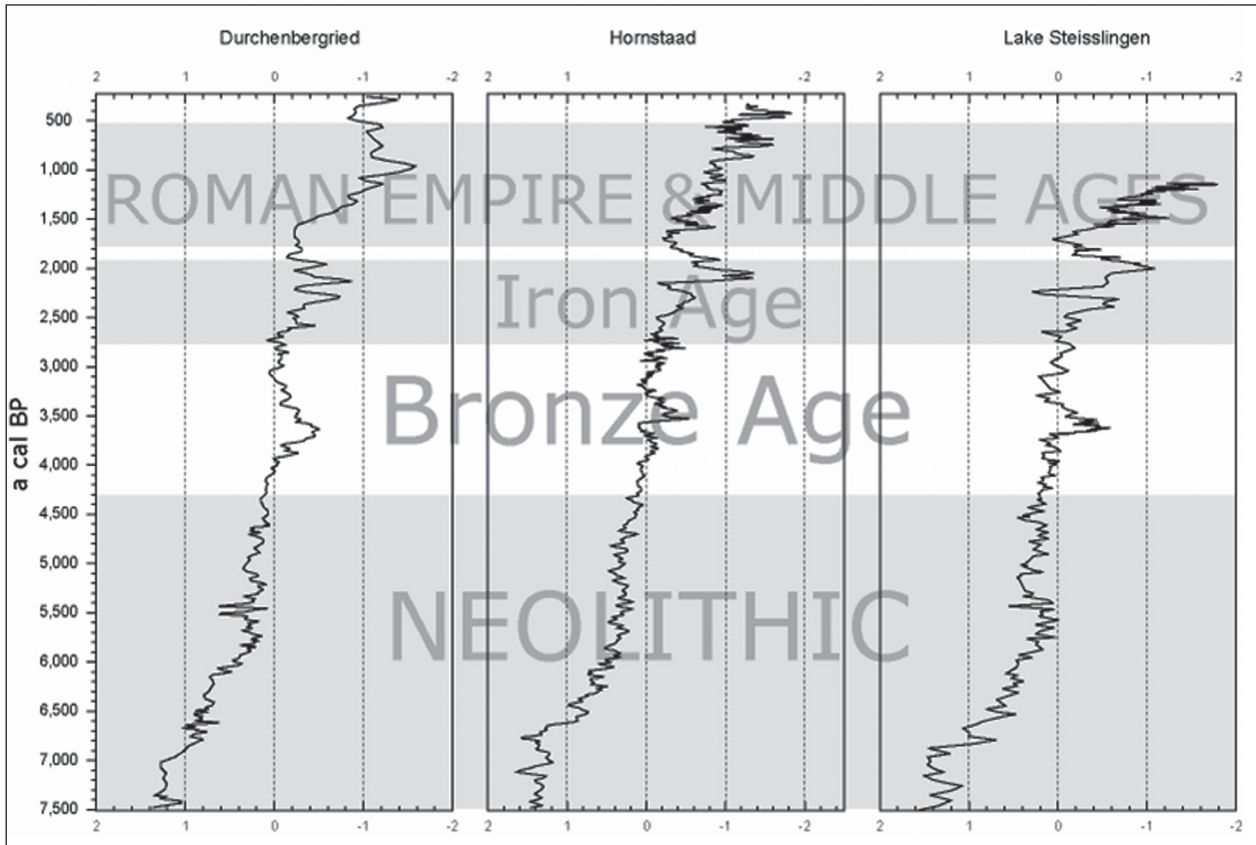


Fig. 3. Human impact curves derived from CCA of three profiles from the Western Lake Constance area.

as it is a kind of regression line, accounts for most of the variation in the dataset. The first eigenvector is mathematically the main dimension of explanation.

The second eigenvector, which is calculated rectangular to the first, accounts for most of the remainder of the variation. All other eigenvectors are calculated in the same way.

The scores on the first CA-axis for the samples show, how much the samples correlate with the main dimension of explanation. The scores can be plotted against time; the resulting curve shows the behaviour of the main dimension of explanation through time.

From the strong correlation between the scores on the first axis of CA and the cultural indicators, together with other evidence, it is concluded that increasing human impact is in fact the main dimension of explanation from the Neolithic to the Middle Ages (LECHTERBECK 2001; KERIG / LECHTERBECK 2001; 2004). The curve is a type of proxy for human impact, and it has the advantage that it contains more information than the sum curve of the cultural indicators alone.

The suitable method for the spatial analysis of palynological data is canonical correspondence

analysis (CCA), as it allows us to analyse several datasets for structures they all have in common. For CCA, a canonical axis is set and the analysis is optimized on those structures which correlate with this dimension. CCA was carried out for profiles from the Western Lake Constance region and the Rhenish Loessboerde (LECHTERBECK ET AL. in press).

Results

For the western Lake Constance area, three profiles (Fig. 2, RÖSCH 1990; 1992; 1993; LECHTERBECK 2001) were incorporated in the CCA. All profiles cover the time span from the Neolithic to the early Middle Ages in high resolution and without any recognizable hiatuses. The three human impact curves (Fig. 3) show strong similarities, sometimes even in small details. However, the peaks are not quite synchronous; there is always a time lag. Further research and revision of the time model will reveal whether this lag is due to an interpolation error between radiocarbon dated samples or whether it is true ecological evidence, which depicts a very dynamic settlement history in this very variable landscape.

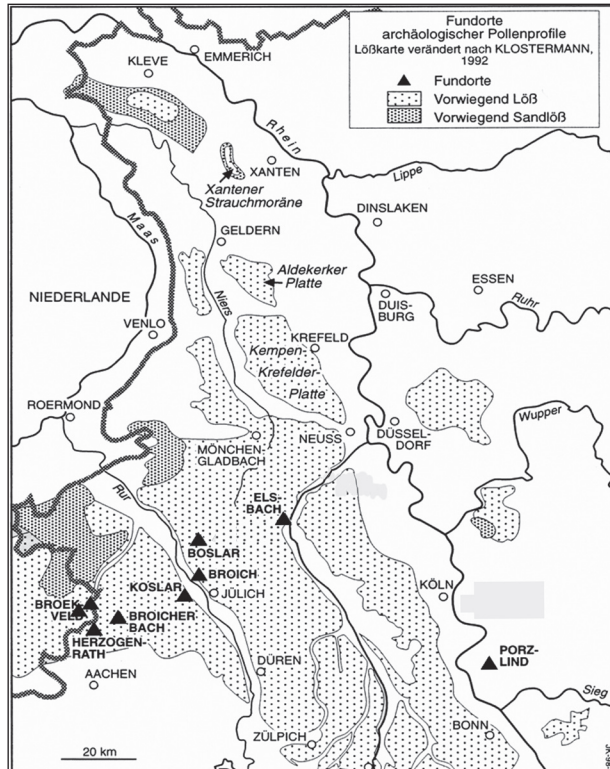


Fig. 4. Localities of pollen profiles in the Rhineland.

The database contains eight profiles from the Rhenish Loessboerde and one from Porz-Lind in the adjacent Rhine Valley (Fig. 4, BUNNIK 1995; JANSSEN 1960; KALIS 1983; 1988; KALIS / MEURERS-BALKE 2003; KALIS / MEURERS-BALKE 2005; KNÖRZER / MEURERS-BALKE 2002; LECHTERBECK / KALIS / MEURERS-BALKE IN PRESS; and unpublished data). These profiles cover the time span between the Neolithic and the Middle Ages in different resolutions. Human impact curves were also computed. The curves for the Loessboerde are not as continuous and the vegetational development is not as uniform as in the Lake Constance area, although the Rhenish Loessboerde is a much more uniform landscape. The profiles from the Rhineland, however, cover a much larger area and are farther away from each other than the three profiles from Lake Constance.

Again in the Rhineland the main dimension of explanation is human impact. This can easily be shown by the species scores on the first axis of the CCA. If all species are ordered according to their score (Fig. 5), then positive scores correlate with forest and woodland taxa, whereas negative scores correlate with taxa for arable land and pasture. Between these two extremes forest edge taxa, ruderal taxa and grassland taxa are ordered along a gradient. Human impact is also the main factor

Code	1rst Axis CCA	Ecotype
UlmuGlab	1.5878	woodland
TiilInd	1.4437	woodland
HedeHeli	1.2678	woodland
FraxExce	0.8132	woodland
CratType	0.6482	woodland
CoryAvel	0.5877	woodland
AcerCamp	0.5235	woodland
PinuSyTy	0.2376	woodland
CapsType	0.1885	grassland
PiceAbie	0.093	woodland
Asteroid	0.0138	fields u grassland
VibuOpp	-0.0932	woodland
QuerPeRo	-0.1266	woodland
PopuTrTy	-0.153	woodland
PterAgui	-0.1899	forest edges
HypePeTy	-0.1999	grassland
CentJaTy	-0.3103	grassland
SorbAucu	-0.3589	woodland
ArteVulg	-0.3798	ruderal
PrunSpin	-0.4368	woodland/cultivated plant
ChaeTemu	-0.4708	forest edges
PapaArge	-0.4739	fields
BetPenPu	-0.4886	woodland
RuAcIla	-0.5041	grassland
Erichnde	-0.5716	lindiff
FaguSylv	-0.5815	woodland
JasiMoTy	-0.6352	others
LamiType	-0.668	lindiff
CarpBetu	-0.7488	woodland
PlanLanc	-0.7637	grassland
CallVulg	-0.7837	others
ChenCeae	-0.8042	ruderal
SangOffi	-0.838	grassland
CastSati	-0.8489	woodland/cultivated plant
PlanInMa	-0.859	ruderal
RhinType	-0.9632	grassland
TrifReTy	-0.9936	grassland
JudlRegi	-1.0234	cultivated plant
TrifPrTy	-1.0328	grassland
RumeCris	-1.0385	grassland
DaucCaro	-1.0407	grassland
RanuAcGr	-1.0788	grassland
SperArTy	-1.0798	fields
LychFICu	-1.0858	grassland
AnthType	-1.0922	grassland/fields
CentCyan	-1.1464	fields
SagiPrGr	-1.22	fields
PolyPeGr	-1.2421	fields
CereInde	-1.2443	cultivated plant
AnthPuTy	-1.2722	fields
SecaSeca	-1.3894	cultivated plant
PolyAeAv	-1.4146	ruderal
RiccType	-1.4654	fields
PhaeLaev	-1.4696	fields
RuAcAc	-1.4736	grassland
PapaRhTy	-1.4789	fields
ScleAnnu	-1.7025	fields

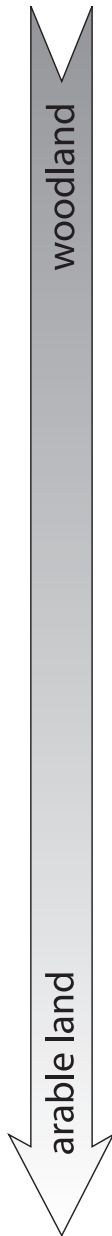


Fig. 5. Taxa of the regional pollen component in the Rhineland ordered according to their score on the first axis of the CCA.

in landscape development during the Holocene. In fact human impact is the most important factor in landscape development in all long-settled landscapes in Middle Europe.

As the scores on the first axis of CCA can be understood as a proxy for human impact and as this proxy can be calculated for several profiles of a region, a stratigraphical plot of the scores shows the behaviour of human impact through time. Now it becomes possible to map these values regionally and display the differences in land use intensity spatially.

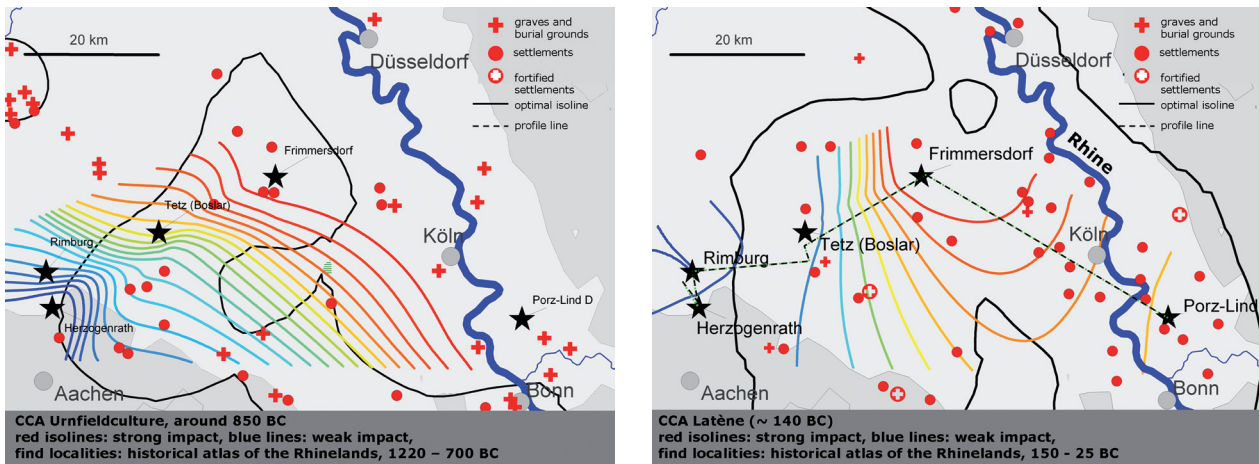


Fig. 6/7. Human impact map for the Urnfield Culture and the Latène Period.

One of the aims of the project is the development of land use intensity maps to show the spatial development of human impact. An archaeological project in the LUCIFS bundle has constructed settlement area maps for different time slices. They are displayed in the form of optimal isolines which are ideally wrapped around most of the settlements or graves. The advantage is that unsettled areas can also be shown separately. The choice of the optimal isoline depends on the settlement density (for the method see ZIMMERMANN 2002; ZIMMERMANN ET AL. 2004). As the scores on the first axis of the CCA are dimensionless, the evaluation of the scores with maps of settlement areas should allow us to allocate the score's values in terms of inhabitants per square kilometer.

Human impact maps for the Rhenish Loessboerde and part of the adjacent Rhine Valley were constructed for different time slices. The isolines for human impact intensity were constructed by natu-

ral neighbour interpolation. Every profile was allocated a value for human impact corresponding to the time slice. In addition, known settlements and graves and the optimal isolines for the settlements are also displayed.

The map for the Urnfield Culture (Fig. 6) for the time slice around 850 BC shows a distinct west-eastern gradient in human impact intensity: the impact increases from east to west. The settlement pattern and the human impact isolines are not entirely congruent. This is due to the fact that the human impact curves represent a relatively narrow time corridor whereas the settlement map is an average over the whole period. Nevertheless, the isolines follow the distribution pattern of the settlements to some extent: Where there are settlements, there are also higher values for human impact just as one would expect. For the graves, however, there is no visual correlation between human impact intensity and spatial distribution. Graves as archaeological sources differ from settlements in many ways. One major difference is their conservation properties.

This picture coupled with the human impact intensity leads to the conclusion that it might have been common practice in the Urnfield Culture to separate the graves from the settlements.

The map for the La Tène Period around 140 BC (Fig. 7) also shows a west-eastern gradient. Here, an even better alignment of isolines and the settlement pattern than in the Urnfield Culture can be observed. Both sources outline the Rhine valley as a preferred settlement area. The time corridor depicted by the settlement pattern is much narrower than in the Urnfield Culture; making the map picture nearer to the human impact isolines.

To compare the human impact intensities of two different time slices, it is possible to draw cross

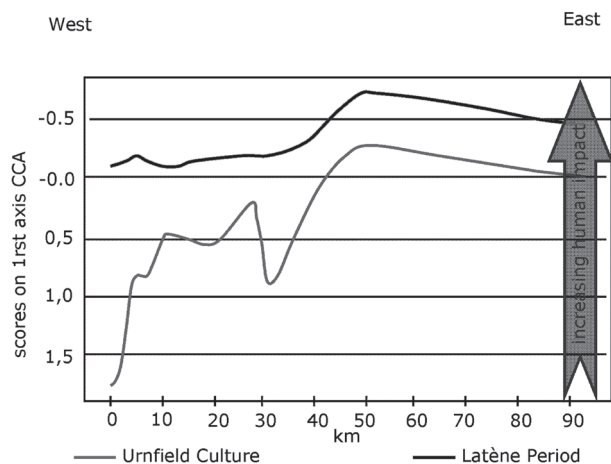


Fig. 8. Cross sections through the grids calculated from the human impact values for the Urnfield Culture and the Latène Period in the Rhineland.

sections through the grids built from the values on the first axis of CCA for the Urnfield Culture and the La Tène Period (*Fig. 8*). The distance between the two curves shows the difference in intensity between the two time slices. In general, the impact in the Urnfield Culture is lower than in the following Iron Age. A general west-eastern gradient is also detectable. Here there are lower impact values in the western than in the eastern part which is true for both the Urnfield Culture as well as for the Iron Age. During the Urnfield Culture the frequency of the curve is much higher however and indicates stronger regional differences in land use intensity. These differences become smaller during the Latène Period, maybe due to the relatively long lasting impact and dense settlement of even intensity. Further analyses will show whether this is a common pattern for long settled landscapes.

Conclusion and Perspectives

In the first phase of the project, the development of a methodology to combine regional pollen stratigraphies and analyse them together in one step as well as the spatial display of the results was the main focus. A number of especially well suited stratigraphies were chosen and collected in a database.

Canonical correspondence analysis extracted human impact as the prevailing factor of vegetational development in the research areas, i.e. the Lake Constance area and the Rhenish Loessboerde. The scores on the first axis of the CCA can be used as a proxy for human impact and CCA is a suitable method to calculate this proxy for several profiles of a region. The scores on the first axis of CCA could be mapped for certain time slices and show differences in land use intensity spatially. Cross sections allow a direct comparison of regional land use intensity of different time slices.

The method offers a variety of perspectives and the perspectives grow with the enlargement of the database. The database will be developed in two directions. More data will be collected from the present core regions especially from the Lake Constance area and datasets will be incorporated from the mountainous regions of the Rhine catchment.

Methodologically, multivariate analyses of certain aspects should be carried out, such as the development of local vegetations, different land use strategies and the large scale impact of innovations. Furthermore, impact maps on an superregional

scale shall be constructed where most importantly the scores on the first axis of the CCA will be standardized by the settlement areas. This standardization cannot yet be carried out because of scale problems.

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