Bronze Age Land Use in the Central Alps: GIS-based Investigation of Influencing Environmental and Economic Factors

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Abstract

Since 2006, the interdisciplinary project "Leventina – Prehistoric Settlement Landscape", funded by the Swiss National Foundation, is being conducted under the coordination of the Department of Pre- and Protohistory of the University of Zurich with researchers from further disciplines. The project investigates prehistoric settlement and economy in various altitudinal zones of the Alpine Ticino valley. One of the aims is to reconstruct the agricultural, pastoral and forestal land use in the Bronze and Iron Ages, and to evaluate the influencing factors on the spatial distribution of subsistence economy areas. A wide range of spatial and archaeological data as well as literature and field data describing properties in particular of the ancient economic plants was available for the purpose. Based on these data, a factor analysis and a subsequent prediction were conducted in order to evaluate the variables with a likely impact on agricultural land use at prehistoric times, and to detect potential agricultural land. Additionally, using predictive modeling, we aimed at extracting factors with impact on the spatial distribution of Bronze age settlement sites and generating a potential map of areas used for settlement. Furthermore, a cost path analysis was conducted to investigate different traffic routes across the main ridge of the Alps in terms of travel time.

Keywords

Bronze Age, factor analysis, GIS, land use, site catchment

1. Introduction

The area of investigation is located in the upper Leventina valley in the Canton Ticino in Switzerland, bordered by the Gotthard pass to the north and the modern city of Biasca to the south. The Department of Pre- and Protohistory of the University of Zurich has been conducting an interdisciplinary research project in this valley and the surrounding mountain areas since 2006, in close cooperation with geographers and archaeobotanists from the University of Zurich, as well as with specialists of the Institute of Geodesy and Photogrammetry of ETH Zurich (Della Casa *et al.* in prep.; Jacquat *et al.* in prep.).

The archaeological part of the project sensu stricto comprises extensive and intensive field surveys in various altitudinal zones of the Leventina (valley floor, terraces, mid-mountain and alpine pastures), and the partial excavation of a Bronze and Iron Age settlement site on the naturally defended hill "In Grop" close to the hamlet of Madrano, com. of Airolo. These excavations, conducted in the years 2004–06, yielded architectural and economic structures (floors, pits, fireplaces) as well as a considerable amount of vegetal macrorests including various crops and charcoal, that will serve to reconstruct the socio-economic background of the settlement in the 2nd and 1st millennium BC.

Two main aims of the project in relation to the spatial characteristics of the area of investigation and the archaeological sites detected during field surveys were formulated within this project:

– To investigate travel routes in the Leventina valley and especially to verify the function of the Gotthard pass as the principal north-south route across the main ridge of the Alps comparing alternative routes by means of cost surface analyses.
– To model the population of Bronze and Iron Age settlements in the Leventina valley based on a reconstruction of probable agricultural land use. Using various factors, we derived site catchments for settlements, demonstrated here for the site of Airolo-Madrano as a case study.

The authors are aware of the fact that neither of these problems can be solved by relying only on modern spatial data at our disposal – although the presented methods are mainly based on it. Further factors which are difficult to obtain or to quantify, such as social and economic factors and archaeological knowledge, must be integrated in order to interpret the achieved results reliably. Nevertheless, the applied spatial and statistical methods yield results suited to serve as a basis for a model of agricultural land use. Furthermore, the developed methods and workflows can be applied to other projects of the Department of Pre- and Protohistory (*Fig. 1*) located in alpine regions with similar characteristics, which in turn can serve as a means to refine the methods. In this paper, we focus on the reconstruction of land use and the investigation of travel routes, whereas for the predictive modeling of settlement sites further data would be required in order to achieve reliable results.

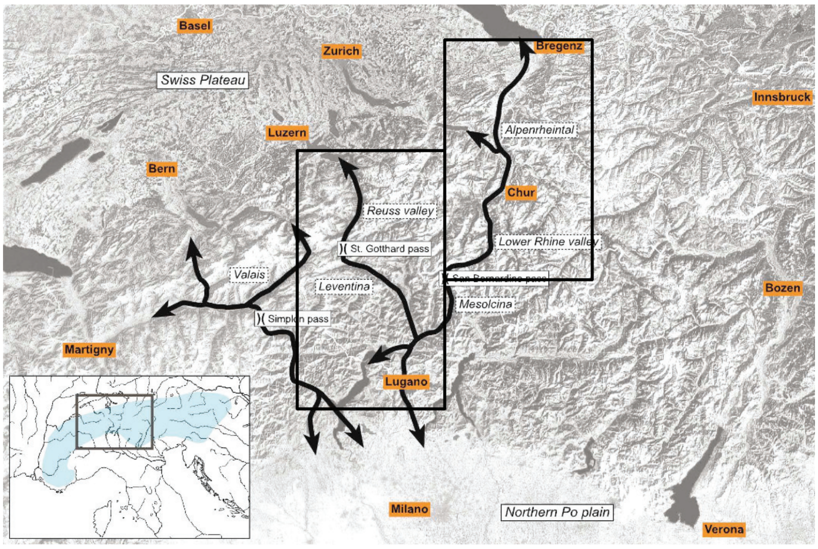

Fig. 1. Overview of projects of the Department of Pre- and Protohistory.

2. Methods for land use reconstruction

Agricultural land use is represented in our case by a site catchment area of raster type containing a value that describes the suitability of each raster cell for being used as crop land, grass land or forestal land. In order to derive such descriptions of a catchment, spatially related factors most likely influencing land use were identified in a first step:

- terrain elevation
- terrain slope
- terrain exposition
- solar radiation.

These factors could be derived from a DTM (Digital Terrain Model) which was at our disposal, namely the DHM25 kindly provided by swisstopo© (Swiss Federal Office of Topography), a DTM with a cell size of 25m and an accuracy between ±1.5m and ±10m depending on the terrain characteristics. The factors *slope* and *exposition* were derived using ArcGIS (ESRI) from the DHM25. *Solar radiation* was determined by the according function in ArcGIS, using recent solar orbits, additionally we verified that solar orbits had not changed significantly compared to Bronze Age ones by means of the online software Calsky (http://www.calsky.com). Originally, it was planned to incorporate further data such as *precipitation*, *temperature* and *soil data* available in the "Atlas of Switzerland 2" (Sieber and Huber 2007) and in scanned maps (Jeanneret and Vautier 1977). Due to the fact that these data were not available in the required spatial resolution, they moreover were incomplete, first tests showed that they could not contribute to the results in a meaningful way, and they therefore were not further considered. However, further data from our own soil samples will be included in the analysis once processed, which will possibly allow to determine a catchment at a higher level of detail, e.g. to distinguish catchments for different plant types.

2.1. Travel route investigation and site catchment determination

The method of investigation for travel routes across the main ridge of the Alps was based on a cost surface derived from the DHM 25 by means of an empirically determined hiking time formula (Tobler 1993), according to:

$$W = 6 * \exp(-3.5 * abs(S + 0.05)),$$

where W is the walking velocity in km/h valid for a pedestrian using existing paths and S the slope expressed by dh/dx, the elevation change per horizontal distance unit.

In contradiction to common least cost pathway calculations, we followed a mixed procedure: On the one hand, we calculated least cost pathways between

Airolo-Madrano (TI) and Altdorf (UR) (*Fig. 2*) including routes forced to take course via pathways which featured archaeological evidence. On the other hand, we calculated the required travel time for similar routes digitized by archaeologists using knowledge about traditional pathways being in use for centuries. For a more comprehensive comparison, interpretation and investigation on the alternative travel routes we would like to refer to Fasler 2008.

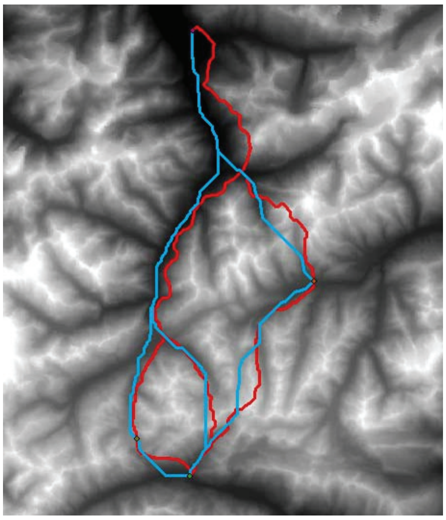

Fig. 2. Least cost paths (red) compared to digitized pathways (blue) from Madrano to Altdorf.

Tobler's hiking time formula was additionally applied in order to generate a site catchment for the area around Madrano so that each cell of the resulting catchment area could be classified quantitatively in terms of the probability of being cultivated from the according settlement. A hiking time of maximum 3 hours was used to limit the area absolutely (*Figs. 3* and *4*), while the individual cell values of the hiking time raster were used as one layer in order to distinguish the site catchment area qualitatively. Additionally, we mapped the rivers in the area using an orthomosaic with a 2m resolution, derived from swissimage orthoimages with a 0.5m resolution provided by swisstopo© and introduced them as barriers by means of weighting. *Figures 3* and *4* must be understood as qualitative illustrations of the impact of barriers on the site catchment obtained by hiking time calculation as exact weights describing the influence of each individual barrier; due to the fact that local topographic conditions were not available, darker cells require longer hiking times from Madrano.

2.2. Weighting of data layers

In a first approach, we evaluated how each single factor influenced the suitability for cultivation of areas with respect to the settlement of Madrano. The factors considered for this approach were *elevation, slope, solar radiation*, all derived from the DHM 25, and *agricultural soil suitability*, extracted from the scanned map. Subsequently, the values of these raster layers were multiplied by weight factors of 1, 1.5, 2, 2.5 and 3, thus the addition of the layers showed the change caused by weighting variation. This method only allowed qualitative conclusions to be drawn from the results, nevertheless it provides a simple method for a first estimation of a factor's influence.

2.3. Conditions necessary for plant growth

The second approach was based on conditions necessary for the growth of the corn types known in the Bronze Age. For this purpose, we consulted agricultural research institutions and recommended literature (Schmidl *et al.* 2006; Schmidl and Oeggl 2007; Schmutz and Böhler 2002a, 2002b, 2002c; Schilperoord and Heistinger 2007). The available information allowed us to border potential growth areas by means of various parameters, such as

Fig. 3. Site catchment with the river Ticino included as a barrier.

Fig. 4. Site catchment with all existing rivers as barriers.

monthly precipitation, elevation, solar radiation, slope exposition and temperature conditions required for typical crops. As a result, we obtained binary rasters indicating the suitability of each raster cell for each investigated plant type with a value of 1, exemplarily shown in *Figures 5* and *6*, also considering different seasons of the year. Insufficient conditions were assigned the value 0.

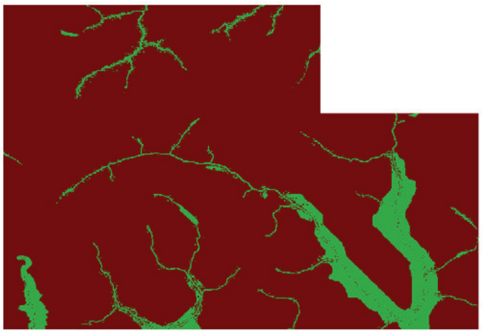

Fig. 5. Areas with sufficient conditions for pea growth in April (green=1, red=0).

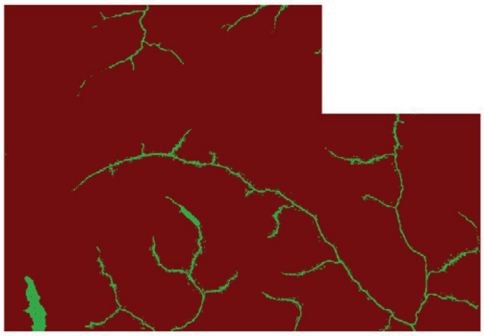

Fig. 6. Areas with sufficient conditions for field bean growth in march (green=1, red=0).

The disadvantage of this method, due to the available data which distinguish areas of suitability in a binary way, is again that only qualitative conclusions can be achieved.

2.4. Statistic modeling by factor analysis

Following a third approach, we aimed at the determination of potential grass land and crop land. In this approach, we included the results from 2.2 as limiting parameters, and then tried to determine latent factors which most likely influence the potential land use for each raster cell from sample data by means of a factor analysis and the according histograms. Furthermore, factor analysis allows to determine to what degree each considered factor influences the observed parameters, and if the factors are statistically significant, whereas from the histograms the preconditions for potential grass and crop land can be derived.

2.4.1. Workflow for factor analysis

In order to conduct a factor analysis, one first has to generate a control sample which serves as a data source to extract the factor values from. Based on an orthoimage mosaic with a 2m resolution generated from swissimage orthoimage tiles, we digitized the recent forest, grass, and agricultural crop land in ArcGIS and generated a polygon layer respectively. The factor analysis was conducted for the three classes of land use, agricultural crop land, grass land, and forest. For the digitization, we considered that the sample data should cover the whole range of the areas of investigation in terms of spatial distribution, terrain elevation and terrain exposition. In a next step, the polygons were converted to raster layers and combined with the elevation, exposition, and solar radiation layers. The resulting layers were combined with the binary crop suitability rasters obtained in 2.2, and the raster cell values exported into a dBASE file, which served as a basis for a factor analysis using the statistical software package SPSS.

The factor analysis was then performed in SPSS following the Principal-Axis method with an Oblimin-rotation of the factors. The factor analysis is based on the correlation matrix, where the principal diagonal elements are replaced by estimated commonalities, and runs iteratively. The selected variables were tested concerning their suitability for factor analysis by means of the Kaiser-Meyer-Olkin-Measure (KMO); variables were accepted if KMO > 0.5 (Janssen and Laatz 2005).

As influencing factors, we extracted agricultural crop land and grass land elevation as significant factors which describes 58.2% and 52.2% of the total variance, whereas for forest areas solar radiation was detected to describe 44.0% of the total variance.

Furthermore, we generated histograms of the sample areas for all considered factors, from which we derived boundary conditions for each factor (*Table 1*).

Finally, based on the boundary conditions derived from the histograms and the results of the factor analysis, we derived potential areas for grass land (*Fig. 8*) and agricultural crop land (*Fig. 7*) within a radius of 3 hours walking distance from the Madrano settlement using the Raster Calculator tool of the ArcGIS Spatial Analyst extension.

3. Results

The obtained areas for potential agricultural crop land are mainly distributed in the valley floors, with

	Crop land	Grass land
Elevation	250 – 1000m.a.s.l.	< 2000m.a.s.l.
Slope	0 – 10°	0 – -30°
Exposition	-1 – 250 gon Azimuth	100 – 250 gon Azimuth
Solar Radiation	750'000 – 1.1 Mio. Wh/m²	850'000 – 1.25 Mio. Wh/m²

Table 1. Boundary conditions for crop land and grass land derived from the histograms.

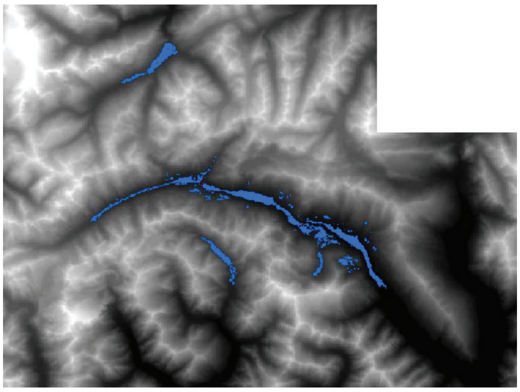

Fig. 7. Potential agricultural crop land inside the Madrano site catchment.

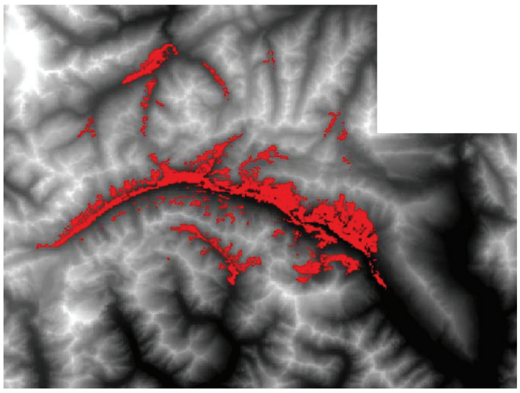

Fig. 8. Potential grass land inside the Madrano site catchment.

a few areas in the higher elevation regions. If we take into account that accessibility of valley floors was limited due to meandering rivers, this result appears somehow biased. A model for the use of valley floors still has to be developed. Potential grass land was located also on steeper slopes and areas with high elevation values, mainly exposed towards south and south-west. Furthermore, areas nowadays covered by forest were classified as potential grass land, which lets us draw the conclusion that they might have been used as grass lands in earlier times. Additionally, it is known that forest density has increased in the last centuries. The obtained results coincide well with recent land use, nonetheless some factors causing uncertainty remain. One important point is that the control samples were generated using recent crop data, without consideration of the plant types cultivated in the Bronze Age, for which little eco-dynamic information is currently available. Additionally, it can be assumed that different cultivation techniques were applied, and that harvesting might have been conducted before ripeness – as practiced for barley in sub-recent times. In future studies, we will incorporate soil sample data from which we expect to derive further information on these uncertain issues.

4. Conclusions

The developed workflow and the applied statistical method factor analysis provide a powerful tool for the reconstruction of ancient land use in general. Key issues to be considered when interpreting the obtained results are the input data, namely the control samples which, in most cases consist of recent data and do not take into account changes, in agricultural cultivation techniques. Moreover, socio-economic factors, which are difficult to quantify, cannot be included into the statistical analysis and therefore are also not considered. Nevertheless, factor analysis provides the degree of explanation of the total variance of the variables and therefore clearly indicates if the regarded factors are sufficient in order to yield a reliable result.

In addition to the results presented here providing potential areas for crop and grass land in a quite general way, we conducted further factor analyses for certain specific types of crop and plants, e.g. spring wheat, *triticum aestivum, pisum sativum,* and *lens esculenta*. The results of these investigations, which are expected to provide a detailed basis for a more accurate and reliable site catchment for Madrano and further sites in the Leventina valley, such as Dalpe, Giornico and Osco, will have to be refined again by data from the soil samples acquired during recent field surveys. Finally, we expect to generate site catchments on the detailed level of individual plant types combined with the conditions given by the spatial variables of *elevation, slope, solar radiation* and *exposition*.

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