Modelling the agricultural potential of Early Iron Age settlement hinterland areas in southern Germany

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Abstract
Agriculture was the main basis of daily life in most prehistoric periods in Europe. The possibility of a settlement to produce more than the basic needs in a subsistence economy was in many cases the background of a surplus-based superiority of some settlements over others.

In our paper we will present a GIS and database system with which we model the agricultural potential of settlements within their natural surroundings based on topography and soil quality. Within the framework of the research project ‘Early Centralisation and Urbanisation – The Genesis and Development of Early Celtic Princely Sites and their Territorial Surrounding’ (http://www.fuerstensitze.de) we have developed a model which is used to calculate the maximum amount of people that can be fed from within the hinterland of both princely sites and ‘regular’ settlements by cattle and crop. The surrounding itself can be defined by cost-based calculations, creating a hinterland border based on walking time. The model is then used to compare the agricultural potential of different settlement sites as well as of sites from different periods.

It is the aim of our working group to further develop a runtime database file, which can be used to model the agricultural potential from any given archaeological site within a given surrounding and to calculate the amount of people that can be nourished from this hinterland. The database file will be distributed online as free software.

Keywords
GIS analyses, agricultural potential, hinterland, cost distance, calorie expenditure
The project ‘Princely Sites’ & Environs (‘Fürstensitze’ & Umland, funded by the German Research Foundation within the framework of the Priority Programme ‘Early Processes of Centralisation and Urbanisation – Studies on the Development of Early Celtic Princely Seats and their Hinterland’, http://www.fuerstensitze.de) is investigating the so-called ‘Princely Sites’ or ‘Fürstensitze’ of the Early Iron Age around 500 BC in south-western Germany, eastern France and comparable places in Bavaria and western Bohemia (http://www.fuerstensitze.de/1121).

Following a definition mainly described by W. Kimmig (1969), ‘Fürstensitze’ are rich fortified settlements, mainly situated on a hilltop, with large and rich grave mounds in their vicinity and with finds of imported goods, mainly ceramics from the Mediterranean. They seem to be the result of a social and maybe even cultural change or transformation of the protoceltic societies which we still do not understand to its full extent (cf. Schier 1998).
The aim of the project ‘Princely Sites’ & Environs (Posluschny 2007) is to investigate the dynamics of settlements and people from the so-called late Bronze Age Urnfield Period to the Early Iron Age Hallstatt and the following Early Latène Period on the basis of the interconnection between man, culture and environment (fig. 1).

THE MEANING OF THE HINTERLAND

One of the main questions in this field of research is the mutual interdependency between the ‘Princely Sites’ – which we could compare to Christaller’s ‘Central Places’ (Christaller 1933) to a certain extent – and their surrounding area, their hinterland and the settlement places around. The hinterland of prehistoric settlements played an important role for the agricultural livelihood and the economic exploited area in general. The sizes of these hinterland areas may have differed depending on the environment and on the needs of prehistoric people in different periods. Following this thesis we might assume that changes in size and layout reflect a change in settlement behaviour and in the use of natural environment for economic reasons. Both regular settlements and ‘Princely Sites’ are dependent on their own hinterland as a basis for economic needs. This might be compared with the model of core and periphery or with Thuenen’s isolated state and ring-shaped economic model (fig. 2).

The definition of such a hinterland is of greater importance for questions on the economic abilities of the settlements, for questions of subsistence vs. surplus production. The shape and the size of these areas might differ in a regional as well as in a chronological perspective; there may also be differences between ‘Princely Sites’ and regular settlements. And last but not least, the potential of a settlement to feed its inhabitants and to even produce a surplus is based on the agricultural capacity of each hinterland thus the feeding potential of a settlement could give an idea of how many people might have lived in this settlement at most.

Figure 2. The idea of Thuenen’s isolated state (after Rodrigue et al. 2006, Fig. 7.8 [with modifications]). Legend from top to bottom reads as from inside to outside in figure shown.
DEFINING A HINTERLAND

The model to define the potential hinterland of a prehistoric site that we used in our project is based on site-catchment analyses which in general are not new for archaeological research. Site-catchments were used more than 40 years ago (e.g. Vita-Finzi & Higgs 1970), in the earlier days based on Euclidean distances (e.g. Saile 1998; Conolly & Lake 2006, 209-211). With the advanced computer abilities that GIS have to offer and that have been increasing since the 1970s, it soon became possible to not only build site-catchment buffers from Euclidian distances but also to take into account topography and other factors of the natural environment like streams, vegetation or soil properties.

When calculating the agricultural potential the first problem is to define the area of the hinterland itself. Most GIS software offers push-button algorithms to calculate cost distances and least cost paths, generally based on a cost model that defines the costs of passing along in a landscape (cf. Conolly & Lake 2006, 213-226 for a short introduction to cost surface calculations, see also van Leusen 2002, 6-4–6-9 and Herzog & Posluschny in press). The same is true for the calculation of a cost dependent area, based on the maximum vicinity that can be reached within a maximum of time, with a maximum of abstract costs or with a maximum of calorie expenditure. It is not the aim of this paper to discuss the (dis)advantages of the various software algorithms in GIS programmes, nor do we want to go into detail regarding the mathematical background of the cost surface calculations. Various papers have been published on these topics during the last years, especially in the context of the annual CAA conferences (cf. i.a. Herzog & Posluschny in press). This paper concentrates on a case study that makes use of cost surface based calculations and environmental modelling (cf. i.a. Posluschny 2010) and whose greatest advantage is the relative easy way of modelling rather coarse data which is more or less easy to derive.

The background of the calculations that will be used to define a hinterland area for modelling its ag-
Agricultural feeding potential is the use of a cost surface model that transfers slope into walking speed. The so-called Gorenflo/Gale algorithm is based on empirical data that has been collected from soldiers hiking different types of terrain (Gorenflo & Gale 1990). The result is a model of walking speed, calculated in kilometres per hour (fig. 3). For the use as a friction surface it then has to be recalculated into a cost model with minutes per kilometre as units. The modelling of the potential hinterland that can be reached within a certain time is then calculated within the IDRISI Andes software (module COSTGROW, Eastman 2003, 93). To avoid overlapping areas around close sites it was necessary to calculate one buffer for each site at a time so a macro has been built which was able to calculate the cost based buffer areas of more than 300 sites, based on a 25m resolution cost surface grid, using a buffer of 1 hour walking distance within approx. 10 hours.

Another problem when modelling a hinterland or the area of every day extensive use is to define the border of such an area. It is of course not very likely that prehistoric people had strict rules for a limitation of their usable vicinity. But on the other hand, it is very likely to assume that it was not very advisable to use land beyond a certain distance from a settlement simply for economical reasons. Chisholm (1962) and following him Bintliff (1999, 2002) argued – based on cost-benefit ratios – that the land used for agricultural needs, mainly for ploughing, is usually not further away than 1 km which is approximately a 12 or 15 minutes walk. The hinterland that has been used for cattle farming, exploiting forestal resources and so on, but also for a more intensive use in order to be able to produce a surplus, should be no further away than 5 km or 1 hour walking time. The potential models that will be calculated for all settlement sites of the project will therefore be based on a surrounding that can be reached within 15 minutes walking time; some calculations were made for a 1 hour environs.

Figure 4. Cost based hinterland areas within 60 mins. walking time in the area of the Marienberg ‘Fürstensitz’ (Northern Bavaria). b. Cost based hinterland areas within 15 mins. walking time in the area of the Marienberg ‘Fürstensitz’ (Northern Bavaria). – DEM D-25 (25 m grid), © German Federal Office for Cartography and Geodesy 2004.
HINTERLAND SIZES AND THEIR MEANING

To test the thesis that the size and layout of the area around a settlement that has been in economical use during prehistoric periods has a meaning for the understanding of the societies under research: first calculations were made to model the area within 1 hour walking time for all regular settlements and all ‘Princely Sites’ based on the Gorenflo/Gale algorithm within the research area around the ‘Fürstensitz’ on the Marienberg in Würzburg (fig. 4a).

The overlapping of most of the areas makes clear that the exploited areas might not only belong to one but to several settlements even when we take into account that many of the settlements from one of the periods – which lasted approximately 300 years – were not coexistent. Social interaction as well as some kind of ‘political’ agreements must have been the basis for contemporaneous settlements, using the same (economic and cultural) hinterland. The picture is significantly different for the areas used for everyday farming activities within a distance of 15 minutes walking (fig. 4b), overlapping is reduced to a minimum and is to be expected for those sites only that are not contemporary existent.

Comparing the sizes of the hinterland areas within 60 minutes walking distance from the ‘Princely Sites’ with those from the regular settlements (fig. 5) can be used as a means to analyse economic strategies of places with a different social meaning. Figure 5 shows the median values of the ‘hinterland’ sizes of the regular settlements in each area of research, compared to the size of the hinterland of its ‘central place’. This large surrounding area instead of the 15min area, which was used for everyday agricultural activities, was calculated to take into account (or to question) the potential role of the hill forts as surplus producing sites whose wealth could be based on producing and trading agricultural surplus, but which may also have been much larger than the ‘normal’ sites and therefore might have had to feed a larger amount of inhabitants.

The median values do not differ so much in the interregional perspective as do the sizes of the ‘Central Places’ surroundings. In general the hinterland areas of the regular settlements are more or less comparable, whilst the ‘Fürstensitze’ and other important places obviously did differ much more. Within the area of the Nördlinger Ries, with its sites of the ‘Fürstensitz’ Ipf and the two ditch enclosures of Osterholz, we can see the biggest spread between the regional mean value and the central places values. Only the for-

![Figure 5. Median values of the hinterland size (km²) of the regular settlements within each research area (grey) compared to the size of the hinterland of the ‘central place’ itself (black).](image)
5.8 Modelling the Agricultural Potential of Early Iron Age Settlement Hinterland Areas

The identified hillfort Goldberg in the same area can be compared with the regular settlements in that region. The significant difference between the sizes of the surrounding areas of the regular sites compared to those of the ‘Princely Sites’ cannot be explained by the location of the latter on hilltops. This is because the difference of the site locations has been taken into account by calculating the cost surface surroundings not from the top of the hill with the ‘princely sites’, but from their outer fortification or the foot of the hill. Also the topographical situation of that specific type of settlement did not play a role because not all of the ‘Fürstensitze’ are situated on very prominent hilltops in a rather mountainous surrounding. The Heuneburg, for example, lies on a plateau not very much higher than the environs, which is – as are the environs of the other hill forts mentioned in the text – not very much influenced by steep slopes.

**QUANTITY AND QUALITY**

Not only the size of a settlements hinterland might have played an important role but also the natural resources in terms of soil quality and other factors directly related to agricultural activities.

The Ipfb itself has the largest share of soil with low suitability for plant cultivation in its surrounding as well as the smallest share of high-quality soils (fig. 6). In contrast the availability of good or at least medium suitable soils is higher around the ditch enclosures of Osterholz, which is balancing their smaller surrounding areas. The Goldberg site with its large hinterland area had a relatively high percentage of good soils as well.

![Figure 6. Share of soil classes in a 60min surrounding around the Ipfb 'Fürstensitz' and neighbouring settlement sites.](image-url)
We know that the people in Celtic times made their living mainly by crop and cattle farming. So large hinterland areas, where the mean values are more or less the same as the value of the hinterland size of the ‘special settlement’ itself, are the indication for a mainly agricultural based way of living of the people of the ‘Central Place’. We can assume that for the Goldberg, while the ‘Fürstensitz’ on the Ipf itself as well as the ditch enclosures of Osterholz on his foothills seem to have played a different role in the settlement system.

The Ipf is more or less a landmark in both a cultural/ritual way and in an economical way as part of a traffic and trading system, whereas we have some still very weak evidence that at least one of the Osterholz ditch enclosures might have been a place with a ritual meaning.

**MODELLING THE AGRICULTURAL POTENTIAL OF HINTERLAND AREAS**

The analyses of the hinterland area models have shown that the size of a hinterland has the potential for an assessment of the settlement it belongs to. In order to further investigate the hinterland areas of the Late Bronze and Early Iron Age sites the agricultural potential of the settlements should be modelled. One of the main research questions was to test, whether a ‘Princely Site’ can be understood as consumer site, being dependent not only on its own hinterland but also on the backing of regular settlements in its vicinity, or as a producer site with a large productivity which gained a surplus that might have been the basis for the wealth of its inhabitants.

Cattle and crops were the main basis of nourishment for prehistoric societies in Middle Europe. Calculating the agricultural potential of a settlement could therefore also be used to estimate the maximum number of inhabitants that could be fed (for a more detailed discussion on the following aspects cf. Fischer et al. 2010; Ebersbach 2004).

**Factors of Land Use Classification**

Soil is one of the main factors that have an influence on the potential of any hinterland to produce crops or other food. Based on the data from the Geological Survey of Baden-Württemberg we have recalculated six classes of soil, taking also into account climatic factors that had an influence on soil fertility. The data we were using are of course actual data – which might represent lower values than have been available during the Iron Age –, but comprehensive information on the Iron Ages soil and climate is not available. The main outcome of this classification is the allocation of soil values of more than 40 based on the so-called ‘Reichsbodenschätzung’ (Posluschny 2002, 76) being suitable for crop farming (fig. 7; Fischer et al. 2010). The ‘Reichsbodenschätzung’ was a project, undertaken in Germany in the 1930s and revised several times afterwards, which aimed to provide a specific value for each field in Germany (based on the type of soil, soil condition, climate…) which should represent the quality of that field for agricultural needs. This value was also used for tax classification based on the expected yield of the field. High values (max 100) represent good soil conditions, low values represent less valuable soils.

Part of the classification that was used for our preliminary modelling are specific soil types and their general fertility as well as their workability. The latter generally had a lower impact on soil fertility in modern times (like the 1930s when the ‘Reichsbodenschätzung’ was started) than it the Iron Age with its more limited techniques for ploughing so we have chosen rather conservative measures as thresholds.
Topography is another parameter, which is part of the model calculation. We have allocated the slope values into different classes and agreed on a rough estimation that land with a slope of more than 10 degrees cannot be ploughed or at least ploughing causes erosion effects that had a significantly negative influence on the land (fig. 8; Fischer et al. 2010).

The combination of soil values and slope classes leads to a classification of the agricultural potential. For crop farming needs we calculated up to five classes of applicability. Areas with a soil fertility value of less than 40 or with a slope of more than 10° have been classified as meadows and woods, suitable for stock farming and a last class represents areas where the information is too sparse to be taken into account (fig. 9).

**Food Supply by Crops**

The main basis for food supply during Prehistory was mainly crops in different variations. A couple of very intense investigations on the plant remains from several settlement sites from the Bronze and the Iron Age have been undertaken in Baden-Württemberg (fig. 10; Fischer et al. 2010). These investigations give a good overview of the species that where cultivated, their share in the daily food supply and their popularity during different periods and in different areas. On the basis of this knowledge it became clear
Figure 8. Slope classification in the area around the 'Fürstensitz' Heuneburg (Baden-Württemberg). The dark brown slopes indicate areas with more than 10 degrees of slope which are not suitable for ploughing. – DEM D-25 (25 m grid). © German Federal Office for Cartography and Geodesy 2004. See also the full colour section in this book.

Figure 9. Combined classification of soil and slope values in the area around the 'Fürstensitz' Heuneburg (Baden-Württemberg). – Fischer et al. 2010. See also the full colour section in this book.
that on a very rough scale the nutritional value of the main crop species were quite comparable taking into account the share of the species in the finds from archaeological sites.

The potential of specific soil types to produce crops and other nutritional plants is dependant on various factors; many of them are subject to change due to soil degradation. Nutrients are removed by the growing of plants and have to be replaced depending on the amount of harvested crops per year. This can be done by having an annual change between cultivation and fallow for each field and by putting dung on the fallows. In our model we act on the assumption that cattle is grazing on the fallows and that dung from the stables – if existent at all – is placed manually on the fields as well. The actual model is working on the hypothesis of a more or less sustainable cultivation with a balanced nitrogen budget. Future refinements of the model will try to take into account a small amount of soil degradation as well.

**Adding all Factors**

The basis for the calculation of the potential of a surrounding of a settlement is the measurement of the area of the potential fields and their classes of soil quality. The cultivation/fallow ratio is a parameter that leads to minimum and maximum values, depending on the chosen ratio. We are well aware that not only grain species have been used as plants for feeding. People used a great variety of leguminous plants or oil seeds as well. Especially in the Hallstatt period, the first phase of the Early Iron Age, *Leguminosae* had a high degree of steadiness within the various settlements. On a general level it is possible to estimate their...
value in the same way as the grains, taking into account their nourishing values and their share in the plant remains from the archaeological sites. The calorie needs that we are using for our model at the moment can be discussed; in this first attempt it is quite low (1650 kcal/person/day) but of course the input from crop can be amended by other plants like vegetables, mushrooms, nuts and so on and of course by meat as well (fig. 11).

**AGRICULTURAL POTENTIAL AND ITS MEANING**

Our first modelling attempt is still based on circular surroundings around the investigated sites. The results of cost-based areas will be the basis of our further work. Even in this preliminary stage we can already make some statements on the potential of several sites, which are the starting points for the further interpretation of their meaning in the social and economic network of the Early Iron Age.

From our point of view the gain of crops in the Iron Age is much lower than the gain of Late Neolithic societies and of course also much lower than in modern times, but it is also higher than during mediæval times. Based on the coarse assumption that the yield of crops on medium suitable soils is 1,000 kilo per hectare per year (based on the results of various field experiments; cf. Fischer et al. 2010; Landesamt 2005), we can conclude that the work that is needed for its production and harvesting equals 110 days of labour. A share of 200 kilo, which is the annual amount of crops food per person, can therefore be produced by that person within 23 days. We can come to the general conclusion that the expenditure of human labour was not the restricting factor for the production of cereals, especially because it is very likely to assume that work with more or less fixed dates like sowing or harvesting might have been supported by other people of the community that have been released from their usual work for those purposes.

Given a ratio for cultivation and fallow of 1:1 first of all we see great differences when comparing the four sites of the Heuneburg, of Walheim, of Hochdorf and of the Ipf (fig. 12). The Heuneburg and the Ipf both are classical ‘Fürstensitze’ sites whilst Walheim and Hochdorf represent more or less ‘normal’ settlement sites – even if Hochdorf is a place of a potential higher social or political ranking. The surrounding areas of both ‘Princely Sites’ could nourish only half the number of people that could be fed from the Walheim and the Hochdorf hinterland. This picture matches with the results of the calculations shown.

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Figure 11. Flow-chart of the model to calculate agricultural potential.
above, indicating that the hinterland of the Ipfs was definitely not able to feed as many people as the hinterland of the nearby Goldberg (figs. 5, 6). Speaking in absolute numbers this means that around 1,500 people could live from the Ipfs hinterland, 2,000 from the Heuneburg and 4,000 from the Hochdorf surroundings. It is hard to evaluate the size of the Heuneburg region with its large suburban settlement, but at least for the site of Hochdorf a number of 4,000 inhabitants seems to be relatively high. This means longer periods of fallow, resulting in cultivation: fallow ratios of 1:2 or of 1:3, would have been possible, and allowing the soil to recover from degradation. Alternatively a surplus based on cattle and crops could have been produced as a basis for trade, or to be stored for various purposes like feastings, stockpiling and so on.

The Ipfs might have housed 1,500 people but taking into account the sparse knowledge about the settlement structure (von der Osten-Woldenburg 2004, 54; figs. 7-13) it seems to be much more likely that the number of people living there was much lower, possibly less than 800 persons. A surplus production might only have been possible if we calculate a 1:1 cultivation: fallow ratio which then would have led to a faster degradation of soils.

Again a 6 km/1h hinterland was used as a larger area which could produce a surplus and which is also a first estimation that has to be compared with the results of a 15 min hinterland as the main area of everyday agricultural activities in future. The regular settlements seem to be situated in better suited areas for agriculture and it is assumed that their greater agricultural potential was used to produce a surplus which could either be traded, distributed, stored as a reserve, used for social activities connected to ritual feeding and feasting or to support settlements with a not so clear focus on agricultural activities like some of the ‘princely sites’ – or as a combination of some of these aspects. It is not very likely that they were used from regular settlements to produce larger quantities to feed larger numbers of people because excavations in these settlements have shown that they are usually rather small hamlets.

All these calculations do not yet account for the results of the pollen analyses, which might change the picture to a certain extent by better estimating the amount of land use for cattle, crops and fallsows. This is one of our future tasks when refining the model.
ADDING CATTLE TO THE MODEL

Besides the supply of crops animal products were of course used for nutrition as well. Due to the ongoing discussion within our team we can only show first aspects of the potential for producing meat, milk and other animal products.

The general idea of the calculation is pretty much the same as for crops. Based on the size of the potential pastures and the carrying capacity the number of livestock units of 500 kg live weight is calculated. Taking into account that proportions of horse, cattle, sheep/goat and pig were much smaller during the Iron Age than today, the potential numbers of animals were recalcuated using the ratios of these species in the investigated settlements. Finally, the ratio of slaughtering, the dressing percentage and the nourishing value of meat and milk are estimated for each species and the food value of milk and meat is determined (fig. 13).

A first result of the model is the conclusion, that animal products could cover only a very low fraction of the daily caloric needs of the people in the settlements. Recent research has shown that game and fish did not play a significant role in the nourishment of Early Iron Age people (Kerth & Wachter 1993). The main use for animal husbandry was the need for proteins in the daily diet as well as for secondary products like wool, dung, leather, bones and so on. In the case of cattle, we also have to take into account that they were used as draught animals.

The amount of animals that are grazing in the vicinity of a settlement and the amount of dung they produced had of course a great influence on the soil, especially on the nitrogen values. Periods of cultivation and of fallow therefore are dependant on these values. Also in very woody areas like around the Heuneburg livestock could balance lower disposability of crops to a certain extent. Refining these influences in our model will be another future task.

Figure 13. Calculation of agricultural potential, based on livestock. – Fischer et al. 2010.
FUTURE WORK

Some aspects still have to be discussed and refined in the model, like the problem of soil exhaustion or the incorporation of the results from the palynological analyses. The model itself is prepared to be rather flexible, so parameters can be adjusted quite easily. Especially the results of various pollen profiles that have been investigated (Fischer et al. 2010) can be used to further refine our knowledge about offsite landscape reconstructions.

It is our aim to build a database software that is able to calculate the agricultural potential of any given hinterland in any given period and area with the possibility to change the parameters of the calculation like the caloric needs, the nutrient removal, the periods of fallows and cultivation and so on. In a first stage we will therefore convert existing Excel spreadsheets into a FileMaker database, which we plan to distribute as a free runtime version. As much of the calculation will be done within a GIS – like the definition of cost based surroundings and the merging of soil and topographic information – we would also like to develop a calculation model that runs in the free GIS software gvSIG.

Within the ‘Fürstensitze’ Priority Programme we plan to calculate the agricultural potential not only for the ‘Princely Sites’ but also for all others settlements that are under research in the project ‘Princely Sites’ & Environs – depending on the availability of sufficient soil data. This would result in the modelling of the agricultural potential of the hinterland of up to 5,000 settlement sites that can be analysed and compared.

CONCLUSIONS

The use of GIS in the research project – though the results are still somewhat preliminary – did not only show its potential for landscape archaeology in general but also to bridge the gap between environment, culture and social behaviour. The way prehistoric people acted in their surrounding environment was of course driven by economic needs to a certain extent. But other factors had an influence on their behaviour as well, thus creating recognisable patterns of different kinds of activities in the landscape.

The ‘Fürstensitze’ themselves are one of the results of these activities, being a manifestation of both economic and social needs. Even though most of the ‘Fürstensitze’ of the Early Iron Age seemed to be quite similar in their appearance, a greater variety now becomes obvious, which shows the adoption of man to its environment as well as his use of landscape as a stage for social and cultural interaction.

REFERENCES


