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Finding the Limits of the *Limes*

Modelling Demography, Economy and Transport on the Edge of the Roman Empire

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Preface

Background

This volume in the series Simulating the Past and in the introduction Computational Social Sciences presents the results of a 5-year research programme titled 'Finding the limits of the *limes*: Using spatial dynamical modelling to reconstruct and understand the development of the cultural landscape in the Dutch part of the Roman *limes*'. The programme, which ran from September 2012 to August 2017 at the Faculty of Humanities of the Vrije Universiteit Amsterdam, was financed by NWO (the Netherlands Organisation for Scientific Research) under the VIDI Innovational Research Incentives Scheme (project number 276-61-005) and aimed to apply spatial dynamical modelling to reconstruct and understand the development of the cultural landscape in the Dutch part of the Roman *limes* zone from 12 BCE to 270 CE. It focused on modelling economic and spatial relations between the Roman army and the local population, in particular the interaction between agriculture, animal husbandry and wood management and the related development of settlement patterns and transport networks in the area.

The project was in essence intended as a testing ground for a number of computer (simulation) modelling approaches that, up to then, had had very little impact on Roman archaeological research in the Netherlands and beyond. The idea for the project originated at a small workshop organised by the University of Basel in January 2011 themed 'Calculations in (bio)-archaeology', where an overview was presented of the state of the art of quantitative approaches to environmental archaeology for the Roman period in NW Europe. While advanced computer simulation models had already been applied to archaeological research questions in many parts of the world and for many time periods (see Van der Leeuw and McGlade 1997; Kohler and Gumerman 2000; Bentley and Maschner 2003; Kohler and Van der Leeuw 2007), Roman archaeology at the time seemed to be largely unaware of the utility of simulation modelling to address archaeological research questions. Also, the adoption of GIS as an analytical and modelling tool seemed, with some exceptions (Vermeulen et al. 2001; Van der Leeuw et al. 2003; Goodchild 2007; Kay and

Witcher 2009), to have been relatively slow. This terra incognita, to use an appropriate Latin phrase, therefore seemed a potentially fertile ground for extending advanced computer modelling approaches. In particular, it was anticipated that the then emerging technologies of agent-based modelling (ABM) and social network analysis (SNA) could contribute to a better understanding of economy, land use and demographic development in the Roman period, especially when combined with more traditional, static and GIS-based models – hence the reference to 'spatial dynamical modelling' in the project title. However, it was also clear that in order to demonstrate and test the utility of this approach, a rich archaeological and palaeo-environmental data set was needed that would cover a substantial geographic space.

Since the Dutch *limes* area ticked both boxes and had also been the subject of extensive previous research by scholars from the Vrije Universiteit Amsterdam and other Dutch universities, it was decided to apply for the project with NWO in October 2011 (Verhagen 2011). The key objectives were defined as follows:

- Producing new perspectives on the development of the cultural landscape in the *limes* area during the Roman period, by translating current theoretical approaches into spatial dynamical models that include the macro-regional scale, the temporal dimension and the interaction between the natural, economic and sociocultural factors shaping the landscape
- Producing a set of procedures and tools (best practices) on how to use spatial dynamical modelling, and in particular ABM, for this purpose

It was the ambition to connect models of subsistence production at the household level to regional and supra-regional trade models, to link models of agricultural production to models of natural vegetation development, to connect models at different scale levels (micro- and macro-regional) and to find suitable methods to confront the model outcomes with the available archaeological and palaeo-environmental data.

The project proposal was positively evaluated in May 2012 and consequently work started in September 2012 by the applicant and two PhD students. Jamie Joyce fully focused on the archaeobotanical and archaeozoological aspects and developed agent-based models of agricultural production and fuel consumption at the settlement level. Mark Groenhuijzen worked on the palaeogeographical reconstruction and developed computer-based analyses of settlement patterns and transport networks at the regional level. Philip Verhagen took care of archaeological data collection, analysis and interpretation and focused on palaeo-demographic and palaeo-economical modelling.

Project Outcomes

Formally, the project was finished in August 2017, but publication of the research findings has taken some more time, with this volume as one of its results together with various articles already published (Groenhuijzen and Verhagen 2015, 2016,

2017; Joyce and Verhagen 2016, Verhagen et al. 2016a, b) and two PhD dissertations (Joyce 2019; Groenhuijzen 2018). As indicated in the proposal, the methodological approach was completely new for the area and time period addressed and aimed to integrate different geographical, temporal and thematic scales of analysis. Apart from developing new methods and tools in simulation modelling, network analysis and GIS, we have also compiled a new, comprehensive database of archaeological records of the area, prepared a detailed palaeogeographical reconstruction and performed the first macro-regional analysis of the development of land use and settlement in the area.

It is, however, important to stress that the research done in this project has not only focused on modelling as a methodological improvement but also to evaluate archaeological research questions of a larger scope and geographical scale than many of its predecessors. Our approach proved to be most valuable for two aspects of the research. First of all, it integrated models of agriculture, animal husbandry and wood production and investigated their interdependency. The models of agricultural production (see Chap. 7; Joyce) are, as far as we are aware, the first to achieve this kind of integration. Second, it contributed to understanding the spatial effects of changes in economic and settlement systems. The question of distribution of goods and interaction between Roman and local settlements was tackled using network construction and analysis techniques that can be integrated into simulation modelling approaches (see Chap. 12; Groenhuijzen).

A major challenge for the agricultural production models was the translation of 'expert judgement' models into formal simulation models, since the assumptions underlying expert judgement models have varying degrees of certainty. Simulation modelling offers an environment to experiment with different scenarios, so this can be seen as a strong point of the chosen approach: uncertainties can be made (more) explicit, and their consequences for the behaviour of the system under consideration can be explored. However, the sometimes anecdotal evidence and contradictory archaeological interpretations available implies that the level of detail of the individual model components is not the same. This implies a large degree of freedom in experimenting and a wide array of possible conclusions on the interplay of the factors involved, highlighting the crucial importance of sensitivity analysis. It has also become clear that scaling up of the agricultural production models from the level of the individual household to the full study region is a task that is at the limits of the capabilities of currently available, off-the-shelf modelling solutions. Experiments carried out by De Kleijn et al. (2018) with our data sets show that other spatial modelling techniques may be helpful for this.

For the transport network modelling, we had to deal with uncertainties in the interpretation of archaeological information and its spatial distribution. In particular, the (lack of) chronological accuracy of find spots can potentially play havoc with the network reconstructions for specific time periods, and simulations of many potential networks were therefore necessary to assess the robustness of the reconstructions and analyses. Furthermore, the development of tools to reconstruct and analyse potential transport and communication networks needed much work to refine existing techniques and making these operational for use with spatial data.

Apart from these methodological results, the project has tried to address two major archaeological research questions. The first one is the question of surplus agricultural production for the Roman army in the study area, based on the hypothesis of Van Dinter et al. (2014) that (partial) provisioning of the soldiers with food must have been possible. From our modelling, it is concluded that the major limitation to agricultural production must have been the availability of workforce, as the area must have posed few limitations to the expansion of settlement and growth of agricultural production, with the exception of the marshlands in the west of the Netherlands. Specialised production, while evidenced to some extent in the archaeological record, does not seem to have been a necessary condition to produce the required surplus, but the models do not rule out the possibility either. Also, scaling up from subsistence-only to surplus production must have been relatively easy given the available land and workforce, even when the exact amount of possible surplus is hard to gauge given the uncertainties surrounding population densities and demographic development (see Chap. 3; Verhagen). However, the low availability of woodland in most of the region may have had long-term effects on the possibility to collect fuel and building material in the immediate vicinity of settlements. Also, the gathering of wood for fuel may have had a significant effect on the availability of workforce.

Secondly, the transport network modelling has resulted in new insights regarding the possible transport and distribution of goods. Local transport networks were thus far mostly neglected in studies on the Dutch *limes*. Our research shows that the position of sites within local networks can explain some of their characteristics, such as stone-built architecture, the presence of grain storages and their (assumed) function as a redistribution site. These results lend support to earlier assumptions on the existence of a system of collection and redistribution through local centres. However, the precise mechanisms responsible for the growth of certain sites still need to be explored. Social and economic interaction between the military and local population also remains a somewhat underexplored modelling theme, with at the moment only tentative interpretations possible of, for example, the negative effects of army recruitment on available workforce and the balance between taxation or forced requisition and market-based trade.

The impact of the project is currently mostly visible in the community of archaeologists involved in simulation and network modelling. Some of our approaches were never applied before, in particular the integrated agricultural production model developed by Jamie Joyce and the transport network reconstruction techniques by Mark Groenhuijzen, and we are confident that these will be useful tools for future research in other contexts. The impact on the archaeological discipline at large and Roman archaeology in particular is harder to gauge at this moment. Simulation modelling is not yet very well established in archaeological research, and the final results from our studies, while pointing indeed to novel explanations for observed settlement patterns, also raise a number of new questions, in particular where it concerns the economic and social theories underpinning the interpretative frameworks used to understand the development of the Roman *limes*. This implies that further research should focus even more on finding ways to translate expert

judgement and incomplete evidence into formal models and to investigate socio-economic issues at larger scales than the settlement level.

Setup of This Volume

Importantly, this volume is not just a final report of our project. In January 2017, we organised a project conference in Amsterdam to present our preliminary results (https://limeslimits.wordpress.com/project-conference-2017/) and invited various other researchers to present case studies and reflect on the application of computer (simulation) modelling to the four most important themes we focused upon: subsistence economy, demography, transport and mobility, and socio-economic networks in the Roman period. The papers presented at this conference form the core of this book, with most of the presenters having submitted a chapter.

In this volume, we do not present a general theoretical framework and introduction to the modelling approaches used. Several good introductions exist on how to use ABM (Premo 2010; Kohler 2012), SNA (Collar et al. 2015) and GIS (Conolly and Lake 2006; Verhagen and Whitley 2012) to tackle archaeological research questions, and numerous case studies have appeared over the last two decades where these are used and sometimes even combined to good effect.

The volume is roughly subdivided into three sections: demography and settlement (Chaps. 2, 3, 4, and 5), economy (Chaps. 6, 7, 8, 9, and 10) and transport and movement (Chaps. 11, 12, 13, 14, and 15), although some papers also make connections between the subjects. After a general introduction to the Dutch *limes* zone (Chap. 2; Verhagen, Joyce & Groenhuijzen), Section 1 starts with a chapter by Isabelle Séguy, who provides backgrounds and thoughts on the demography of the *limes* zone, highlighting the special character of the region as an immigration zone. This is followed by a discussion of the demographic model we developed (Chap. 3; Verhagen) to better understand the mechanisms of population growth and decline in the area, which highlights the importance of social and economic factors when trying to project demographic developments and to estimate population sizes from generalised demographic assumptions. Tyler Franconi and Chris Green (Chap. 4) then demonstrate how 'broad-brush' approaches based on large datasets can provide valuable information on large-area population and settlement dynamics, especially when considered over longer time spans than just the Roman period. Antonin Nüsslein (Chap. 5), on the other hand, shows how the detailed study of the development trajectories of excavated settlements in NE France was used to understand the characteristics and diversity of survey data and thus could be applied to study the development of settlement patterns in larger areas.

Section 2 starts with a discussion by Willem Jongman of the macro-economic setting of the *limes* zone (Chap. 6). Jamie Joyce then summarises the set-up and outcomes of the agricultural production model for the *limes* zone (Chap. 7). Antoni Martín i Oliveras and Víctor Revilla Calvo (Chap. 8) then take us to Spain in a study on modelling the economy of wine in the Roman period. Eli Weaverdyck (Chap. 9)

stays close to home, with a GIS-based statistical model of the distribution of settlements with regard to possible markets in the Dutch *limes*, applying an approach that he developed earlier for the Lower Danube *limes*. Stefano Bertoldi, Gabriele Castiglia and Angelo Castrorao Barba (Chap. 10) then bring us to the Ombrone Valley in the heart of the Roman Empire, where they show how combining spatial and network analysis and the study of diagnostic find categories can shed light on the spatial and economic organisation of hierarchical settlement systems.

The last section starts with an extensive overview of modelling of routes and transport networks (Chap. 11; Verhagen, Nuninger & Groenhuijzen). Mark Groenhuijzen then presents his work on reconstructing the local transport network of the Dutch *limes* (Chap. 12) and its implications for the interpretation of the settlement pattern. After that, Pau de Soto (Chap. 13) shows that network analytical approaches can be used to understand connectivity over the large scale, by analysing the Roman road network of the Iberian peninsula. Another Spanish case study is then presented on modelling and understanding the development of the Roman road network in the northwestern Iberian peninsula (Chap. 14; Parcero-Oubiña et al.). Katherine Crawford (Chap. 15), finally, takes us to the micro-scale with her analysis of movement in the city of Ostia.

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Amsterdam, The Netherlands

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