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

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OUTLINE OF THIS TALK

- Introduction
  - project background and approach
- Archaeological dataset
  - issues with interpretation of existing inventories
- Demography
  - modelling recruitment
- Agriculture
  - simulating the farm
- Transport networks
  - estimating transport costs
  - analysing networks
THE DUTCH LIMES
PROJECT BUILDING BLOCKS

DATA
- archaeobotany and archaeozoology
  reconstructed consumption and production
- archaeology
  reconstructed rural and urban settlement, military infrastructure
- palaeogeography
  reconstructed natural and cultural landscape

CONCEPTUAL MODELS
- subsistence
  energetics, production capacity
- demography
  labour force, settlement density
- macro-economy
  markets, flow of goods and people, taxation

QUANTITATIVE MODELS
- spatial dynamical modelling
  (ABM, GIS, SNA)
  subsistence/surplus production, population development, local/ ‘Roman’ economic interaction

household / settlement scale
- (supra-)regional scale
Why this area?

- intensive archaeological research
  - but so far, few synthetic studies
- generally well-preserved organic remains
- special case within the Roman Empire
  - landscape setting
  - political position of Batavians
- so: a perfect test bed for new modelling approaches
- simulations of aspects of human behaviour
  > not mimicking reality, but aiming to be realistic

- spatial AND temporal dimension

- agent-based modelling
  > from micro- to macro-scale

- explore cause and effect
- scenario-based
- compare outcomes to known data
MODEL SETUP ISSUES

- assumptions (middle-range theory)
  - unambiguous
  - cause-and-effect
  - uniformitarian
  - independent of general theory

- parsimony vs. realism

- sensitivity to uncertainty and error
  - assessment of potential error margins
  - effects of error on modelling results
The archaeological (settlement) dataset includes:

- existing inventories
  - Willems (1986)
  - Vos (2009)
  - Vossen (unpublished)
  - van Dinter et al. (2013)
  - local inventories (e.g. Den Haag, 2008)
  - ARCHIS (> 13,000 records)
  - DANS archive

- restricted to publicly accessible data
unreliable find registration
> focused on ceramics; features often ‘forgotten’

no direct link to literature
> literature listings often incomplete
> digital availability limited
> needs to be checked on ‘forgotten’ items

base documentation poorly archived and often incomplete
> much improved since 2006 (DANS archive)
DEFINING ARCHAEOLOGICAL SITES

- Vos (2009): inventory Roman rural settlement Kromme Rijn-area
  > mainly survey data

- criteria used
  > number of sherds (> 10)
  > proximity of finds (< 250 m)
  > ‘diagnostic materials’

- uncertainties
  > location
  > dating
  > function
  > documentation

‘In all these investigations, it seems that hardly any use was made of previous studies and it is impossible to understand why almost every study – at a more detailed level – has led to different outcomes’

(Vos 2009, note 151)
DENSITY OF FINDS WITHIN 125 M
ARCHIS dating codes
- 1 timeslice: ROM
- 3 timeslices: ROMV-ROMM-ROML
- 6 timeslices: ROMVA-ROMVB, ROMMA-ROMMB, ROMLA-ROMLB

Dating provided per object
- Counts often not registered
- Object category can be unspecific - e.g. AWH – AWG (thrown/turned pottery)

Site dating often based on ‘educated guess’
1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1
3 3 3
1 4 7 7 7 4 4 34
0.03 0.12 0.20 0.20 0.20 0.12 0.12 1

5 records, average 'dating quality' 1.4

1 3 3 3 3 3 3 3
0 0 0 0 0 0 0 0
3 3 3
2 2
3 3 3
3 3 3
3 3 3
2 2
1 1 1 1 1 1 1
0 1 1 3 21 26 23 75
0 0.01 0.01 0.04 0.28 0.35 0.31 1

12 records, average 'dating quality' 2.4
RELIABILITY OF DATING LATE IRON AGE
RELIABILITY OF DATING EARLY ROMAN PERIOD
RELIABILITY OF DATING MIDDLE ROMAN PERIOD
RELIABILITY OF DATING LATE ROMAN PERIOD
Departing from the data obtained from those trenches, an excavation pit was dug, in which a Roman house plan soon appeared. The three-aisled house was located on a rectangular compound surrounded by ditches, that could be investigated almost in full. The house seems to date from the first quarter of the second century. It does not seem probable that the house was part of a larger settlement. However, since not all outer limits could be reached, this cannot be proven. A wide parcel ditch leaves the settlement area in the direction of the nearby, larger settlement of Rijswijk-De Bult.

Hessing et al. 1990

excavation report (half page) mentions a 3-aisled house plan and ditches - but no finds
REVISED DATABASE

- > 1100 settlements
  > dating based on ARCHIS codes, and excavation reports where available
  > interpretation (for the moment) based on expert judgement
  > obsolete sites kept in database

- linked to
  > ARCHIS and other inventories
  > available literature
DEMOGRAPHICS

- demographic processes not well understood
  - Roman sources scarce
  - skeletal material problematic
  - fertility / mortality estimates based on (early) modern correlates

- population growth?
  - did life become healthier after the Romans came (less famine, less warfare?)
  - did people change their reproductive behaviour?

- the special Batavian case
  - recruitment of male surplus
## ESTIMATES OF POPULATION SIZE

### household and settlement estimates
- 5-8 persons per households?
- 1 – 2 settlements per km²?
- 1.5 or 3 – 4 farms per settlement?

### military recruitment estimates
- approx. 5,000 Batavian soldiers
- surplus of ca. 1.2 - 1.5 males per 20 years per household needed?

### carrying capacity estimates

<table>
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<tr>
<th>settlement model</th>
<th>Batavians</th>
<th>Cananeiates</th>
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<td>Bloemers (1978)</td>
<td>10,500 – 16,800</td>
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<td>Willems (1986)</td>
<td>13,500 – 28,800</td>
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<td>Vossen (2003)</td>
<td>49,400 – 117,800</td>
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</table>

<table>
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<th>recruitment model</th>
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<td>Bloemers (1978)</td>
<td>18,500 – 36,800</td>
<td>2,675 – 9,520</td>
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<table>
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<th>carrying capacity model</th>
<th>Batavians</th>
<th>Cananeiates</th>
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<tr>
<td>Bloemers (1978)</td>
<td>3,590 – 19,040</td>
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</tbody>
</table>
RECRUITMENT

- Batavian regiment sizes
  - based on limited written evidence
  - nominal strength ≠ real strength?
  - ethnic regiments may have been ‘multi-ethnic’
  - recruitment was reduced after mid 2nd century AD

- replacement rate
  - service increased from 16 to 25 years in early 1st century AD
  - mortality among soldiers (in peace-time) is not significantly higher
  - how many people came back?
A DYNAMICAL DEMOGRAPHIC MODEL

- household reproduction model
  - fertility based on historical evidence
  - experimenting with different mortality regimes (high / low)
  - age difference between spouses
  - assuming non-marriage of soldiers

- recruitment
  - fixed recruitment rate of males 18-25 years
  - 25 years service

- ice_video_20151109-124100.webm
MODELLED EFFECTS OF RECRUITMENT

The graph illustrates the modelled effects of recruitment on the population size, showing how different recruitment rates impact the % of starting population. The curves represent different scenarios, each labeled with specific recruitment rates, and demonstrate varying degrees of population growth or decline in response to recruitment levels.
EFFECTS OF RECRUITMENT ON DEMOGRAPHY

- **recruitment rate**
  - balance between recruitment and fertility needed
  - low rates: large population needed
  - high rates: population will decline

- **population size**
  - stable recruitment for 5,500 soldiers needs ~ 80,000 people
  - higher than previous estimates!

- **possible alternatives**
  - marriage for soldiers
  - multi-ethnic army units
  - ...
THE SURPLUS QUESTION

“Batavian lands were never able to provide the necessary food for all the soldiers stationed there [the limes region]”


“No local community could suddenly have started to produce the surplus required to feed the troops”


“The total rural population, even estimated at a minimum, was also able to produce enough surplus cereals, e.g. emmer and barley, to fulfil the demand of the Roman army and its associates for these cereals”

van Dinter, M. et al. 2014. Could the local population of the Lower Rhine delta supply the Roman army? Part 2, p. 32
MODELLING AGRICULTURE OF THE PAST

- a mechanism to explore uncertainties within archaeobotanical and zooarchaeological analysis
- a platform to incorporate spatial and temporal depth
- a method to analyze relationships and interactions between the various elements of an agricultural economy
SIMULATING THE RURAL ECONOMY

Landscape

Producer settlements

Mode of production

Wood/fuel

Stock breeding

Arable farming

Climatic

Fertility etc.

Demography

Demand

Supply

Consumer settlements
SHEEP HUSBANDRY MODEL
Het begint met een idee

2 production scenarios
- sheep: meat vs. wool
- cattle: meat vs. traction/manure

meat production:
- smaller herds
- lower resilience to calamitous events
- riskier strategy
- will still produce wool

wool/traction-manure:
- larger herds
- will still provide meat
- more land and labour needed
MODELLING TRANSPORT

- where did all the produce go?
  - who traded with whom?
  - how were goods transported?
  - where were the markets?

- most evidence on regional to imperial scale
  - very little evidence for local transport

- modelling of transport networks can fill the gap
  - GIS tools (cost surfaces and least-cost paths)
  - formalized network analysis
TRANSPORT COST ESTIMATION

\[ V = \sqrt{\frac{M - 1.5 W - 2 (W + L) \left(\frac{L}{W}\right)^2}{1.5 \eta (W + L)}} \]

\( V \) = velocity (m/s)
\( M \) = metabolic rate (W)
\( W \) = subject weight (kg)
\( L \) = carried load (kg)
\( \eta \) = terrain coefficient
### TRANSPORT COST ESTIMATION

<table>
<thead>
<tr>
<th>Terrain</th>
<th>Time over 50m (s)</th>
<th>Terrain coefficient</th>
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<tbody>
<tr>
<td>Water</td>
<td>20.0</td>
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<tr>
<td>Military road</td>
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<tr>
<td>High levee</td>
<td>1.1</td>
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<tr>
<td>Moderately high levee</td>
<td>1.1</td>
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<tr>
<td>Low levee</td>
<td>1.2</td>
<td>39.1</td>
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<tr>
<td>Residual gully</td>
<td>1.5</td>
<td>43.8</td>
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<tr>
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<tr>
<td>Reed and sedge fields</td>
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<tr>
<td>High Pleistocene sands</td>
<td>1.5</td>
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<tr>
<td>Cover sand</td>
<td>1.2</td>
<td>39.1</td>
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**Legend**

- **Water**
- **Reed and sedge fields**
- **Cover sand**
- **Fen woodlands**
- **High Pleistocene sands**
- **Low levee**
- **Residual gully**
- **High levee**
- **Moderately high levee**
- **Low floodplain**
- **High floodplain**
BETWEENNESS CENTRALITY
ROBUSTNESS OF NETWORK MEASUREMENTS

- network analysis is often applied on the complete network
- results can be dependent on complete network structure
- can we test the robustness of the results?
### KEY SITES (TOP 10% AVERAGE BETWEENNESS)

<table>
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<tr>
<th>ID</th>
<th>Toponym</th>
<th>Site type</th>
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<th>W40_B rank</th>
<th>MC_B rank</th>
<th>OC_B rank</th>
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SITES WITH STABLE PERCENTUAL RANK

- betweenness centrality is inherent property of location
- possibly result of ‘natural evolution’ in transport networks
SITES WITH STABLE PERCENTUAL RANK

- 75% of sites in top 10% of their network show stabilisation
- 8 out of 24 sites show stabilisation in all networks
  > robust position in all networks as a result of ‘natural evolution’
  > this includes two sites with *horrea*
betweenness centrality partly inherent property of location
other factors could have played a role as well
> e.g. political/military in the case of castella
betweenness centrality depends on presence of entire network
  > site location is not the result of ‘natural evolution’
  > other factors: suitability for farming/animal husbandry, political/military factors
INTRODUCING CHRONOLOGICAL UNCERTAINTY
EFFECTS OF CHRONOLOGICAL UNCERTAINTY

- reinterpreted dataset matches archaeological expectations
- change in global network measurements often related to change in number of nodes
- for all Roman periods, most global network measurements remain stable up to site likelihood values of ~0.15, even though number of nodes decreases
OUTLOOK: TESTING

- plausible vs. probable
  > sensitivity analysis
  > (extreme) scenarios
  > equifinality

- on the ground effects
  > what could be left behind?
  > bias in preservation
  > bias in recording
  > classification and interpretation
OUTLOOK: LINKING MODELS

- different regimes of operation
  - spatial scale
  - temporal scale
  - agent interaction

- modular modelling structure
  - scaling up / down / sideways

- connecting technical solutions
  - software limitations