The spread of Neolithic herders – a computer aided modelling approach

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ABSTRACT

Archaeologists are often faced with the situation that they are aware of the results of former human behaviour, while the processes leading to these outcomes are less understood. One possibility to answer questions about actions in the past is the computer aided simulation of these processes. Building upon such efforts, a model has been developed to simulate the migration patterns of Neolithic herders over the Arabian Peninsula. Primarily concerned with an interaction between humans and their dependence on a marginal environment, this model is implemented in a geographic information system as the simulation environment.

1. INTRODUCTION

The Neolithic developed within a restricted area of the Near East around 9000 cal. BC as a new way of life that included permanent settlements, farming and herding. The spread of the "Neolithic idea" and of domesticated animals can be demonstrated at 7000-6500 cal. BC both to the southern Levant and to southeastern Europe. Evidence for the spread of the Neolithic across the Arabian Peninsula comes from assemblages of stone artefacts found in Qatar which date to ca. 6500 cal. BC and closely resemble forms typical of the PPNB period in the southern Levant (Inizan, 1980). Another indication of the spread of Neolithic herders comes from animal remains excavated at the Neolithic graveyard of al-Buhais 18 in the southeastern corner of the Arabian Peninsula. About 90% of the remains come from domesticated sheep, goat and cattle, dating between 5200 and 4200 cal. BC (Uerpmann and Uerpmann, 2000). Because this area is beyond the territory of their wild ancestors, the domesticates had to be brought into this area by man.
Different hypotheses have been postulated for the spread of domesticated animals across the Arabian Peninsula. One hypothesis proposes the migration of mobile Neolithic herders (Köhler-Rollefson, 1992), while another involves the integration of domestic livestock into the economy of mobile hunter-gatherers in the steppic zone of the Levant (Byrd, 1992). Apart from these hypotheses, potential pathways for this spread are controlled by environmental factors that forced either an adaptation in behaviour or the avoidance of unfavourable areas.

2. A NEW MODEL FOR THE SIMULATION OF SPREADING

2.1. MODEL DESCRIPTION

Present models for the spread of the Neolithic from the Levant are either descriptive (Hassan, 2000) or mathematical, calculated with Euclidian distances (Ammerman and Cavalli-Sforza, 1984; Fort and Méndez, 1999). However, these existing models fail to incorporate the quality of geographic space as a significant factor that influences the spreading process. While this is of less importance in temperate Europe, where a more productive environment can be assumed, in a marginal zone like the Arabian Peninsula, the influence of local environmental conditions cannot be neglected.
The spread of the Neolithic across the Arabian Peninsula is seen as a process of innovation diffusion (*sensu* Hägerstrand, 1956) dependent upon the population density within a given space. As population density is influenced by local environmental conditions, a high interdependence between the ways in which spreading took place and the environment can be assumed. In this model these conditions are represented by a raster surface, where each raster grid cell stores the information about local resistance to the movement of people and their animals. The spreading process itself is simulated by a repeated generation of random points that represent mobile populations. With this approach, the random component in the simulation represents the archaeologically incomprehensible decisions that lead to human displacements. Because it is more likely that "wandering groups" populate nearby places than far away places, the possibility for the adoption of an innovation is highest in the direct neighbourhood of prior acceptance of innovation. Therefore the random points cluster more frequently around the "parent" points.

2.2. THE SPREADING SURFACE

The spreading surface represents a combination of environmental parameters that are considered fundamental to the dispersal of Neolithic herders across the Arabian Peninsula. It integrates the climatic conditions represented by precipitation, topography, hydrography, vegetation and the distribution of coastal areas, which are reconstructed for the Early Holocene climatic optimum (Fig. 1). For the simulation these parameters were evaluated for their influence on the movement of human groups, reclassified and combined to obtain a spreading surface that represents local resistance to the process of spreading.

2.3. THE SPREADING POPULATION – ENVIRONMENT INTERACTION

Under the assumption that the original centres of the Neolithic were located in the Fertile Crescent, the starting points of spreading are also situated in this area. For every iteration that the simulation runs, the number of consecutive points within the next generation, as well as the maximum spreading radius, depends on the information that the current point gets from the underlying raster value. Unfavourable conditions promote rapid movement across the landscape with larger spreading distances, or may even lead to extinction of the current population when the grid value descends below the threshold. Favourable environments stimulate more permanent settlements and minor spreading activities. However, with the passage of time these areas show a decrease in their favourability, thus forcing more intensive dispersal after several iterations. As a result, the general shape of the frontier of the point distribution resembles a wave of innovation that is strongly dependent on the raster surface.

2.4. IMPLEMENTATION OF THE MODEL

The model was implemented using the programming language Avenue in an ArcView 3.x GIS environment. The reasons for using Avenue instead of another programming language are the easy integration of GIS-specific processes and the possibility to quickly test and modify any of the parameters. Implementing this model in an ArcView 3.x environment also allows a subsequent analysis of the distributions of the modelled points without any further import/export procedures. Disadvantages include the somewhat slower performance on big datasets and a limitation to about 32,500 interactions between a vector shapefile and an underlying grid dataset. The latter problem was overcome by splitting the calculations into several steps.

The model is based on the interaction between a growing point shapefile (a digital vector format for storing geometric location and associated attribute information) representing the wandering groups and the continually updated, temporary raster files which represent the changing local, environmental conditions that force the movement of human groups.

The implementation of the model in ArcView 3.x is schematically shown in Figure 2. It starts with an initial point (or several initial points) in a point shapefile. There is a dynamic interaction between the point and the underlying raster dataset that represents the local conditions:

- Every point in each generation decreases the underlying raster value at the specific location ("drain on resources", "exploitation value"). If the grid value drops below a user-defined threshold, the point will stop producing descendants in the following generations ("degradation of the local conditions", "threshold of survivability").
- The number of descendants of each point in each generation depends on the value of the underlying raster at this specific location. The higher the raster value ("better conditions"), the greater the number of descendants in the next generation.
- The maximum spreading distance ("how far a new generation will go") can be determined by the user, but the actual spreading distance in this range also depends on the underlying raster value. As with the number of descendants, there exists a linear coherence, but in inverse proportion. The lower the raster value at a specific point, the higher the spreading distance ("higher pressure for migration").

The localization of the descendants is implemented by using a random algorithm. It uses a sine/cosine formula to spread the descendants around the "parent" point in a circular manner. The spacing between the points is determined by the user. This spacing value should prevent a too high density of points ("population pressure"). If the conditions at the location of a new point are below the survivability threshold, the point will not be created. This should simulate "trial and error" migrations (extinguished populations). Due to the use of the sine/cosine algorithm, the points cluster nearer the "parent" point than to farther-flung places within the spreading distance. This is intentional because it is more likely that "wandering groups" populate nearby places than those far away. Tests with evenly distributed descendants support this theory.

The user can specify the number of generations or how many iterations the model will perform. The attribute table for each point is updated permanently with a unique identification (Id), the value of the underlying raster file, the first generation number (in which generation the point was created), the last generation number (the number of the generation in which the point "died") and the identification (Id) of the "parent" point. These values allow for a very intensive interpretation of the results afterwards. Table 1 presents an overview of the model parameters, broken down by user-determined and automatically calculated parameters.

Table 1 – List of the model parameters differentiating between necessary input provided by the user and calculations made automatically by the program

Model parameters	*User input necessary*	*Calculated automatically*
Maximum number of generations	✓	×
Maximum spreading distance	✓	×
Real spreading distance	×	✓
Spacing between new points	✓	×
Maximum number of descendants for each point	✓	×
Real number of descendants (depending on local conditions)	×	✓
Survivability threshold	✓	×
Exploitation value of local conditions	✓	×
Point distribution of new generations	×	✓
Initial point shapefile	✓	×
Development of point shapefile during time (migration of descendants)	×	✓
Initial situation of local conditions	✓	×
Degradation of local conditions during time	×	✓

It is important to mention that the model will never produce the same results for multiple trials using the same parameters. An exact reproduction of a calculation is not possible due to the random component implemented in the spreading algorithm for the descendants of each generation. This effect is intentional and endeavours to simulate human behaviour, which is based more on instinctive, rather than rational, decision-making.

3. MODEL BEHAVIOUR IN AN ARTIFICIAL ENVIRONMENT

This modelling procedure can be tested in an artificial environment consisting of areas which are of different favourability to the spreading of populations. The final result is a point distribution in which more points are located within more favourable areas. Unfavourable areas whose values are below a threshold remain unpopulated (Fig. 3). The result of several iterations is a wandering point cloud that spreads over the surface from a single point. This starting point, as well as each of the following consecutive points, generates one consecutive point in its neighbourhood for every modelling step and reduces the underlying raster value until a threshold is reached. The spreading width of the consecutive points is determined by the value of the spreading surface.

4. THE SPREAD OF NEOLITHIC HERDING POPULATIONS ACROSS THE ARABIAN PENINSULA

In the present model only environmental parameters influencing the spread of Neolithic herding populations are included (see Fig. 1). Therefore the point cloud, starting from several initial points at the western edge of the Fertile Crescent, first wanders northerly towards the Euphrates drainage system. In this region the spreading surface indicates the most favourable environmental conditions. After a complete infill of this area with a high density of points, the less favourable areas of the northern part of the Arabian Peninsula become sparsely populated, while the Zagros mountains present a barrier to further northward spreading. Once the point cloud reaches the southern part of the Arabian Peninsula, where more favourable conditions exist due to higher precipitation and a denser covering of vegetation, a significant increase in the population density becomes visible. Another increase in population takes place towards the southwest after reaching the high plateau of Yemen and the Mandab Strait.

At the end of the modelling process, every region within the modelling area will be covered by populations if its environmental conditions allow it, which means its values are above a threshold. This is not the case for the northwestern part of the Arabian Peninsula, where minimal precipitation creates unfavourable conditions. Only one other scenario for the absence of populations is conceivable, the presence of an insurmountable environmental barrier. An example of this is the Sinai Peninsula, which prevents the population from spreading into the Nile valley. More interesting in archaeological terms are the patterns that result from the process of spreading. Favourable areas, which are spatially connected, show an earlier access by population groups than unfavourable or remote areas.

5. CONCLUSIONS

This type of modelling combines a stochastic component, representing unknown forces that influence the demographic diffusion of the past population, and a deterministic component, which depends on past environmental conditions. The result is a distribution of spatial points that represents the actual trajectories of past movements of population much better than either a simple, stochastic model of random movements or a deterministic model of least-cost paths.

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FIGURES

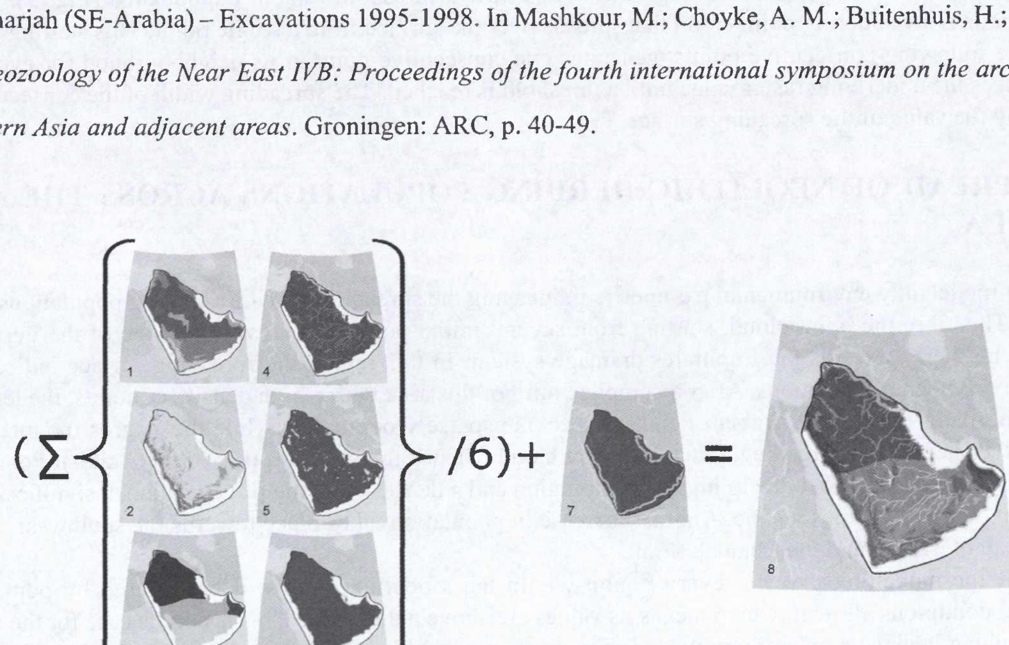

Fig. 1 – Calculation of the spreading surface (8) using the reclassified data layers representing precipitation (1), topography (2), vegetation (3), hydrographic network (4), basins (5), coastal areas (6) and sea coast (7). Brighter colours represent more favourable areas for spreading.

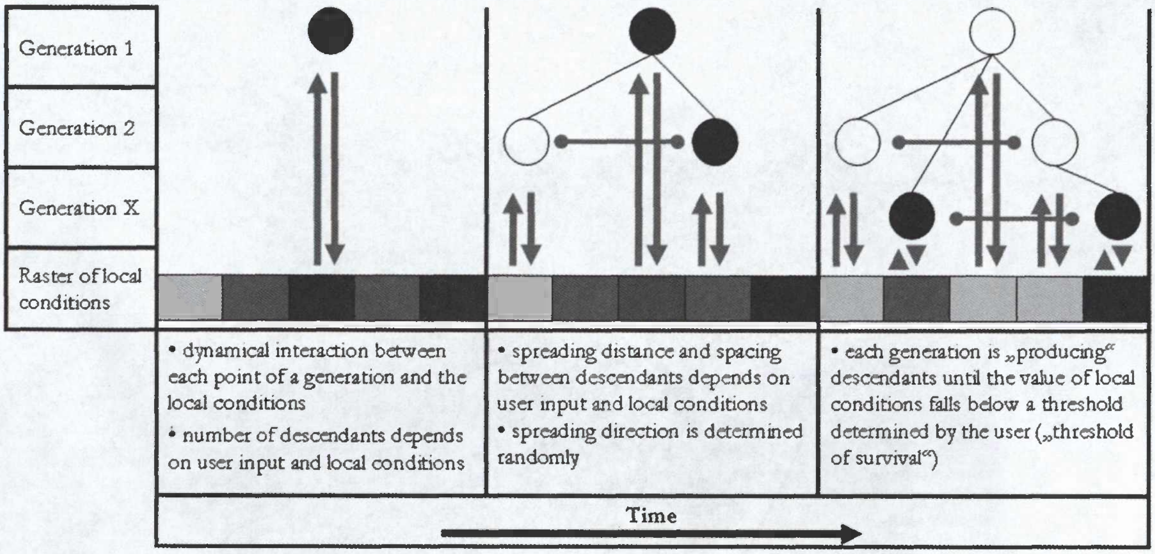

Fig. 2 – Interaction between local conditions represented by a raster file and different generations of descendants. A darker value represents a more favourable local condition. Shaded circles represent active ("living") elements, while unshaded ones are inactive ("dead").

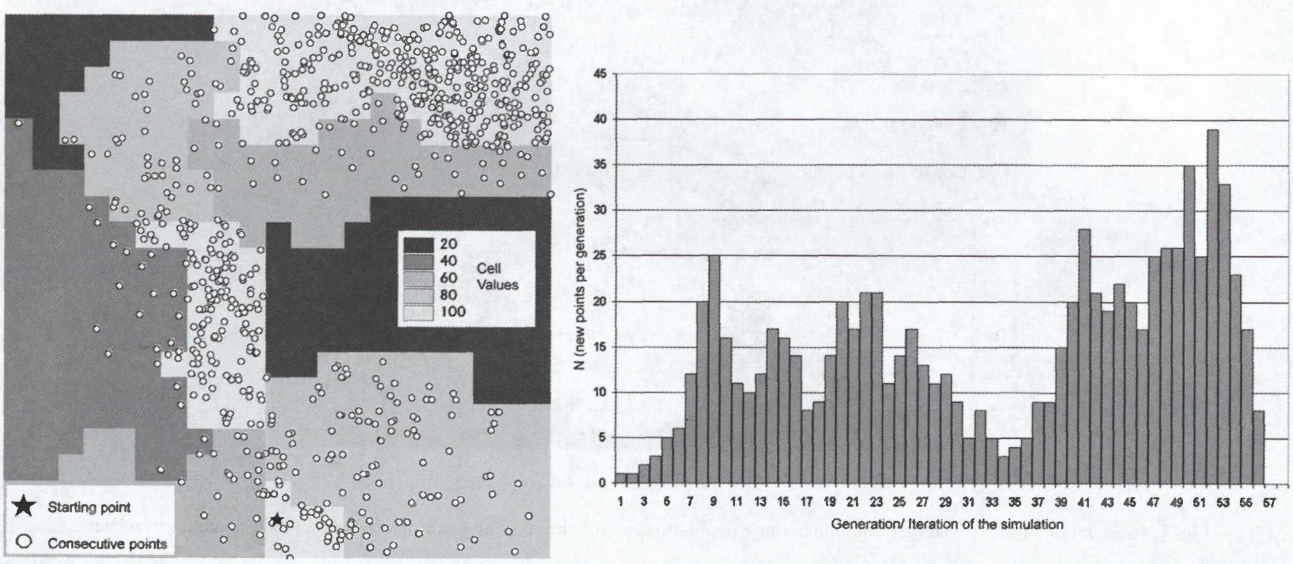

Fig. 3 – Simulation of the spreading process within an artificial environment consisting of patches with different resistance to spreading (left) and the number of generated points per iteration of the simulation (right).

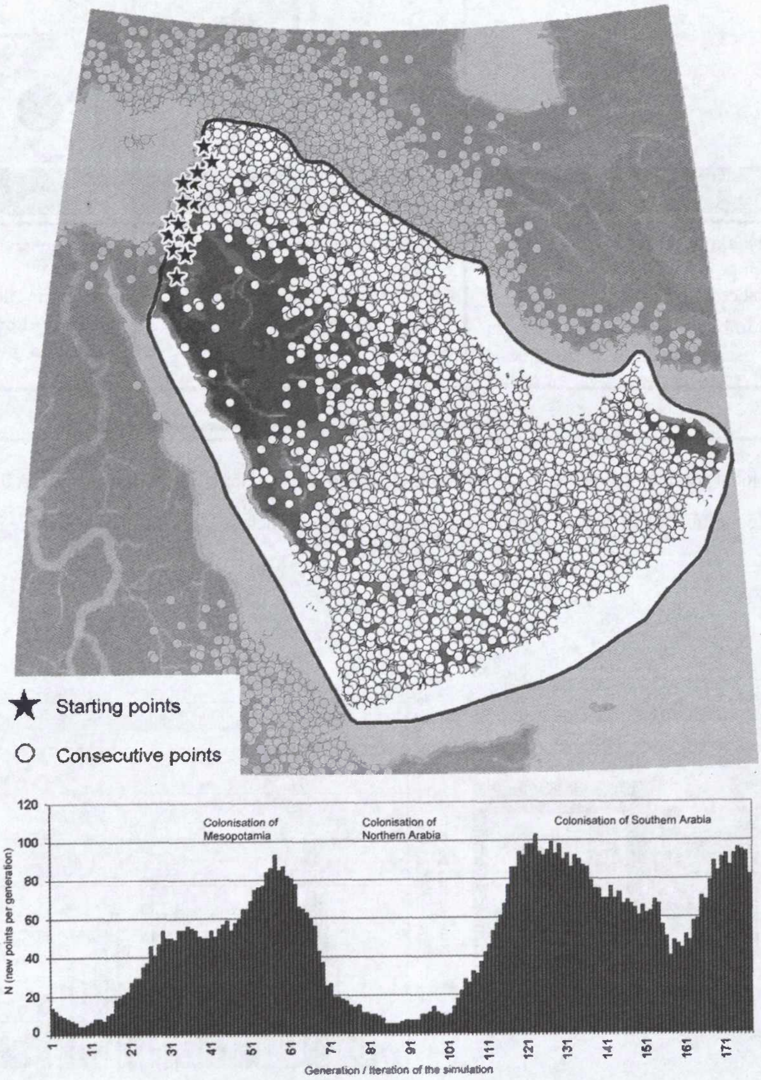

Fig. 4 – Simulation of the spreading of mobile herding populations across the Arabian Peninsula based on environmental parameters.