Modelling Mesolithic-Neolithic Land-Use Dynamics and Archaeological Heritage Management: An Example from the Flevoland Polders (The Netherlands)

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Abstract. The present paper discusses the possibility of combining environmental and behavioural models into an integral model of Mesolithic and Neolithic land-use for the Flevoland polders (The Netherlands). The Flevoland area was gradually inundated during the Mesolithic-Neolithic. Environmental changes have been modelled on the basis of a Digital Elevation Model (DEM) of the Pleistocene surface and water-level time/depth proxies in 0.1 Ka time intervals for the time period 7000–4000 BP. Seven vegetation zones have been mapped in relation to groundwater landscape structure and diversity. Based upon both expert knowledge and archaeological data, 'perception' probabilities have been spatially modelled for various behavioural settings. Some qualitative/quantitative aspects are briefly discussed in relation to large mammal hunting behaviour. Modelled 'perception' surfaces are combined with data on erosion, thus producing surface intactness maps. The relevance of the approach and results are discussed in the context of archaeological heritage management.

1. Introduction

With the forthcoming implementation in the Netherlands of the Valletta-treaty based "Monuments and Historic Buildings Act", archaeology has successfully acquired a strong position in the development and spatial planning of our modern day environment (Willems 1997). Local authorities and developers are required to take inventory of and validate archaeological remains at an early stage in the spatial planning process. The outcome of this archaeological prospection and assessment is gaining an increasingly large role in the actual planning process. Original plans often have to be changed or even abandoned altogether. In other cases, alternative and generally more costly construction techniques are utilised in order to avoid serious disturbance of archaeological remains. Finally, when no such possibilities exist, excavation is the only alternative. Consequently, the integration of archaeology into the field of spatial planning has financial implications which are not always easy to meet within the bounds of development projects.

The necessity for good predictive models has significantly increased as a result of the growing implications of this kind of research. (Peeters et al 2002). On a national level, the Indicative Map of Archaeological Resources developed by the National Service for Archaeological Heritage, presents an inductive predictive model on a 1:50,000 scale which expresses the possible encounter of archaeological remains (Deeben, Hallewas and Maarleveld 2002). This map departs from the correlative analysis of environmental input variables and archaeological aggregate data. Even though the indicative map has been shown to be reasonably applicable to some areas, research also has highlighted major deficiencies. Of these, the lack of spatial and temporal resolution has been identified as a crucial issue (Van Leusen et al 2002). The approach is a static one, which neglects the dynamics of the underlying formation processes of the archaeological landscape (Peeters forthcoming a). There is an urgent need to develop models which integrate these factors.

It could be argued that the ability to spatially predict and quantify the occurrence of archaeological material is of prime importance, however, it is essential that this information be combined with insight into the nature of the expected remains, as this has significant consequences with regards to the design of prospection strategies, assessment and the integration of archaeological resources in the planning process (Peeters forthcoming b). This demands a more dynamic approach, in which the issue of how distribution patterns emerge is central. It is important to formulate hypotheses on the dynamics of pattern formation and the way qualitative/quantitative characteristics of archaeological patterns are related, and try to understand the structure of the archaeological landscape. In essence, such models are process driven and refer to causal relationships (Whitley 2000, and Whitley forthcoming). In this paper I will investigate these aspects of predictive modelling. Several possibilities and problems will be presented in the form of a case study focused on the Flevoland polders in the Netherlands.

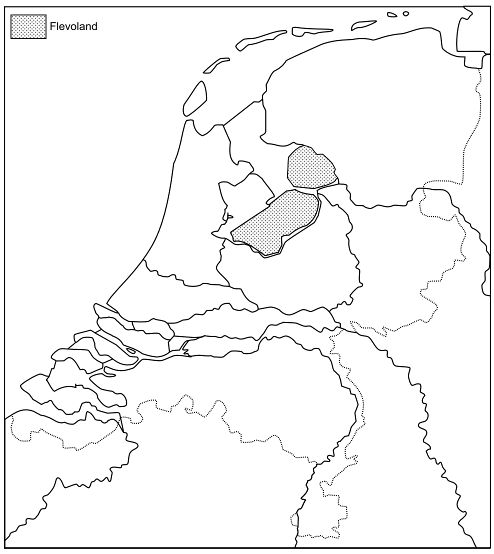

Fig. 1. Location of the study area within the Netherlands.

2. Landscape, Behaviour and Modelling

The present study addresses the issues relating to the detection and assessment of Mesolithic-Neolithic remains from a landscape oriented perspective. An important aspect is the modelling of qualitative and quantitative characteristics of the hidden archaeological landscape, and the integration of data on the geological evolution of the study area as the major temporal control (Peeters forthcoming a). In the course of the Holocene, the shaping of the Flevoland landscape was dominated by a gradual process of inundation, due to the structural rise in sea-level. Consequently, most archaeological phenomena encountered in the region date from the Mesolithic and Neolithic, and generally consist of low density find scatters found at depths of 1 to 9 m below the present surface. Taking landscape evolution as a basis for behavioural modelling could suggest that I take a environmental determinist position. Much of the polarized discussion on environmental determinism and socio-cultural factors in predictive modelling has, in my view, neglected the intrinsic relationships between the two. The explicit distinction between 'nature' and 'culture' is an expression of the western perception of our own relationship with the environment. However, our perception is far from a universal human trait. It is my belief that the environment should be seen as a framework within which choices in variable and dynamic socio-cultural settings are made. As such, the 'natural' environment only determines the extreme limits of land-use but within these bounds (which are by definition dynamic) the possibilities are endless. Instead of asking whether environmental or socio-cultural factors should be used, I believe we should focus on the question of how to link diverse and changing landscape characteristics to equally variable and dynamic dimensions of human behaviour.

Furthermore, I regard archaeological landscapes as continuous distributions of artefacts and features with variable spatial densities (cf. Zvelebil, Green and Macklin 1992). Predictive modelling in the context of archaeological heritage management (AHM), should primarily focus upon the spatial qualitative and quantitative characterization of density distributions instead of predicting so-called 'sites'. Prospective research does not map 'sites' but different densities of archaeologically recognizable indicators, the spatial patterning of which has to be interpreted in terms of formation processes and behavioural meaning. Lower or higher densities of phenomena with variable characteristics can be expected to have accumulated according to the intensity and way in which landscape zones and locales were used. Initial patterns have subsequently undergone and continue to undergo post-depositional transformations, thus determining the spatial features of the archaeological landscape.

As mentioned, the study area was gradually inundated in the course of the Mesolithic and Neolithic. This process of inundation provides a keystone for the modelling of land-use dynamics, as it provides an archaeologically independent means to increase the temporal resolution and at the same time represents an important drive behind aspects of landscape evolution.

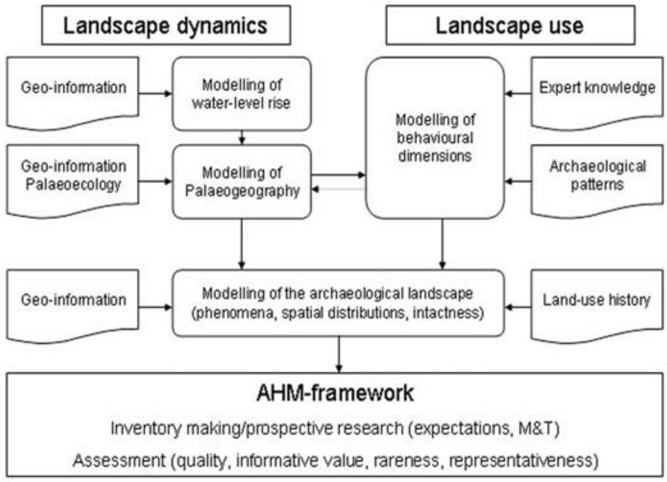

Fig. 2. Schematic representation of the relationship between modelling levels and data sources.

My approach combines a series of modelling levels (Fig. 2) which will briefly be discussed below (a more detailed description of procedures and decision rules will be published in Peeters forthcoming a).

3. Modelling Early Holocene Landscape Dynamics

The first step in the construction of an early Holocene landscape dynamics model was the creation of a DEM of the Pleistocene surface which formed the foundation of the Mesolithic landscape. Data from approximately 19,000 bore-holes spread irregularly over the study area, with a rough average of 20 observations per square kilometre were used for the creation of the DEM. Kriging techniques were then applied in order to obtain a reliable proxy (Isaaks and Srivastava 1989). Geostatistical analysis displayed spatial independence of inter-site differences at distances exceeding 260 metres, whereas the existence of spatially uncorrelated noise in elevations was found in the order of 38 cm, which corresponds to some 20% of the total variance of the dataset. This 20% level was considered a useable measure to apply as a subsequent map scale. A series of grid-cell settings were used to compute surface models by means of block-kriging, allowing the evaluation of the results in combination with their corresponding variance maps. Settings with grid-cells smaller than 500 x 500 m were found to expose maximum map variances exceeding the 20% limit and were rejected. Therefore a 1:50,000 map scale with 500 x 500 m grid-cells was considered acceptable for the entire study area (at a subregional scale higher resolutions can be obtained).

As inundation of the Pleistocene surface was regarded as crucial to the palaeogeographic evolution of the area, it was necessary to develop a time/depth proxy of water-level rise. Existing models of the rise in Post Glacial sea-level have been shown to provide only a rough guide as to regional and subregional water-level dynamics. In the Netherlands alone, three regions with different regimes have been distinguished (Beets and Van der Spek 2000). In order to check for its regional validity, a time/depth proxy of water-level rise which was established for the northern part of our study area was compared with a large series of new basal peat dates from the southern part of the study area (Makaske et al 2003). It was found, however, that both areas saw a regime which diverged with time, indicating that models of landscape dynamics have to integrate some sort of watershed with different rates of water-level rise in order to account for subregional differences.

The next step in the modelling process involved simulation of the palaeogeographic evolution, making use of the DEM, the inundation model and a Boolean classification of vegetation zones in relation to groundwater. Assignment of a specific vegetation zone to an individual grid-cell at each time-step was based on a series of decision rules. Considering the large size of grid-cells, it was decided to leave neighbouring grid-cell information out of the assignment process in order to prevent excessive blurring of the picture. The effects of gradual inundation on the relative importance of vegetation types have been measured in time steps of 100 years for a series of models. The most complex model integrates structural water-level rise, capillary groundwater rise, peat growth rate, clay sedimentation rate and some major erosive events as known from the geological record. Typically, this model gives rise to fluctuating importance of vegetation types (and indirectly, sedimentary environments), instead of simply producing monotonous linear replacement models. This feature corresponds more closely to the alternating stratigraphic sequences found in the bore-hole descriptions.

My simulation of landscape evolution essentially focuses on the period 7000 BP – 4000 BP and covers the late Mesolithic and Neolithic periods. This is due to the fact that the structurally rising sea-level did not start prior to ca. 7000 BP and early hydrological regimes were more dependent on local conditions. The resulting spatial model of landscape evolution shows a clear shift from a dry woodland dominated environment toward a wetland dominated, mosaic environment.

What also becomes clear is that within this changing landscape some areas appear to be more stable than others, that is, have seen less vegetation zone shifts. Furthermore the cumulative time-depth of the various vegetation zones is spatially variable. The aspect of landscape stability and instability may well have played a role in past landscape perceptions and particularly influenced choices as to the way landscape zones were used.

4. Introducing Human Behaviour

Archaeological interpretations of relationships between environmental factors and specific dimensions of forager and early farming behaviour can be integrated in a dynamic land-use model and tested against archaeological observations. In order to illustrate the effects of landscape evolution on the spatial prediction of archaeological phenomena related to specific behavioural domains, I will take a look at large mammal hunting. In this example, large mammal hunting probabilities are dependent upon three factors: large mammal encounter probability, feasibility of aquatic travel and feasibility of terrestrial travel (Fig. 3).

A score between 0 (low/bad) and 1 (high/good) was assigned to each of the previously defined vegetation zones , for each of the behavioural factors. Based on these scores, three cost/benefit maps were generated for the large mammal hunting factors, the

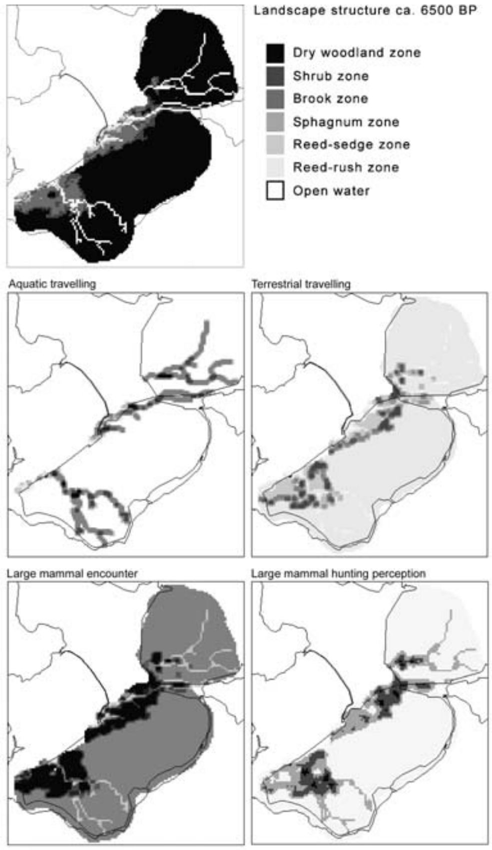

Fig. 3. Example of maps used for the modelling of a large mammal hunting perception surface for 6500–6400 BP. The upper map shows the palaeogeographic situation and the spatial distribution of vegetation zones. The aquatic and terrestrial maps express travel feasibility weights (dark tones = good; light tones = bad), the large mammal encounter map expresses probability weights (dark tones = high; light tones = low). The large mammal hunting perception surface expresses the probability that hunting practices occurred (dark tones = high; light tones = low).

combination of which resulted in a 'large mammal hunting perception surface'. In contrast to the spatial modelling of palaeoenvironmental evolution (where assignment of a target grid-cell to a vegetation zone depended of the elevation/water-level relationship of this target grid-cell), calculation of large mammal hunting probability weights of any target grid-cell also takes neighbouring grid-cells into consideration. The procedure involved the following transformations (naturally alternative transformations are possible):

$$TW = avgLT(Sc1...c9) + avgWT(Sc1...c9) \quad (1)$$
$$wHP(c) = pLM(c) * TW \quad (2)$$

where TW = travel feasibility weight; avgLT(Sc1...c9) = weight of the average feasibility for terrestrial travel of the target and neighbouring grid-cells; avgWT(Sc1...c9) = weight of the average feasibility for aquatic travel of the target and neighbouring grid-cells; wHP(c) = hunting perception weight of target grid-cell; pLM(c) = large mammal encounter probability of target grid-cell.

Clearly, as the landscape changes its composition and structure, the resulting perception surfaces describe very different patterns (Fig. 4). The mere probability of large mammal presence is not enough to attract hunting activity. For

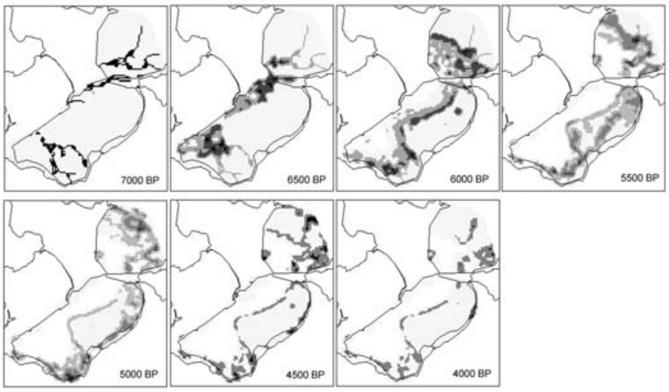

Fig. 4. Time series of large mammal hunting perception surfaces (dark tones = high probability; light tones = low probability).

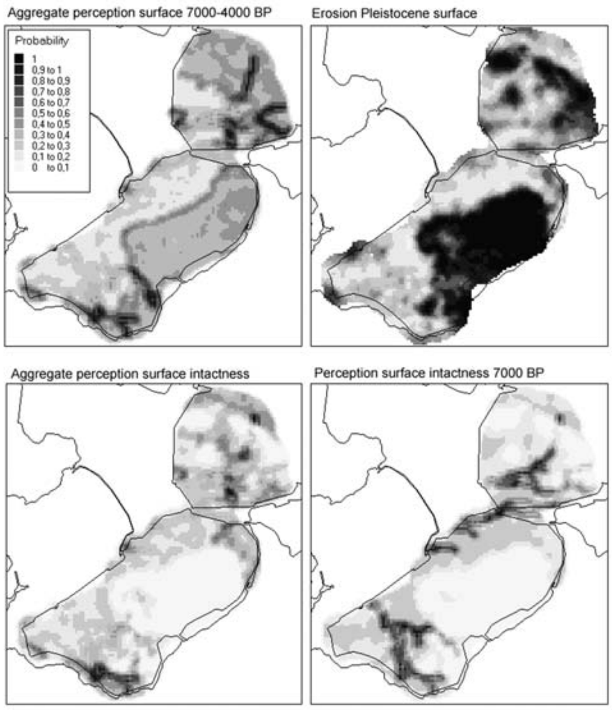

Fig. 5. Example of maps expressing the probable intactness of perception surfaces. The aggregate perception surface expresses the average probability (dark tones = high; light tones = low) that large mammal hunting practices occurred during the period 7000–4000 BP. The erosion map expresses the probability (dark tones = high; light tones = low) of erosion of the Pleistocene surface. The lower maps show the effect of erosion on the intactness of perception surfaces.

instance, if the target grid-cell has a high large mammal encounter probability but is surrounded by grid-cells with low feasibility of transport, the target grid-cell may be assigned a relatively low perception weight. In other cases, accessibility may be good whereas the large mammal encounter probability is low, thus resulting relatively low perception weights.

Apart from the spatial shift of large mammal hunting probability zones, probability weight distributions are also subject to change. With the increase of open water, the available land surface decreases for the entire area. However, at the same time the inundation process leads to lower aquatic and terrestrial travel costs due to the opening up of the landscape, whilst the diversified (mosaic) environmental structure provides attractive habitats for many animals. Thus, absolute loss of land surface was compensated for by the relative increase of the large mammal hunting potential due to diversification and better accessibility. However, at a later stage continued inundation resulted in a decrease in the large mammal encounter probability.

5. Visualizing Archaeological Landscapes

The 'initial' formation of the archaeological landscape is not the only factor to consider in AHM predictive modelling. Erosive processes (mechanical and chemical) are responsible for post-depositional deformation of the 'initial' landscape (Fig. 5). Thus, in order to determine the probability of detectable archaeological phenomena, it is necessary to combine erosion maps with land-use probability weights. At the present time, it is only the occurrence of large scale erosion of the Pleistocene surface that can be mapped with any degree of accuracy.

The aggregate probability surface from my example clearly demonstrates the effects of erosion on the probability of encountering archaeological phenomena related to large mammal hunting. It appears that many areas with high probability weights for large mammal hunting behaviour have been subject to erosion, thus in some cases reducing the probability of encountering well preserved archaeological phenomena to practically zero. However, the possibility of temporal differentiation within the research area should not be forgotten. When considering the various time slices, it becomes clear that the probability surface for the earlier periods have been barely affected by erosion, whereas probability surfaces for later periods seem to have undergone more profound alterations.

6. Conclusions

With the introduction of an independent temporal control and the adoption of a more process led approach, it becomes possible to construct predictive models which integrate aspects of landscape evolution and human behaviour in a more dynamic fashion. Model testing can be accomplished through comparison with existing and future observations from the region. Even though much work still has to be done to develop the approach, I feel it to offer great potential for the archaeological assessment of prehistoric landscapes, design of (prospection) research strategies and spatial planning.

With regard to the assessment of prehistoric landscapes, the approach offers a framework which enables the spatial and temporal prediction of archaeological manifestations of human behaviour. Since the effects of erosion are also considered, the models give an indication of the potential of the research area as a source of information for the study of various types of behaviour. In this way, it becomes possible to acquire temporal differentiation in relation to questions of representativeness in AHM.

The design of prospective research strategies can clearly benefit from the creation of models with a high degree of temporal resolution. These models aid in the prediction of the nature and density of archaeological phenomena and help in the prediction of the geographical location (horizontal and vertical) of archaeological remains. As such, they play an essential role in the choice of suitable equipment and sampling strategies. In return, prospective research can integrate strategies in order to verify basic assumptions with regards to sedimentation, erosion and landscape structure, and thus help to improve the spatio-temporal resolution of the model.

Spatial planning can benefit from such models in several ways. In a quantitative sense, they can be used in directing the decision making process with regards to risk analysis and the use of the modern landscape. In a qualitative sense, they can augment designs for modern landscapes, thus making the past, present and future complementary to each other.

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