

ANALECTA
PRAEHISTORICA
LEIDENSIA

28

PUBLICATIONS OF THE INSTITUTE OF PREHISTORY
UNIVERSITY OF LEIDEN

INTERFACING THE PAST

COMPUTER APPLICATIONS AND QUANTITATIVE
METHODS IN ARCHAEOLOGY CAA95 VOL. I

EDITED BY
HANS KAMERMANS AND KELLY FENNEMA



UNIVERSITY OF LEIDEN 1996

contents

VOLUME I

Hans Kamermans Kelly Fennema	Preface
Data Management	
Jens Andresen Torsten Madsen	IDEA – the Integrated Database for Excavation Analysis 3
Peter Hinge	The Other Computer Interface 15
Thanasis Hadzilacos Polyxeni Myladié Stoumbou	Conceptual Data Modelling for Prehistoric Excavation Documentation 21
E. Agresti A. Maggiolo-Schettini R. Saccoccio M. Pierobon R. Pierobon-Benoit	Handling Excavation Maps in SYSAND 31
Alaine Lamprell Anthea Salisbury Alan Chalmers Simon Stoddart	An Integrated Information System for Archaeological Evidence 37
Jon Holmen Espen Uleberg	The National Documentation Project of Norway – the Archaeological sub-project 43
Irina Oberländer-Târnoveanu	Statistical view of the Archaeological Sites Database 47
Nigel D. Clubb Neil A.R. Lang	A Strategic Appraisal of Information Systems for Archaeology and Architecture in England – Past, Present and Future 51
Nigel D. Clubb Neil A.R. Lang	Learning from the achievements of Information Systems – the role of the Post-Implementation Review in medium to large scale systems 73
Neil Beagrie	Excavations and Archives: Alternative Aspects of Cultural Resource Management 81
Mark Bell Nicola King	The MARS Project – an interface with England's past 87

Archaeometry

- M.J. Baxter
H.E.M. Cool
M.P. Heyworth
Detecting Unusual Multivariate Data: An Archaeometric Example 95
- Jon Bradley
Mike Fletcher
Extraction and visualisation of information from ground penetrating radar surveys 103
- Gayle T. Allum
Robert G. Aykroyd
John G.B. Haigh
Restoration of magnetometry data using inverse-data methods 111
- W. Neubauer
P. Melichar
A. Eder-Hinterleitner
Collection, visualization and simulation of magnetic prospection data 121
- A. Eder-Hinterleitner
W. Neubauer
P. Melichar
Reconstruction of archaeological structures using magnetic prospection 131
- Phil Perkins
An image processing technique for the suppression of traces of modern agricultural activity in aerial photographs 139
- Statistics and Classification**
- Clive Orton
Markov models for museums 149
- Juan A. Barceló
Heuristic classification and fuzzy sets. New tools for archaeological typologies 155
- Kris Lockyear
Dmax based cluster analysis and the supply of coinage to Iron Age Dacia 165
- Christian C. Beardah
Mike J. Baxter
MATLAB Routines for Kernel Density Estimation and the Graphical Representation of Archaeological Data 179
- John W.M. Peterson
A computer model of Roman landscape in South Limburg 185
- Sabine Reinhold
Time versus Ritual – Typological Structures and Mortuary Practices in Late Bronze/Early Iron Age Cemeteries of North-East Caucasia ('Koban Culture') 195
- Leonardo García Sanjuán
Jesús Rodríguez López
Predicting the ritual? A suggested solution in archaeological forecasting through qualitative response models 203
- Johannes Müller
The use of correspondence analysis for different kinds of data categories: Domestic and ritual Globular Amphorae sites in Central Germany 217
- J. Steele
T.J. Sluckin
D.R. Denholm
C.S. Gamble
Simulating hunter-gatherer colonization of the Americas 223

- Paul M. Gibson An Archaeofaunal Ageing Comparative Study into the Performance of Human Analysis Versus Hybrid Neural Network Analysis 229
- Peter Durham Image Processing Strategies for Artefact Classification 235
Paul Lewis
Stephen J. Shennan
- Gijsbert R. Boekschoten A new tool for spatial analysis: "Rings & Sectors plus Density Analysis and Trace lines" 241
Dick Stapert
- Susan Holstrom Loving Estimating the age of stone artifacts using probabilities 251
- Oleg Missikoff Application of an object-oriented approach to the formalization of qualitative (and quantitative) data 263

VOLUME II

Geographic Information Systems I

- David Wheatley Between the lines: the role of GIS-based predictive modelling in the interpretation of extensive survey data 275
- Roger Martlew The contribution of GIS to the study of landscape evolution in the Yorkshire Dales, UK 293
- Vincent Gaffney Extending GIS Methods for Regional Archaeology: the Wroxeter Hinterland Project 297
Martijn van Leusen
- Trevor M. Harris Multi-dimensional GIS: exploratory approaches to spatial and temporal relationships within archaeological stratigraphy 307
Gary R. Lock
- Philip Verhagen The use of GIS as a tool for modelling ecological change and human occupation in the Middle Aguas Valley (S.E. Spain) 317
- Federica Massagrande The Romans in southwestern Spain: total conquest or partial assimilation? Can GIS answer? 325
- Shen Eric Lim Recent examples of geographical analysis of archaeological evidence from central Italy 331
Simon Stoddart
Andrew Harrison
Alan Chalmers
- Vincent Gaffney Satellite Imagery and GIS applications in Mediterranean Landscapes 337
Krištof Oštir
Tomaž Podobnikar
Zoran Staničič
- Yvette Bommeljé The long and winding road: land routes in Aetolia (Greece) since Byzantine times 343
Peter Doorn

- Javier Baena Preysler
Concepción Blasco Application of GIS to images and their processing: the Chiribiquete Mountains Project 353

Geographic Information Systems II: The York Applications

- Julian D. Richards From Site to Landscape: multi-level GIS applications in archaeology 361
- Harold Mytum Intrasite Patterning and the Temporal Dimension using GIS: the example of Kellington Churchyard 363
- A. Paul Miller Digging deep: GIS in the city 369
- Julian D. Richards Putting the site in its setting: GIS and the search for Anglo-Saxon settlements in Northumbria 379
- Jeffrey A. Chartrand Archaeological Resource Visibility and GIS: A case study in Yorkshire 389

Visualisation

- John Wilcock A description of the display software for Stafford Castle Visitor Centre, UK 405
- Christian Menard
Robert Sablatnig Pictorial, Three-dimensional Acquisition of Archaeological Finds as Basis for an Automatic Classification 419
- Katalin T. Biró Simple fun – Interactive computer demonstration program on the exhibition of the Szentgál-Tűzköveshegy prehistoric industrial area 433
- György Csáki
Ferenc Redő Documentation and modelling of a Roman imperial villa in Central Italy 437
- Maurizio Forte
Antonella Guidazzoli Archaeology, GIS and desktop virtual reality: the ARCTOS project 443
- Germà Wünsch
Elisabet Arasa
Marta Pérez Dissecting the palimpsest: an easy computer-graphic approach to the stratigraphic sequence of Túnel VII site (Tierra del Fuego, Argentina) 457
- David Gilman Romano
Osama Tolba Remote Sensing and GIS in the Study of Roman Centuriation in the Corinthia, Greece 461
- F.J. Baena
F. Quesada
M.C. Blasco An application of GIS intra-site analysis to Museum Display 469

Education and Publication

- Robin B. Boast
Sam J. Lucy Teaching with objects 479

- Martin Belcher
Alan Chalmers
Andrew Harrison
Simon Stoddart
Teaching the Visualisation of Landscapes – Approaches in Computer based learning for Archaeologists 487
- Anja C. Wolle
Stephen J. Shennan
A Tool for Multimedia Excavation Reports – a prototype 493
- G. Gyftodimos
D. Rigopoulos
M. Spiliopoulou
Exploring Archaeological Information through an Open Hypermedia System 501
- Martijn van Leusen
Sara Champion
Jonathan Lizee
Thomas Plunkett
Toward a European Archaeological Heritage Web 511
- Mike Heyworth
Seamus Ross
Julian Richards
Internet archaeology: an international electronic journal for archaeology 521
- Virgil Mihailescu-Bîrliba
Vasile Chirica
A Survey of the Development of Computer Applications in Romanian Archaeology 529
- Kris Lockyear
Computer-aided publication in practice 535

J. Steele
T.J. Sluckin
D.R. Denholm
C.S. Gamble

Simulating hunter-gatherer colonization of the Americas

1 Introduction

Simulation modelling of the Palaeoindian expansion into the Americas was pioneered by Paul Martin, who proposed an ‘overkill’ model in 1967. Taking demographic parameters from a compilation of data by Joseph Birdsell (1957), he calculated that humans reproducing at a rate of about 3.5% per annum, with directional migration southwards at an average rate of 16 kilometres per year, would have reached Tierra del Fuego 1,000 years after entering the land south of the ice sheets. His model had a dense ‘front’ of pioneers overexploiting the megafauna in their path, and moving on to leave a faunally depauperate environment occupied by humans at merely one tenth of that initial population density (Martin 1973). With James Mosimann, he developed this ‘overkill’ model in a later paper in 1975, in which it was demonstrated that hunters with unchecked population growth and moderate or heavy kill rates, or alternatively a focus on preferred mammoth and mastodon prey, could push their prey species into extinction throughout North America in a period of 300-500 years (Mosimann/Martin 1975). Calculations of the velocity of expansion of the front were also made in this paper, and reinforced the finding that rapid growth (2.5 to 3.5% per annum) was a necessary condition of very rapid expansion, although a slow growth model was summarized in which pioneers reached the Gulf of Mexico 1,157 years after entry at Edmonton, with an intrinsic growth rate of only 0.65%.

In our own work, we have been concerned to evaluate the effect of spatial habitat variation, and of the distribution of geographical barriers to dispersal, on the rate and routes of expansion of pioneer Palaeoindian populations. Such effects have generally been omitted in previous models, which have used averaged habitat values applied to the whole continental land area; but their importance has nonetheless been noted. Mosimann and Martin (1975: 306) observed that ‘while we acknowledge their importance in an ideal model, we do not attempt to [...] incorporate the inevitable local differences in carrying capacity at the time of invasion.’ Whittington and Dyke (1984: 462), who developed the Mosimann and Martin model, also observed that ‘a better approximation of reality than uniform population densities would be a model that allows for interactions between

megafaunal and human populations whose densities were based on the distribution of various resources. Since this would be a radical departure from Mosimann and Martin’s simulation, a reformulation of the model was not undertaken.’ Finally, Belovsky (1988: 353) also set the parameters for his own simulation of Palaeoindian expansion so that ‘rather than tracing the growth of the human population from vegetation type to vegetation type across the two continents, an average primary productivity was used.’

2 The simulation model

In modelling the effects of barriers and habitat variation on the rate of expansion of pioneer human populations, we have departed radically from the simulation paradigms of these workers. We have discretized both time and space for our simulations, using a two-dimensional lattice in which each cell has cell-specific fixed values for the habitat terms, and an updated cell-specific value for the human population size. The update algorithm is a discretized approximation of a continuous differential equation describing the process of demographic expansion. For our initial phase of work, we have been using a discrete approximation of R.A. Fisher’s classic equation for the ‘wave of advance’ of advantageous genes (Fisher 1937), which has already been generalized to the case of animal range expansion and is widely used for this purpose in biogeography. Fisher’s model is also the basis for Ammerman and Cavalli-Sforza’s work on the expansion of Neolithic colonists in Europe.

The Fisher equation is:

$$\frac{dn}{dt} = f(n;K) + D \nabla^2 n \quad (1)$$

where $n(\mathbf{r},t)$ denotes the local human population density (number per unit area) at time t and position $\mathbf{r} = (x,y)$. The diffusion constant D (in $\text{km}^2 \text{yr}^{-1}$) and the carrying capacity K are functions of position. The function

$$f(n) = \alpha n \left(1 - \frac{n}{k}\right)$$

describes the rate of population increase, and is the logistic function widely used in theoretical ecology (Murray 1990); the quantity α denotes the annual population growth rate.

We approximate time differentials at particular sites by finite differences (Press *et al.* 1986):

$$\frac{dn(\mathbf{r},t)}{dt} \approx \frac{n(\mathbf{r},t+\Delta_t) - n(\mathbf{r},t)}{\Delta_t} \quad (2)$$

Typically we use $\Delta_t = 1$ year.

Space differentials are similarly approximated by finite differences:

$$D \nabla^2(\mathbf{r}_0) = h^2 \sum_{\alpha} w_{\alpha} D_{\alpha} [n(\mathbf{r}_{\alpha}) - n(\mathbf{r})], \quad (3)$$

where for a given position \mathbf{r}_0 the sum is taken over nearest neighbour sites \mathbf{r}_{α} on the lattice, and where the lattice size is h . There are two types of neighbour sites: those along the lattice axes and those along the diagonals. The sum is weighted appropriately with parameters w_{α} ; this parameter is typically $2/3$ for sites α along the lattice axes and $1/6$ along the diagonals. The effective diffusion parameter D_{α}' , appropriate to motion between the sites \mathbf{r}_0 and \mathbf{r}_{α} , is given by

$$D_{\alpha}' = \sqrt{D(\mathbf{r}_{\alpha})D(\mathbf{r}_0)}.$$

In practice in any given simulation, only two values of D are used: $D = D_0$ and $D = 0$, the latter representing the fact that the particular cell is inaccessible.

The crucial input parameters for the model are then the carrying capacity K , the so-called Malthusian parameter α and the diffusion constant D . D represents the degree of mobility of an individual (e.g., Ammerman/Cavalli-Sforza 1984). In general individuals will move from their birth place a distance λ during their lifetime τ . The square of this distance will in general be proportional to the time available; the constant of proportionality is the diffusion constant D :

$$D = \frac{\lambda^2}{4\tau} \quad (4)$$

The differential equation (1) in the case of constant D and K , and for populations which can only move in one rather than two dimensions, predicts that there will be a population wave of advance, with the frontier travelling with velocity (Ablowitz/Zepetella 1979):

$$v = 2.04 \sqrt{D\alpha} \quad (5)$$

Our discretized model gives accurate results so long as the natural length scale in this equation

$$\xi = \sqrt{\frac{D}{\alpha}} > h$$

Otherwise the simulated velocity is faster than that predicted analytically. For simulations with $h \sim 50$ km with $0.005 \text{ yr}^{-1} < \alpha < 0.05 \text{ yr}^{-1}$, and with $D > 10 \text{ km}^2 \text{ yr}^{-1}$, our discretized lattice yields consistently accurate results (fig. 1).

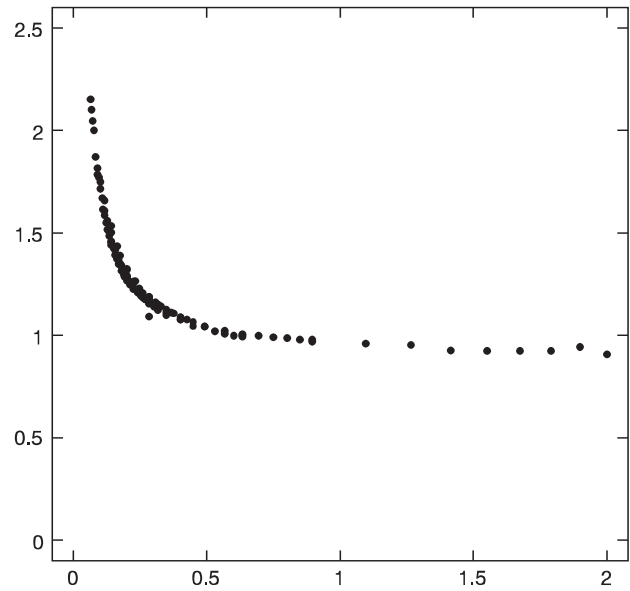


Figure 1. Ratio of simulated to theoretical velocity of expansion of the front, plotted against the 'natural length scale' (the independent variable). The latter is given by dividing $\sqrt{D/\alpha}$ by the cell dimension (in these simulations, 50 km).

We note also a methodological point; in principle (even if in practice this will be difficult!) we may have independent estimations of D , α , K and v . We predict that v will be independent of K and dependent on D and α according to equation (5). If these predictions are not borne out — if, for example, the values of D and α required to be consistent with archaeologically sensible values of v are not themselves plausible — we are bound to use more sophisticated models of population movement, for which the Fisher equation, at least in its naive form, would no longer be helpful.

3 The use of geographic information in the lattice model

For the first set of experiments, we have used a projected representation of the surface of North America and its surrounding oceans, rasterized from an interpolated surface generated in IDRISI from the original vector format point file as a grid of cells coded for their accessibility to a diffusing population. Sea and other impassable areas are '0', colonizable land is '1'. Population can either diffuse into the cell, or not. The projection transformation (Transverse Mercator, meridian 90° W., scale factor = 1) was selected to avoid distortion of area and orientation, and the interpolated vector file was used to generate raster output with a cell size of approximately 50 km by 50 km. To make it easier to understand the real time output to

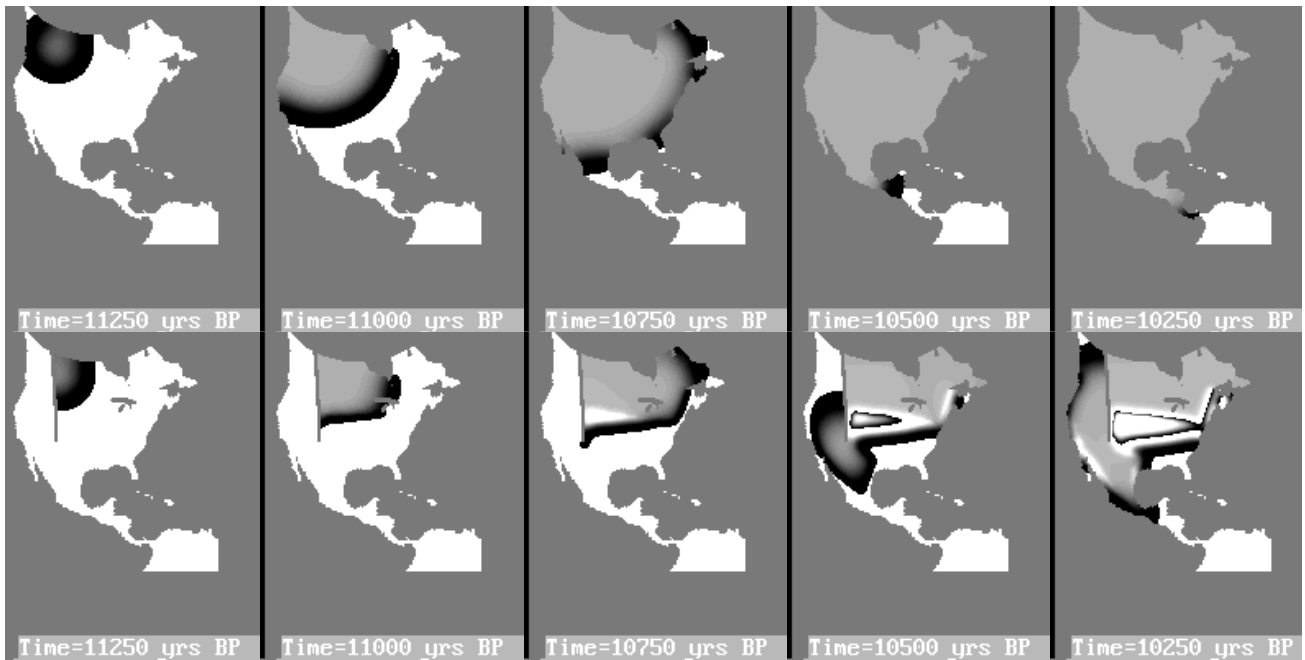


Figure 2. Screen capture shots of the travelling wave at $t = 250, 500, 750, 1000$ and 1250 years. Seed population at Edmonton. Carrying capacities: 0.04 p.p.km^2 (background), 0.2 p.p.km^2 (coasts and plains). Population growth rate = 0.03 p.a. (background), 0.01 p.a. (coasts and plains). Dispersal rate = $400 \text{ km}^2 \text{ p.a.}$ (background), 100 km^2 (coasts and plains).

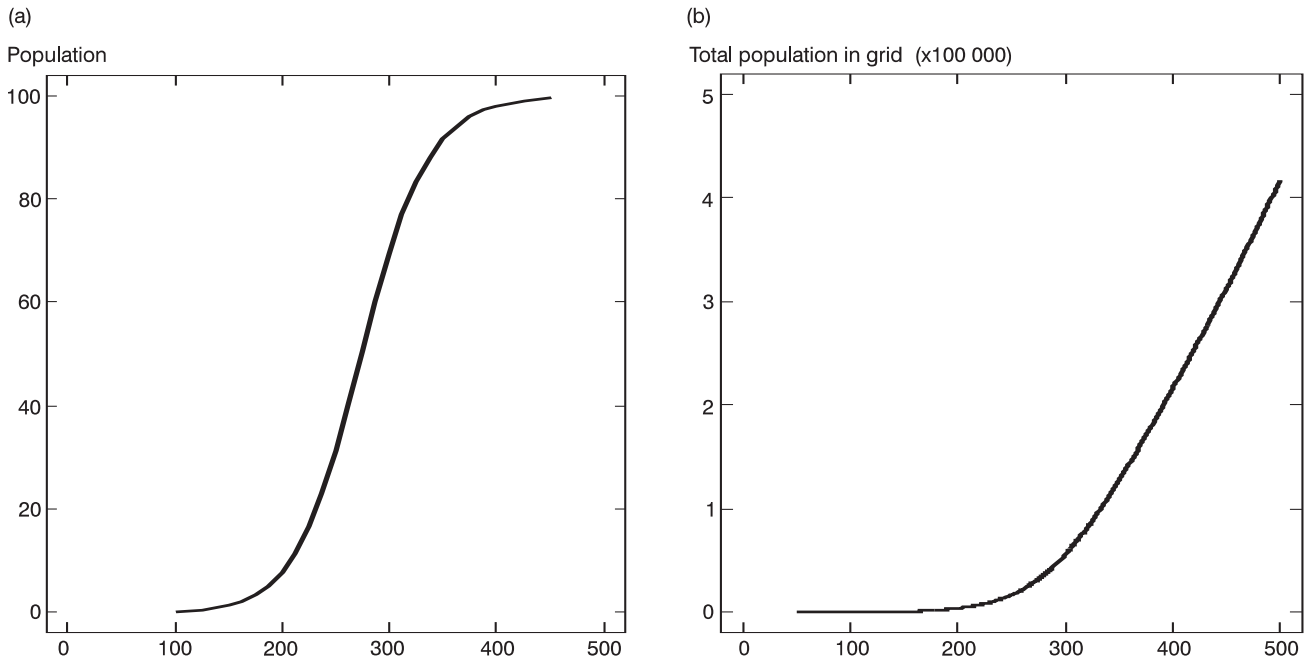


Figure 3. Population growth curves for (a) a sample cell and (b) the whole grid, for a sample set of conditions ($\alpha = 0.03, D = 500$). $K = 100$ persons per cell.

screen while the simulation is running, barrier cells are coloured blue — since they are mostly sea — while cells where people can go are coloured green (since they are nearly all areas of land surface with significant primary plant production). Population densities on the colonized portion of the accessible surface are grey-scaled, making it easy to follow the expansion of the front as it is updated and written to screen in real time during the simulation (fig. 2). Figures 3 (a) and (b) show the curves for increasing population in a single cell and in the whole colonizable portion of the grid, against time, for an example set of values for the demographic parameters. It is evident from these that while the population in each of the cells follows a logistic growth curve, the growth curve for the total population is exponential. This is what we would expect from the original model.

The simulations shown in figure 2 also demonstrate the effects of varying the barrier locations and the demographic parameters as cell-specific attributes. The first series represent demographic expansion over a homogeneous plane, while the second series has barriers at the Rockies and the Great Lakes, and two categories of habitat with covariation in the carrying capacity (κ), mobility (D) and growth rate (α) terms. The varying times taken to first colonization of points on the surface if they are located beyond such hypothetical barriers, or in habitats with differing carrying capacities or disease ecologies, will clearly be detectable in archaeological radiocarbon dating of earliest cultural remains at such locations. Thus the simulation model is capable of generating archaeologically testable predictions about the effect on demographic expansion of spatial heterogeneity in barriers and in vegetation zones.

4 Future development of the model and its applications

These initial results are now being extended in a second phase of development of the model, in which ice sheet locations and vegetation mosaics at successive periods in the earliest Holocene of the Americas will be reconstructed

by a palaeoecologist and used to predict spatial variation in Palaeoindian carrying capacities, and more extensive sets of simulations will be run to generate alternative predictions about possible effects of such spatial variation on colonization rates and routes.

Young and Bettinger (1995), in a study which independently developed the same demographic diffusion equation to model late Pleistocene human demic expansions, suggest that the high values of α and D needed to generate the observed velocity of Palaeoindian expansion into the New World under the conditions of Fisher's model are nonetheless biologically plausible. They suggest values for α of 0.03 and for D of 1000 km²/yr (which would mean the travelling front would reach Tierra del Fuego in about 1,500 years). We believe that such values for the diffusion constant are, in fact, biologically implausible for almost all hunter-gatherer social systems for which recent ethnographic parallels exist. It is essential to remember that the diffusion term denotes mobility which is random with respect to direction: it is not a term denoting 'directional migration'. The value for D chosen by Young and Bettinger (1995) implies a lifetime mean dispersal distance for all individuals of about 300 km from the place of birth, or of about 600 km for the dispersing sex where diffusion is due to dispersal from the natal group by all members of one dispersing sex. It is difficult to see how such a high level of lifetime mobility, random with respect to direction, could be adaptive in a landscape that was also sustaining such a high net population growth rate. We therefore suspect that the rate of colonization of the Americas was driven by some further dynamic, such as directional migration by 'over-exploiters' up a gradient of herbivore prey densities in a very fragile ecosystem, and we are currently exploring new models which can be implemented in the existing discrete time and space simulation paradigm.

Acknowledgement

We are very grateful to Nolan Virgo for his work on the simulation program during the summer of 1994.

references

- Ablowitz, M.
A. Zeppetella 1979 Explicit solutions of Fisher's equation for a special wave speed, *Bulletin of Mathematical Biology* 41, 835-840.
- Ammerman, A.J.
L.L. Cavalli-Sforza 1984 *The Neolithic Transition and the Genetics of Populations in Europe*. Princeton: Princeton University Press.
- Belovsky, G.E. 1988 An optimal foraging-based model of hunter-gatherer population dynamics, *Journal of Anthropological Archaeology* 7, 329-372.
- Birdsell, J. 1957 Some population problems involving Pleistocene man, *Cold Harbor Springs Symposium on Quantitative Biology* 22, 47-69.
- Fisher, R.A. 1937 The wave of advance of advantageous genes, *Annals of Eugenics* 7, 355-369.
- Martin, P.S. 1973 The discovery of America, *Science* 179, 969-974.
- Mosimann, J.E.
P.S. Martin 1975 Simulating overkill by Paleoindians, *American Scientist* 63, 304-313.
- Murray, J.D. 1990 *Theoretical Biology*. Berlin: Springer-Verlag.
- Press, W.H.
B.P. Flannery
S.A. Teukolsky
W.T. Vetterling 1986 *Numerical Recipes: The Art of Scientific Computing*. Cambridge: Cambridge University Press.
- Whittington, S.L.
B. Dyke 1984 Simulating overkill: experiments with the Mosimann and Martin model. In: P.S. Martin/R.G. Klein (eds), *Quaternary Extinctions*, 451-465, Tucson: University of Arizona Press.
- Young, D.A.
R.L. Bettinger 1995 Simulating the global human expansion in the Late Pleistocene, *Journal of Archaeological Science* 22, 89-92.

J. Steele
Department of Archaeology
e-mail: T.J.M.Steele@soton.ac.uk

T.J. Sluckin
Department of Mathematics

D.R. Denholm
Department of Physics,

C.S. Gamble
Department of Archaeology
University of Southampton
Highfield
Southampton SO17 1BJ
United Kingdom