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Recent Directions and Developments in Geographical Information Systems

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Geographical information systems (GIS) are tools for handling and processing spatially referenced information that have permeated all facets of archaeology, frequently revolutionizing research by allowing easy access to vast amounts of information, new ways of data visualization that promote insight through pattern recognition, and unique methodologies that allow entirely new approaches to the study of the past. This comprehensive review examines and critiques recent advances achieved through GIS in regional and within-site databases, locational analysis and modeling, regional simulation, studies of landscape perception through intervisibility analysis, and models of spatial allocation, territoriality, and site access. The future prospects of GIS are enormous with the growth of the Internet, the resultant linking of databases, expected enhancements in satellite remote sensing, and the increasing pervasiveness of global positioning systems for spatial data capture.

KEY WORDS: geographical information systems; regional analysis; spatial databases; computer cartography.

> *If there is a persistent theme that emerges from the chronicles of contemporary scientific cartography, it is that the creation of a map almost inevitably leads to unexpected revelations.*
>
> —Hall, *Mapping the Next Millenium: How Computer-Driven Cartography Is Revolutionizing the Face of Science*

INTRODUCTION

Competence in data analysis through applied statistics requires a considerable amount of difficult training. It is therefore not surprising that archaeologists and

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other social scientists have turned to user-friendly computers to analyze their data through computer graphics and visualization software. Simply by pressing a few keys or clicking a mouse button, researchers can instantaneously display vast amounts of information graphically, in multidimensional views and formats not possible only a few years ago. These tools are beginning to have an impact on the way we conduct archaeological studies because trends, patterns, and relationships are so easily visualized, particularly when data are presented in map form.

Geographical information systems (GIS) are collections of interrelated computer programs designed for the handling and processing of spatially referenced information. With data organized on the basis of location, unique capabilities are derived. Information may be assembled according to its position in space and displayed in the form of maps, allowing ready visualization of structure and relationships in complex regional data sets and creating something of a revolution in the transmission of information. With modern computer graphics the GIS map goes a long way beyond traditional cartographic representation by utilizing continuous color palettes, simultaneous displays of multiple spatial variables, simulated three-dimensional views, overlays, backdrops, rotations, profiles, and much more. In short, GIS can be regarded as an information visualization engine, but one with extensive analysis, data generation, and manipulative capabilities. These tools, combined in one place, are not only revolutionary, but evolutionary. After all, more than half of the human cortex is involved in vision and designed to readily perceive pattern in two, three, or higher dimensional views. When viewing a map, the mind erupts with ideas about a landscape, and more so with GIS. There is a synergism that derives from the possibility of comparing a host of environmental, economic, or social variables over the same piece of ground, and GIS permits regions of any scale to be employed, from that of a continent to the microscopic edge of a stone tool. It leaves small wonder, then, that in little more than a decade of reasonable access to GIS, it and related cartographic tools have transformed the way academics in virtually every spatial science approach their data-interpretation and problem-solving tasks. [See Hall (1992) for a pan-disciplinary summary.]

Historical Roots and Overview

Although significant use of GIS in archaeology has existed for little more than a decade, multiple summaries of its historical development have already appeared (Aldenderfer, 1996; Harris and Lock, 1990, 1995; Kvamme, 1995; Maschner, 1996a; Savage, 1990a). This development has its roots in the 1970s with computer cartography and computer-aided drafting (CAD; Clark, 1979; Copp, 1977), the linking of computer-drawn maps with relational databases (Effland, 1979; Flude *et al.*, 1982), in quantitative spatial analyses and their mapped by-products (Feder, 1979; Larson, 1975), in views and uses of three-dimensional terrain models

(Arnold, 1979; Green and Stewart, 1983), in remote sensing and image processing applications (Ebert, 1978; Scollar, 1966), and in regional simulation and modeling exercises (Chadwick, 1979; Zubrow and Harbaugh, 1978). All of these applications, in some way, performed the functions we now do more routinely with GIS.

In the past decade numerous new GIS application areas and problem foci have evolved, and the number of archaeological users of the technology and publications that have resulted are legion. (A 1995 annotated bibliography of GIS in archaeology by Petrie *et al.* cites nearly 400 papers, for example.) Aldenderfer (1992) recently classified these uses of GIS in three levels. The first involves using GIS to do the simple things we have always done. The second employs GIS to perform complex operations we seldom or almost never do. The third applies GIS in brand new ways that revolutionize our thinking and approaches to the study of archaeological phenomena. Yet, very few overviews and critiques of GIS in archaeology have been written. The most comprehensive essay, by Kvamme (1989), is nearly a decade old and predates many application areas of the technology as well as some of the technology itself! More recent summary papers have focused only on particular domains of GIS or are mere introductions to the technology that make no pretense of being a comprehensive review (e.g., Aldenderfer, 1996; Harris and Lock, 1990, 1995; Limp, 1996; Maschner, 1996). This situation begs for an intensive examination of archaeology and GIS as it exists *today*. To what extent do we employ GIS to do complex things we seldom do or brand new revolutionary things? What exactly are archaeologists doing with GIS? Why is it so popular? Is it really useful? Are there common domains of application and inquiry? This paper addresses these questions.

Our tour of GIS begins with a brief overview of its capabilities for those unfamiliar with the technology and points to major archaeological references on the topic. The general introduction continues with an examination of the profound impact of GIS on data exploration and visualization and its influence on archaeological and other scientific research. I necessarily review pattern discovery in the sciences and its role in theory building and the scientific cycle.

With state-supported mandates for cultural resource databases at local, regional, and national levels, the principal use of GIS already lies in this domain, and consequently our survey of applications begins here. Inevitably, every region around the globe will some day move toward GIS or GIS-like databases that link information with maps. In recent years, though, this GIS database concept has played an increasingly important role in site-level projects, the next focus of our survey. At the site level, extensive data collection through excavation and surface mappings of artifacts, topography, and other features commonly occur, and GIS is necessary to efficiently manage these data and address fundamental research and spatial analysis questions. One kind of within-site information is derived from ground-based geophysical prosection, commonly employed in northern Europe and increasingly in North America. The discussion on remote sensing anticipates a movement, already underway, toward GIS for handling and processing these complex spatial data sets and incorporating them into comprehensive site databases. With sensors moved off the ground and into space, GIS has a functionality for analyzing and manipulating remotely sensed satellite imagery, and I review archaeological applications in this domain as well.

The most exciting developments in GIS are in the analytical arena, for it is here that we actually see new research topics and strategies never before contemplated. Because GIS allows actual landscapes and environments to be digitally captured, most of these approaches focus in some way on locational behavior, landscape use, settlement choice, and territoriality at the regional level. Although there was initially wide variation in approaches to these topics, distinctive and well-defined methodologies have evolved. The first section examines locational analysis at the regional level where a variety of statistical analysis approaches have been made possible through GIS to assess quantitatively site or settlement relationships with features of environment and address the fundamental question of why people placed their settlements where they did. The second section builds on what is learned through locational analysis by combining results in a multivariate sense to make predictive statements about archaeological distributions. Archaeological predictive modeling is one of the earliest applications made possible by GIS, yet it continues to grow in importance as a tool for cultural resource management and planning and, indeed, now forms the basis of a multimillion dollar archaeological industry.

The next two sections move away from a heavy environmental focus and consider more strongly the social landscape and its influence on behavior. Spatial allocation, the assignment of territories to sites, has had a long history in archaeology, and GIS certainly facilitates these approaches in all their diverse forms (e.g., Thiessen polygons, circular catchments). GIS also allows more realistic results by considering the cost or difficulty of movement over a landscape, or by weighting territory size by the perceived influence of a center, for example. A new domain of inquiry made possible by GIS lies in intervisibility and viewshed studies (the latter refers to all places visible from a point or points on a landscape). This capability allows examination of territoriality through estimated visible areas, of defensibility, and of visual dominance and has opened a pathway toward past cognition through the realization that sites or settlements might be placed so that certain places are visible.

The final analytical section of simulation broaches a topic appropriate for the generation of insights into any archaeological domain. Through GIS, archaeologists have simulated subjects as diverse as lithic scatter formation to likely pathways for the peopling of the New World. Moreover, realistic landscapes may now be employed in place of the featureless plain assumption of earlier regional simulations. Importantly, these studies typically are multitemporal and illustrate a dynamic capability that adds rich new perspectives to the study of the past.

I close this essay with two concluding sections. The first examines the many critiques of GIS by postmodernists, the principal one being that GIS fosters an environmental determinism stemming from its reliance on traditional forms of mapped data. Finally, I look at future directions the technology will certainly take and speculate on the possibilities that will exist in an information-rich world with archaeological and other GIS databases on-line, linked, and available through the Internet. This review therefore takes us on a journey along many different pathways, each facilitated or made possible by GIS. The state of the art of research in each domain is examined and examples from the now prolific literature in many of these areas are reviewed. The end result is a comprehensive summary of GIS in archaeology as it exists today that illustrates its usefulness, versatility, and limitations.

Defining GIS and Its Capabilities

The definition of GIS has proven to be an elusive task (see Fisher and Lindenberg, 1989). Early attempts focused on requisite software elements. Marble (1984), for example, demands four components including (1) a data input system, (2) a system for information storage and retrieval, (3) an analysis, manipulation, data generation, and modeling engine, and (4) a display and reporting capability. More recent characterizations emphasize the problem-solving qualities of GIS, as in: "a decision support system involving the integration of spatially referenced data in a problem solving environment" (Cowen, 1988, p. 155).

A GIS database has a defined region as its focus. Individual map themes, or variables, represent distinct "layers" of information within the database region. The map layers are spatially coregistered to a particular coordinate base (e.g., UTM, longitude-latitude) insuring that any locus in one coincides with the same place in the others. Data layers may be derived from digitized or scanned paper maps, aerial photographs, or satellite imagery, for example; and textual or other information (e.g., artifact locations) may be keyed in manually or obtained from extant computer databases, provided they are associated with spatial coordinates (most GIS allow translation between various coordinate systems). The primary information one feeds a GIS may be encoded through an in-house operation or purchased through government or commercial sources.

The processing power of the computer together with the typical software flexibility of most GIS programs allows a great diversity of secondary layers to be derived analytically from the primary data. Digital elevation contours allow estimation of an altitude surface interpolated systematically across the database region; these elevation data might be employed to determine all locations visible from a point or points; and a distance-to-water layer might be generated from digitized lake, river, and stream locations, for example. More complex and varied operations are illustrated below.

Map features are traditionally displayed through use of three cartographic devices: points, lines, and areas. Point features include a mountain summit, a surveyor's datum, or the locus of a town on a small scale map. Lines are employed to represent rivers, roads, or perhaps elevation contours. The area data type refers to regions of homogeneity such as lakes, forests, or property parcels. A variety of symbol types, colors, or point or line styles might be used to distinguish between them. *Vector* GIS possesses data structures and display formats that are most allied to these fundamental cartographic types. Point, line, and area features are located by spatial coordinates, referred to as *topology*. This information is distinct from *attributes*, which describe particular characteristics of the features. An archaeological site, for example, is bounded by a sequence of spatial coordinates (the topology) that locates its perimeter; linked with it is a series of attributes that identifies its number, name, ownership, cultural and temporal affiliation, and other characteristics.

Grid-based or *raster* GIS represents a distinctly different approach to spatial data handling. These systems control two-dimensional matrices of numbers that represent variations in a map theme. Topology is controlled by row and column position within the matrix or grid, while an individual value represents an attribute code or measurement at a particular grid cell locus. A layer portraying soil distributions will contain a numeric soil type code as each grid element while an elevation layer will hold individual altitude measurements, for example. Spatial resolution and accuracy is controlled by the area represented by each grid element. Computer storage requirements can be enormous if the database region is large or the grid cell size is small, but several data compaction algorithms exist that help to mitigate this factor, especially in spatially redundant layers such as soil classes, where similar attribute codes occur over broad regions.

Vector GIS is required whenever precise location is important, such as in a cultural properties management database, or when accurate area or perimeter data are necessary. Vector GIS is ideal for regional data management applications because the individual points, lines, or area vectors may be linked with data held in relational database management software, allowing the instantaneous display of the results of queries and searches in map form. (This is well illustrated below.) Vector GIS also can produce publication quality maps composed of traditional point, line, and area features.

Raster GIS, on the other hand, is spatially less precise owing to its grid cell structure. Moreover, line and area data suffer from jagged, stair step edges that generally cause inaccurate area and perimeter estimates. Yet, spatial data from satellites, scanned aerial photographs, geophysical survey data, or artifact frequencies per grid square occur naturally in raster structures and are easily displayed by these systems as continuous tone images (using gray or color values assigned grid cell by grid cell). In research applications, most archaeologists have found the numerical processing and modeling capabilities of raster GIS to be clearly advantageous, as sections below demonstrate. Whether raster or vector, most GIS programs support some functionality in the other domain; and point, line, or area features can easily be converted from one format to the other.

GIS allows an amazing array of operations to be performed on spatial data sets, some of which fall in the following domains.

Map reclassification generalizes a map from many to fewer categories. Thirty-five soil classes might be reduced to only three, indicating "good," "moderate," and "poor" soils for maize cultivation, for example.

Map overlaying combines categories from multiple map layers. If classes *A*, *B*, and *C* occur in one layer, and *a*, *b*, *c*, and *d* in another, then an overlay could produce the intersection of all possible combinations: *Aa*, *Ab*, *Ac*, *Ad*, *Ba*, *Bb*, *Bc*, *Bd*, *Ca*, *Cb*, *Cc*, and *Cd*.

Map algebra is a uniquely raster technique that permits algebraic and other operations (e.g., addition, subtraction, multiplication, division, exponentiation, square roots, logarithms, means, diversity measures) to be performed within and between map layers on a grid cell by grid cell basis. A simple operation might be: *newlayer* = 0.3048***oldlayer*, where *oldlayer* contains an elevation in feet in each grid unit, "*" signifies multiply, and the result held in *newlayer* represents elevations in meters. A more complex operation might map a regression function of the form: *newlayer* = *C*0 + *C*1**layer1* + *C*2**layer2* + *C*3**layer3*, where *newlayer* holds predicted agricultural yields based on soil quality (*layer1*), slope (*layer2*), ground moisture (*layer3*), and *C*0–*C*3 are constants (the regression intercept and weights).

Boolean operations permit manipulation of binary maps through Boolean logic. These procedures include *unions* (the "OR" operation), *intersections* (the "AND" operation), and *negation* (the "NOT" operation). If the *soils* layer indicates "good" versus "poor" soil (coded as 1 and 0, respectively) and the *slope* layer indicates "level" versus "steep" ground (coded as 1 and 0, respectively), then *newlayer1* = *soils* OR *slope* computes the Boolean union where either good soils or level slopes or both occur, while *newlayer2* = *soils* AND *slope* maps only those places where the intersection of good soil with level ground both occur at the same place.

Distance operations compute distances from a target locus or loci under linearity or cost-of-movement assumptions. The latter considers land cover, ground steepness, elevation changes, and other factors. When combined with map reclassification, distance surfaces can produce buffers, catchments, or Thiessen polygons around places of interest.

Terrain processing allows, through interpolation, the creation of digital terrain models (DTM) from point or contoured elevation data. Interrelationships between altitudes then allow estimates of ground steepness (slope), aspect (azimuth), ridge and drainage lines, watershed boundaries, mesa or canyon rim settings, lines of sight, regions visible, and much more.

Image processing routines are specifically designed for the handling of imagery whether from satellites, aerial or terrestrial photography, or geophysical sensors and occur within most raster GIS. These programs perform such tasks as digital image classification, rectification and registration to map coordinate systems, image cropping, edge detection, high and low pass filtering, and brightness and contrast improvements.

Although any one of those domains is useful in and of itself, their real power is derived in their *combination*, when several are chained together to achieve complex results that allow us to do brand new things (Aldenderfer, 1992). A more detailed examination of these domains is beyond the scope of this presentation, although archaeological demonstrations of them are presented in the following pages. More information about specific GIS methods may be found in several introductory articles written by archaeologists (e.g., Gaffney and Stančič, 1991; Kvamme, 1989, 1992a; Madry, 1990; Peterman, 1992; Wansleeben, 1988; Zubrow, 1990a).

Data Analysis/Visualization and Scientific Research

When viewing people working with GIS, one soon appreciates how often patterns or relationships are discovered. Merely by displaying maps of archaeological sites with other spatial variables, new associations or tendencies frequently are realized. For example, in Snow (1996) diachronic mappings of Iroquoian settlements reveal a number of new insights. The essence of this computer graphics revolution is its speed, its access to vast amounts of information (recently increased manyfold by the World Wide Web), and the complexity of information that can be easily portrayed. With visualization tools like GIS, archaeologists are encouraged to get more intimately acquainted with their data and to search for patterns. As a consequence, great changes are underway in the manner in which archaeologists conduct their research, and the intellectual climate may finally be right for it.

Under processual archaeology, "induction" became something of a bad word as this school became firmly linked with "deductive" reasoning, which was cast as beginning with *a priori* specified theory followed by post hoc testing with data. While correct, this framework represents a somewhat narrow view of scientific research. To put this in perspective we need to ask ourselves: "What is the source of our theoretical ideas?" Most of us realize that scientific research moves back and forth between theory and data in a repetitive and interactive cycle. Ideas are obtained from somewhere; we then compare them to the world to find out if they are correct. We might obtain only partial confirmation and need to modify our ideas in the face of reality, which initiates a new cycle of testing with data and theorizing. This cycle, of course, may be entered anywhere. We might begin with an *a priori* theory, like central place theory, or alternatively, enter the cycle in the middle by exploring discrepancies between data and theory generated by others. Whatever the case, the heavy archaeological focus on *a priori* theory and the scorn frequently held for more data-grounded ideas is incorrect and limiting. Although empirical generalizations might misrepresent some causal relationships, they can be a tremendous source of insight. Bamforth (1994) notes the worth of these insights "for those of us who are interested in seeing the world as it *is* rather than as we want it to be" (emphasis original).

Medical research provides excellent examples. Almost weekly the press reports on new medical discoveries that are not generally theoretical, but empirical, based on statistical patterns in data. Some of them are well known and currently popular: that aspirin or even red wine reduce the risk of heart disease, for example. Earlier statistical discoveries that have had a far reaching impact on society established the linkage between an exposure to radiation and various cancers, smoking and lung cancer, and fatty foods with coronary disease. These findings did not come about through *a priori* theorizing, but through diligent empirical research by a host of institutions on independent and carefully controlled samples. In each case this work ultimately demonstrated that causal relationships must exist, although initially few or no theoretical mechanisms were understood that might explain these relationships. Theory comes later and usually through hard work. In these contexts it is enough that important relationships discovered through statistical patterns are shown to really exist. It is discoveries such as these that set scientists on the road toward theoretical models that explain underlying causal processes through the scientific cycle of observation, theorizing, testing, modifying theory, testing again, and so on. Even now, some 50 years after Hiroshima, we barely understand at a theoretical level why high doses of radiation induce cancers, but we have made considerable progress.

Computer visualization tools like GIS provide an incredibly powerful mechanism for identifying patterns. Although maps were originally tied to landscapes, now anything that possesses spatial coordinates may be mapped, and at any scale from atomic surfaces to intergalactic spaces. The first Landsat images from space revealed the remarkable structure of the earth's crust, while the first images of the ocean floor from Seasat's radar altimeter fully revealed the nature of mid-ocean ridges and the structure of the continental plates, both of which radically altered theories and ideas about our planet (Hall, 1992, pp. 52–87). In an even larger realm, recent mappings of the cosmos aided by computer visualization tools have revealed amazing structures consisting of galactic filaments, clusters, and voids that were totally unexpected and have caused large revisions in theory, even challenging the Big Bang (Geller, 1988; de Lapparent *et al.*, 1986).

In the following pages I demonstrate that similar new discoveries of importance are occurring in archaeology, largely through GIS-based visualization. Yet, while the benefits of data visualization are clear, there are potential dangers. One complaint, too often justified in archaeology, is that GIS merely makes "pretty pictures" or that there is little substance behind the stunning visual products (Lock, 1995; Madsen, 1996). Another is that GIS graphic results are portrayed as "spatial analyses" while not long ago a formal statistical analysis was required to present conclusions. Additionally, we must recognize that the human eye can be easily fooled. It might perceive patterns in an image that do not really exist or fail to recognize trends that do. For this reason a host of recent papers have called for a dual approach that links GIS visualization with quantitative analysis (Harris and Lock, 1995; Kvamme, 1994; Lock, 1995; Lock and Harris, 1992). Quantitative measures of the strengths of patterns are desirable as a basis for comparison with other results or samples, for example. Moreover, statistical methods can inform us of the existence of tendencies or relationships that are difficult or even impossible to visualize. Statistical tests could play a confirmatory role in documenting "visually apparent" results. At the same time, visualization tools remain essential because simple quantitative measures cannot convey the nature of spatial patterns in the same way that an effective graphic can.

GIS AND DATABASE MANAGEMENT

GIS-driven archaeological databases are of great benefit to researchers and cultural resource managers alike. Yet, in my view they can become an end in themselves and do not well illustrate the exciting potential or power of GIS in the analytical domain. (Although ultimately they may be essential to analysis as principal data sources.) Nevertheless, the chief applications area of GIS in archaeology will undoubtedly lie in database development and management; it is already happening.

Regional Databases

As early as 1992, the volume *Sites and Monuments: National Archaeological Records* (Larsen, 1992) described a host of mostly European national database management efforts that employed GIS or GIS-like (computer cartography) tools. Similar reports now occur frequently throughout the GIS literature for a host of countries and regions around the globe (e.g., Aberg and Leech, 1992; Arroyo-Bishop and Zarzosa, 1992; Bampton and Hamilton, 1996; Boaz and Uleberg, 1993; Bosqued *et al.*, 1996; Canouts, 1992; Chartrand *et al.*, 1993; Farley *et al.*, 1990; Guillot, 1992; Guillot and Leroy, 1995; Harris and Lock, 1992; Lang, 1993; Massagrande, 1995; Middleton and Winstanley, 1993; Mikkelsen and Larsen, 1992; Murray, 1995; Palumbo, 1993; Robinson, 1993; Roorda and Wiemer, 1992a; Stančič and Gaffney, 1996). Overviews of the historical development of information technology for cultural resource databases, from a GIS perspective, are given by Madsen (1996), Hansen (1993), and Harris and Lock (1990, 1995). Wheatley (1995a) offers an introductory presentation of the technology, describing what it can do for cultural resource managers.

The GIS-linked database is a natural evolution from current aspatial databases. The latter, in the form of relational database management systems (RDBMS), are essential to any data management effort. Through them, data in multiple files may be joined, and searches, sorting, or subsetting queries may be made using Structured Query Language (SQL). When linked with GIS, however, their utility and impact is greatly expanded because cartographic elements may be associated and displayed simultaneously with database text. In addition to a map of selected sites, the GIS can illustrate other cartographic features of a region such as river and stream courses, elevation contours, or roads (see Csáki *et al.*, 1995; van Leusen, 1993; Wansleeban and Verhart, 1995).

The GIS-RDBMS link is not a one way street. Database selections may be made graphically, through the GIS. Roorda and Wiemer (1992a,b), for example, describe the Netherland's ARCHIS database, where the user can point to a site in a graphic display resulting in textual information about it from the RDBMS. Alternatively, the user might drag a rectangle across the display or use the GIS to generate a 1 km buffer surrounding roads; in either case all sites within the chosen region are selected in the RDBMS and their data are shown. Farley *et al.* (1990) illustrate an additional improvement to the GIS-RDBMS relationship by demonstrating how Exploratory Data Analysis (EDA) software can enhance interpretation through concurrent displays of maps, database text, and a rich variety of charts, graphs, and statistics.

The many issues in GIS database development are too numerous to fully examine here. Miller (1995) is concerned with the general fuzziness of archaeological data and how imprecisely located features should be represented by systems that require exact coordinates. Harris and Lock (1992) call for "symbolic" rather than "cartographic" representations at the regional level. They argue that within-site features (find spots, excavated materials) more appropriately belong in intrasite GIS databases (see below), not in regional ones where sites are best represented as single polygonal entities. Quite the opposite perspective is offered by Andresen and Madsen (1992) and Arroyo-Bishop and Zarzosa (1992, 1995) who focus on databases appropriate at all possible scales using object-oriented approaches.

Most of the real problems in GIS database development are sociopolitical rather than technical. Madsen (1996) describes the situation in Scandinavia where heavily financed rescue archaeology has access to GIS but is devoid of research ambitions, a situation in marked contrast with academic archaeology, which could use GIS for research but can hardly afford it. Harris and Lock (1992) emphasize the high cost of GIS, the shortage of trained personnel, and political difficulties in the United Kingdom stemming from heavy investment in pre-GIS technology that makes yet another change in computer systems unattractive. Hansen (1993) discusses conceptual, data format, and linguistic barriers to pan-European databases, but points to graphic and museum standards that already exist and the use of common icons to get around language difficulties.

Despite these problems the benefits of GIS-driven regional databases are clear (see Farley and Gisiger, 1996; Harris and Lock, 1990, 1992, 1995; Limp, 1992; Wheatley, 1995a). They potentially allow integration of text and numeric data in RDBMS with maps, drawings, photographs, and environmental data, making easy access to diverse information sources possible for the first time. Moreover, the many analytical and modeling tools available in GIS provide a rich environment for addressing research questions, on topics that are amplified in the following sections. In management contexts, search and query capabilities facilitate routine enquiries and reduce administrative loads. Furthermore, planners at higher levels of government can have access to archaeological data, allowing it to be included more easily in environmental impact and other decisions (Harris and Lock, 1992). Finally, automated databases can facilitate the trend for greater public access to state-sponsored data sets, although potential abuse by artifact hunters warrants protection of sensitive locational information. In any case, with the Internet and World Wide Web, where large data sets may be made available to global audiences, these issues are now of immediate concern. This globalization of information is referred to by Farley and Gisiger (1996) as "corporate metadata." Forecasting trends to come, Limp and Gisiger (1992) provide concrete examples of continent-wide mappings of archaeological distributions that illustrate tremendous potential benefits to archaeology.

Although the original focus of GIS-driven archaeological databases was at the regional level, largely stemming from the need for state or regionwide archaeological databases in cultural resource management contexts, in recent years, attention in archaeological GIS has shifted toward the individual site, particularly in research contexts. After all, extensive work in the form of survey, mapping, remote sensing, and excavation is often conducted at individual sites requiring some form of computerized data management to handle these typically large and diverse spatial data sets.

Within-Site Applications of GIS

In reviewing the literature on within-site GIS, one soon realizes that it frequently is employed as little more than a two-dimensional (2D) cartographic presentation tool. Vector outlines showing the locations of walls, pits, middens, ditches, post holes, and the like, are color coded by feature type, cultural affiliation, or temporal period, and various artifact distributions are similarly portrayed. Sanz *et al.* (1995), for example, examine complex overlapping polygons representing some 350 graves at the Iberian Iron Age cemetery of El Cigarralejo. Sorting and displaying these features by time, sex, wealth, and the richness of grave goods helped them to understand the organization and fundamental characteristics of burial practices. Using similar methods, Snow (1994) examines the structure of Iroquoian site features revealed by thousands of post holes in New York, Potts *et al.* (1996) visualize relationships between artifacts and fossil bones at Olorgesailie, and Bíro and Fejes (1995) plot artifact and feature locations by 5 cm level to better understand a lithic workshop in Hungary. Although these applications aid in site interpretation, they are almost indistinguishable from CAD-based mappings of within-site elements (e.g., compare the CAD drawings of Beex, 1995; Kotsakis *et al.*, 1995). Indeed, this close similarity has prompted Lock (1993, p. 1) to warn that "GIS research will stagnate at the level of drawing maps."

GIS offers a number of distinct advantages over CAD in within-site applications, however. The linkage with RDBMS, so useful at the regional level, allows similar SQL queries and searches within a local database by artifact or feature type, period, cultural association, or other elements of interest. Chartrand *et al.* (1993) and Miller (1995, 1996) explore some of these capabilities and related issues in their focus on the complex urban archaeological setting of York. Arroyo-Bishop and Zarzosa (1992, 1995; see also Arroyo-Bishop, 1991, 1992), however, refuse to make a distinction between within-site and regional levels in their ArchéoDATA program. This object-oriented system is virtually boundary free and permits archaeological features, artifacts, ecofacts, and architecture to be linked into "interpretive entities" at virtually any scale, from a single house feature to a village cluster or large regional areas.

Certain GIS functions and capabilities offer a number of advantages in within-site contexts. Bíro and Fejes (1995), for example, laud the GIS ability to reclassify vectors representing individual site features into useful groups like "houses" or "pits." The flexibility of GIS in incorporating ancillary data like aerial photographs is appreciated by Romano and Tolba (1995) in their work at Corinth, while digitized terrestrial photographs of rock art have greatly augmented the forms of analysis undertaken by Preysler and Blasco (1996) in Colombia. Indeed, terrestrial photography handled within GIS has opened up new possibilities through the use of photogrammetric methods that allow detailed measurements to be performed, permitting exacting documentation that ultimately facilitates the reconstruction of castle walls, for example (Oswald, 1996). More subjectively, but of no less importance, high resolution DTM has allowed visualization of sites in their immediate landscape contexts, allowing better understanding of setting, access, defense, and other issues (Bíro and Fejes, 1995; Csáki *et al.*, 1995; Forte, 1995; Miller, 1996; Romano and Tolba, 1995).

Raster GIS offers display options not available in vector-based CAD systems. It is particularly well suited for gridded excavation data such as artifact counts. Fishnet or pseudo-3D views are typically employed to illustrate artifact, stone, or bone density gradients across a site, and standard 2D rasters are effective in the same way when densities are color coded or gray scaled (Hinshelwood and Dalla Bona, 1994; Meffert, 1995; Wansleeben and Verhart, 1995). Even more flexibility occurs when a raster display is employed as a backdrop over which vectors of important site features are draped. In such a way discrete entities as house walls, hearths, or storage pits may be displayed simultaneously over a continuous phenomenon such as artifact densities (Biswell *et al.*, 1995; Groenewoudt and Wiemer, 1993).

Beyond mere display, a number of GIS analytic tools have been explored in within-site contexts. Map algebra methods allow transformation of artifact counts per grid into ratios between types or proportions that, when mapped, yield very different views and new insights (Ebert *et al.*, 1996; Kvamme, 1996a). GIS-based interpolation and smoothing methods have been employed to estimate a continuous artifact density surface from artifact counts retrieved through systematically placed auger holes that punched through 120 cm of overburden in the Netherlands (Wiemer, 1995). In a somewhat unusual application, Doody *et al.* (1995) obtained 6,700 altitude measurements, randomly placed along the steep, rugged, and heavily vegetated slopes of the 1.5 ha Castle Gale hillfort in Limerick, Ireland. Although few surface features were visible, through creation of a DTM interpolated from these data, vertical exaggeration, and analytical hill shading (a technique that illuminates a surface in order to cast shadows), they were able to show in great detail the nature of inner and outer ramparts, entranceways, and a large cairn feature from the shape of the microtopography alone.

In landscape archaeology contexts that focus not on the site but on the distributions of individual artifacts and features across broad regions (Dunnel and Dancey, 1983), GIS has proven useful as a means to examine and analyze patterns in the data, particularly in arid regions. To illustrate, ground stone and other distributions are examined by Biskowski (1994) at Otumba, an Aztec city in central Mexico, while length/width ratios and other indicators of lithic technology are analyzed by Ebert *et al.* (1996) across an 800 × 800 m space of southern New Mexico. Similarly, Kvamme (1996a) focuses particularly on spatial sorting patterns exhibited by 25,000 pieces of debitage in a 0.6 ha area of Colorado; and in New South Wales, Australia, Holdaway (1996) seeks associations between eroding and accumulating sediments and the distribution of 24,000 artifacts. Groenewoudt and Wiemer (1993) planned to use their substantial results from GIS mappings of surface finds from plowed fields to guide excavations at the Roman fort of Valkenburg in the Netherlands, but funding delays caused their analyses to be available only after excavations were complete.

Despite calls to the contrary (e.g., Harris and Lock, 1995; Kvamme, 1994; Lock, 1995), there has been little linkage of GIS with formal intrasite statistical testing (see, however, Groenewoudt and Wiemer, 1993; Kvamme, 1993, 1996a). One reason is the general lack of statistical analysis software in many GIS and the time-consuming difficulties of exporting GIS data to statistical software packages. Recognizing this deficiency, Reynoso and Castro (1994) created a program called

"VB-GIS" that is specifically designed for data visualization simultaneous with quantitative spatial analysis.

Three-dimensional GIS (Raper, 1989) promises great potential for excavated archaeological sites. These relatively new systems should not be confused with such common GIS practices as the vertical stacking of multiple 2D coverages or a 2D layer like stream courses draped over an orthographic view of landform. True 3D GIS associates attributes with independent x, y, and z axes (unlike other types of GIS that ignore the third dimension), allowing deposits, features, and artifacts to be visualized in their proper 3D contexts. A volume may be rotated, sliced, diced, or "exploded" to yield virtually any possible view of internal relationships (Harris and Lock, 1996). Although not widely available and currently expensive (present applications are principally confined to geological mineral, oil, and gas exploration), these systems allow better understanding of complex deposits and greatly aid in the interpretation of intrasite spatial relationships, site structure, and formation processes.

In recent years, with great strides in better sensor systems and in the digital logging of field information, geophysical prospection methods have come to occupy an increasingly important role in initial archaeological site investigations because they can reveal much about subsurface features and structure. This is particularly true in regions like northern Europe where geophysical surveys are conducted as a matter of course and often as a first step in the site evaluation process (David, 1995). It is not surprising, then, that GIS increasingly plays a role in the manipulation and incorporation of these spatial data sets into within-site databases.

Remote Sensing and GIS

Most geophysical prospection data sets (e.g., magnetometry, resistivity, conductivity) are gathered systematically across an area (with readings taken every half meter, for example), yielding a natural raster data structure readily compatible with GIS. Modern instrumentation, with its high data capture rates and field data loggers, allows rapid coverage of large areas, frequently yielding many tens of thousands of measurements. The special characteristics of these data require sophisticated processing software (Scollar *et al.*, 1990), and their volume requires specialized data handling procedures, both of which are made possible by GIS.

GIS can be employed to coregister diverse geophysical data sets with each other or with aerial photographs, site plans, artifact distribution maps, or topographic maps (Carr and Turner, 1996; Ladefoged *et al.*, 1995; Newman, 1993; Richards, 1996). Most GIS applications contain a suite of image processing and rendering tools that allow the assignment of color or gray scales to geophysical rasters, permitting these data to be treated as continuous-tone imagery. Such a tactic often reveals subtle patterns impossible to see using traditional contouring methods. Procedures developed in air photo interpretation may then be employed where patterned geometries like squares, rectangles, circles, or ellipses suggest features of cultural origin (Scollar *et al.*, 1990). Additionally, image processing and enhancement routines can clip or remove outlying data spikes (a frequent occurrence in these data), balance image brightness, improve contrast, remove noise, or highlight possible boundaries or "edges" through various filters (Ladefoged *et al.*, 1995; Mušič, 1995). In one example the use of analytical shading applied to a magnetic surface yielded shadows that emphasized subtle detail, including indications of possible house structures, at Navan Fort in Northern Ireland (Kvamme, 1996b). Similarly, Ladefoged *et al.* (1995) utilized GIS-based data filtering, color compositing, and image classification methods to highlight significant features in prospection data sets in New Zealand. At a more basic and useful level, Jones (1996) describes how on-screen digitizing of a displayed magnetic surface assists in the definition of significant anomalies.

At the regional level, remotely sensed satellite data have generally proven useful to archaeology. With spatial resolutions in the usual range of 20–80 m (and typically about 30 m), these data have been of little use for intrasite archaeological study. In regional studies, however, satellite data have proven to be extremely important, especially in areas where no base maps are available and for the purpose of determining land cover types, geology, and ecological zones. In general, GIS has been shown to be an efficient tool for the management, handling, and processing of these data (Gaffney *et al.*, 1996; Johnson, 1996; Johnson *et al.*, 1988; Madry and Crumley, 1990; Romano and Tolba, 1995). GIS permits remotely sensed imagery to be rectified and registered to a region's spatial coordinate base, thereby allowing its simultaneous use with other encoded map layers. The image processing tools allow improvements in image quality, color display and compositing, and most importantly image classification. The last converts the digital brightness values represented by each wave length band into likely land cover types (e.g., forest, water, pavement, wheat field) through mathematical or probabilistic means. [Their description is beyond this paper's scope; further details may be found in Limp (1989).] These classified or interpreted maps from space ultimately form the background data central to many regional projects and databases (e.g., Gaffney *et al.*, 1996; Johnson, 1996; Madry and Crumley, 1990).

THE ANALYTICAL CAPABILITIES OF GIS

The diverse forms of analysis promoted by GIS have allowed entirely new research questions to be addressed. This diversity may neatly be grouped into several domains, each of which approaches problems of a regional nature from a different perspective.

Locational Analysis at the Regional Level

The spatial analysis of regional archaeological distributions originally centered around the analysis of point-patterns using, for example, variance/mean ratios, Poisson distributions, nearest-neighbor analyses, or trend surfaces (Hodder and Orton, 1976). These approaches focused on various geometries between the points of interest (usually archaeological sites) and are frequently implemented in GIS. Since the early 1970s, considerable work has also been done in associating settlement distributions with features of environment (e.g., Plog and Hill, 1971; Thomas and Bettinger, 1976). These kinds of analyses have received great attention in archaeological GIS applications in part because environmental variables are easily quantified by GIS. Analyses generally fall into two groups: those that focus on environmental properties at the sites themselves, and those that examine conditions within catchment areas (usually of 1–5 km radius) surrounding sites. In both cases the question is the same and probably represents one of the most common ones asked in regional studies: Are there environmental conditions at archaeological sites or in their neighborhoods that might have influenced their placement by past peoples (cf. Plog and Hill, 1971; Thomas and Bettinger, 1976; Vita-Finzi and Higgs, 1970)? GIS has made possible a number of interesting methodological advances in these analyses.

The first application of a significance test for archaeological location tendencies utilized the chi-square goodness-of-fit test long before the advent of GIS (Plog and Hill, 1971; see Shennan, 1988 for a more current summary). This test forces a comparison of archaeological distributions against a background norm, such as an entire region's environmental distribution. For example, that 70 percent of settlements in a region lie on south-facing slopes is not significant if 70 percent of the entire region faces south. On the other hand, if only 20 percent of the background environment is south facing, a significant pattern is most likely indicated. GIS easily determines areas of background classes and site distribution statistics, making this test easy to implement; and its use in GIS remains common (Altschul, 1990; Gaffney and Stančič, 1991; van Leusen, 1996; Williams *et al.*, 1990). Although it is an ideal test for such nominal-level map variables as soils, geologic, or vegetation cover types, continuous phenomena like elevations, slopes, and distances to water must first be categorized. This amounts to the throwing away of information because the scale of measurement is reduced, which can lead to less powerful inferences, and the examination of mean tendencies or locational variability is precluded.

An alternative tactic is to characterize the background environment through a random sample of control points at which measurements of a continuous variable may be made. This body of measurements constitutes a sample approximation of the region that is then compared against measurements obtained at a sample of archaeological site locations using two-sample *t*, Mann-Whitney, or Smirnov tests (Carmichael, 1990; Kvamme and Jochim, 1989; Wheatley, 1996). Yet these tests, like the previous, merely imitate what was being done manually without GIS (e.g., see Shermer and Tiffany, 1985) and do not make use of any of its special capabilities or simple computational power.

It was soon realized that in raster GIS an entire region, or spatial population, can be represented numerically. Consequently, the region no longer needs to be approximated by a sample; actual population parameters or the entire cumulative population distribution can be determined, simply through consideration of all the grid cells in the region. As a result, movement to one-sample testing strategies could be made where the unusualness of an archaeological sample is evaluated with respect to the population (Kvamme, 1990a, 1992b; McClung de Tapia and Tapia-Recillas, 1996; Wheatley, 1995b). This is an inference strategy only rarely attempted prior to GIS owing to the large computational burden. [See Hodder and Orton (1976, p. 225) for a crude manual approximation.]

Recently, randomization tests based on Monte Carlo methods have been advocated because they are relatively easy to implement in raster GIS (Kvamme, 1996c). Using some index of interest (e.g., a sample mean or variance), analysts can assess the unusualness of the value obtained from an archaeological sample by comparing it against a sampling distribution of index values obtained from 99, or even 999, simple random samples of the same size from the region. If the archaeological sample statistic lies in the upper or lower 5–10 percent of values, then a sample with significantly different tendencies can be claimed. This approach offers freedom from the limiting assumptions of some statistical tests (e.g., normality) and in contexts where it might be computationally difficult to determine population parameters [e.g., only 99 viewshed areas (see below) might be determined in place of all possible viewshed areas].

Archaeological applications of GIS-based locational analysis are many and diverse. Allen (1996), for example, focuses on Iroquoian locational preferences with respect to climate variables across the state of New York. In an unusual diachronic study in the same state, Hasenstab (1996) looks at settlement preference through time as a vehicle for explaining historic Iroquoian culture changes. In Finland, Kirkinen (1996) examines the environmental correlates of nonagrarian Iron Age settlements while Vikkula (1994) investigates landscape changes in glacial and other features and their effects on Stone Age site distributions. GIS analyses of settlement in more complex societies also have been conducted. McClung de Tapia and Tapia-Recillas (1996) explore the Teotihuacan region of Mexico and show no major differences between Middle-Terminal Formative period sites in elevation, slope, aspect, or soil depth preferences. Likewise, Kuna and Adelsbergerová (1995) focus on differences between settlement distributions of the Final Bronze Age and the Roman period in Bohemia, which are analyzed with respect to six relief categories. Historic sites at Fort Hood, Texas, are examined by Williams *et al.* (1990) who combine GIS with relational databases and sophisticated EDA plots in a multifaceted exploration of site location factors.

While the foregoing approaches have concentrated almost exclusively on the analysis of environmental properties at the loci of the archaeological sites themselves, the domain of catchment-based studies should not be overlooked because GIS has played a large role in these studies as well. Most catchment approaches apply the circular form established by Vita-Finzi and Higgs (1970). GIS can add a great deal of flexibility to the form of catchment definition (a topic examined in more detail in a later section on territoriality), and it facilitates the computation of areas of soil, geologic, physiographic, or environmental types within catchments that are usually the basis of analysis. Hunt (1992), for example, argues that GIS does not simply mimic earlier manual approaches, but that it facilitates computation of complex soil productivity indices within the catchments that would be difficult to derive manually. He goes on to show changes in the area within catchments of optimum soils for maize production that parallel known historical and protohistorical circumstances in a diachronic study of Iroquoian settlement in New York. Baena *et al.* (1995) employ a similar approach to examine the relationship between the first metal-working groups (Bell Beaker) of the Madrid region with respect to soils and necessary mineral resources.

If locational analysis methods can give insights into the kinds of variables that influenced, or that are at least correlated with, the kinds of places where past peoples placed their settlements, sites, or activities, then the consideration of these variables *in combination* can provide a means to suggest or predict where undiscovered archaeological sites might be located—an approach that now forms an important domain of cultural resource management and planning.

Predictive Models of Archaeological Location

The various forms of locational analysis of archaeological sites with respect to individual environmental variables can produce great insights into the kinds of phenomena that are related to their placement. Models of archaeological location go a step further by merging what is known through locational analysis multidimensionally. In one sense such models are descriptive statements that summarize the multivariate environmental and spatial pattern of archaeological sites; in another they form predictive statements because a good model can indicate likely locations of as yet undiscovered sites.

Regional models of archaeological site distributions represent one of the earliest major application areas of GIS in archaeology. They are a uniquely GIS endeavor owing to their vast data and computational requirements. Without GIS, high resolution models of archaeological resource locations could not be obtained over large areas, although the early history of modeling predates GIS. [See Kohler and Parker (1986) for an overview of early approaches.]

The impetus behind the development of these models stemmed largely from government agencies in the United States, particularly in the western region where huge tracts of government lands exist. In the early 1980s sample surveys were being conducted to inventory those lands. Several agencies began to ask for a means to utilize locational patterns exhibited by discovered archaeological sites to suggest or "predict" where future sites might be found for management and planning purposes [see Judge and Sebastian (1988) for relevant overviews.]

Two fundamentally different approaches to archaeological predictive modeling were developed. Both are based on the premise that human locational behavior is patterned and that part of that pattern covaries with environmental circumstances (a premise that can be tested statistically through the locational analysis methods of the previous section). The principal methodology examines samples of known archaeological sites in a region, hopefully obtained through some sort of random sampling program, for statistical associations with various mappable environmental conditions such as slope, elevation, aspect, soil type, or distance to water. Typically, multivariate discriminant or logistic regression functions are employed to develop probability equations that contrast environmental differences between an archaeological site sample and a sample of random points known not to contain archaeological sites. One can then go to a map at any point and, based on measurements of relevant environmental variables, use the multivariate function to make a decision about the likelihood, or even the probability, of archaeological site presence. Great rigor in model development is possible through use of random sampling designs, and they may be thoroughly tested simply through the expedient of comparing predictions with actual archaeological circumstances learned through independent sample surveys. See Carr (1985), Kvamme (1990b), Parker (1985), van Leusen (1996), and Warren (1990a) for the many additional details relevant to this approach.

Early pre-GIS efforts attempted to manually apply such models over small regions, but hand measurement of a large number of environmental variables at numerous locations was a tedious and error-prone process. The need for automation was clear. Early projects developed computer programs—essentially GIS—to accomplish this, which yielded systematic model decisions every 50 m across regions ranging in size from a few hundred to over 1,000 km^2 (Hasenstab, 1983; Kvamme, 1984). With commercial GIS readily available by the late 1980s, numerous examples soon followed. Carmichael (1990), for example, illustrates robust models of lithic scatter sites in Montana, despite use of low quality DTM; and Hasenstab and Resnick (1990) describe an application to historical sites at Fort Drum, New York. Maschner and Stein (1995) show how a series of categorical variables can be employed to model site locations in coastal Alaska. They also demonstrate that great insights into locational determinants may be learned from empirical data through log-linear analyses. Rigorous model testing, essential before confidence may be placed in any model, is emphasized by Kvamme (1992c), who utilizes independent sample surveys to test locational models for Great Plains hunter-gatherers. Sites that are not well predicted owing to their nonconformance with trends exhibited by other sites receive special attention from Altschul (1990), who touts "red flag" models that serve to indicate them in a rather crude modeling effort in Arizona. Warren (1990b) does much the same by utilizing a more sophisticated analysis of residuals in a southern Illinois settlement model.

These methods soon spread to Europe where they received particular attention in the Netherlands (van Leusen, 1996). In that country Brandt *et al.* (1992) offer models of surprising power for Stone Age through Medieval sites (suggesting underlying commonalities in settlement location choice), and van Leusen (1993) confronts an unusual difficulty in being forced to first reconstruct ancient drainage patterns before modeling the settlement system. Despite utilizing heavily biased find spot data along the Danube of southern Germany, Kvamme and Jochim (1989) nevertheless model locational patterns that stem, in part, from choices made by the Mesolithic inhabitants.

Surprisingly, there was an early negative reaction to the foregoing modeling approaches by some processual archaeologists who advocated a more "deductively" derived, explanatory approach to modeling past locational behaviors (see Ebert, 1988; Kohler and Parker, 1986; Sebastian and Judge, 1988). These critics seemed not to realize that the variables selected in the empirical modeling approach also stem from *a priori* theory, and that statistical methods merely offer a means for obtaining robust weights for the variables selected because they are derived from the actual data. Indeed, the relative weighting of variables, often based on little more than conjecture, is the greatest weakness of an *a priori* deductive modeling approach. (For example, why should good soils get a weight of "5" while proximity to water receives a weight of only "3" in the model decision rules?) Because of their low power when tested against real data, few useful modeling applications have derived from a deductively oriented perspective, largely owing to our poor knowledge of how past (or even present) settlement systems work and our inability to derive the "law-like" statements that form the basis of this modeling approach (see Kohler and Parker, 1986, for a hypothetical example application).

Dalla Bona (1993) and Dalla Bona and Larcombe (1996) have probably come the closest in a GIS context by intensively examining ethnographic and ethnohistoric accounts pertaining to native settlement in northwest Ontario. This allowed development of conceptual models of seasonal land use that were then implemented in GIS through a map algebra approach that weighted and combined relevant environmental layers, but only after closely "tweaking" decision parameters (i.e., the weights for each variable) by iteratively matching model results with empirical site distributions!

Ironically, one of the best *a priori* deductive models lies in an early study by Chadwick (1978, 1979) that possessed GIS-like capabilities. Utilizing a raster data structure and numerous environmental data layers, Chadwick modeled the Late Helladic Mycenaean settlement system entirely on the basis of premises about environmental preferences and population distribution influences of the previous Middle Helladic period. Recently, in a paper that suggests great promise, Kohler and Gumerman (1996) place loose automata ("agents" representing households) onto GIS paleoproductivity surfaces in the American Southwest and observe their locational solutions to making a living in that landscape using very simple decision rules.

A well-tested archaeological location model can offer an important planning mechanism for cultural resource managers. Greater monitoring, surveillance, and protection can be afforded to regions that are predicted to have high archaeological potential. Land-disturbing activities can be planned around highly sensitive areas and directed to regions with a lesser likelihood of cultural resources. In so doing, the costs for initial survey and mitigation of impacts can be reduced because fewer sites will be encountered (Parker, 1986). In view of the fact that computer planning models exist for most natural resources and contemporary cultural constraints (e.g., real estate value, demographic projections, traffic patterns, endangered species distributions), archaeologists now possess a means, through GIS, to provide models that allow cultural resources to be factored into environmental impact statements and similar planning documents. Indeed, such models recently have been developed and applied on a statewide basis (Hobbs, 1996).

Spatial Allocation, Territoriality, and Cost Surfaces

Previous sections have focused largely on environmental properties of archaeological sites, or in the neighborhoods of settlements, as a means for analyzing and modeling human locational behavior. There is a considerable social dimension to the nature and distribution of human settlements across a landscape, however, that revolves around such concepts as territoriality, settlement hierarchies, and political and economic power. These perspectives have been pursued through GIS as well.

Spatial allocation is a general term for methods that attempt to associate sites or places with territories. GIS has yielded exciting potential in this area because it makes traditional approaches like site catchment analysis or Thiessen tessellations easy to implement, but mostly because GIS makes possible entirely new approaches that carry more realistic assumptions about the nature of territories and human behavior. GIS unifies ideas about access, movement across landscapes, boundaries, and concepts of territoriality, thereby providing a firmer theoretical foundation.

Site catchment analysis (SCA) has been around for some time in archaeology (Vita-Finzi and Higgs, 1970). Despite its many theoretical weaknesses, it has gained new interest in archaeology most probably because simple catchments are so easy to compute through GIS. Under the assumption that nearby places will be of greater economic importance than distant regions, simple circles of fixed radii (e.g., 1–5 km) are placed around loci of interest, usually prehistoric settlements. Economic or other resources are then examined within the catchments to explain settlement location under the assumption that they are sited to allow easier access to them. This approach is followed by Baena *et al.* (1995) and Hunt (1992), for example, for grouping environmental data for analyses of settlement location, as described earlier. In an entirely different application of SCA that focuses on its geometric properties, Lock and Harris (1996, p. 236) contend that the spatial distribution of 400 m circular catchments in the Danebury Iron Age of England suggests "an infield system under the control of individual settlements," while a 1,000 m catchment is shown to coincide with natural landscape features.

Like circular catchments, Thiessen polygons are geometrically derived spatial entities; but they differ in that an *entire region* is partitioned into territories, each assigned to a site. They are traditionally constructed by drawing a perpendicular at the midpoint of a line that connects two sites; this is performed between each pair of sites yielding polygonal regions. GIS provides an interesting conceptual link between Thiessen polygons and site catchments. One can "grow" distances outward from a collection of sites. Circular catchments result when the growth is stopped at a fixed distance; if it continues until the entire region is filled, Thiessen polygons are achieved at the boundaries of the individual growth zones. [See van Leusen (1993) for an example.]

The principal criticism of these spatial allocation methods is that they are constructed under unrealistic isotropic conditions that do not account for the natural landscape. Van Leusen (1993) notes that characteristics of terrain probably influenced the size and shape of territories; boundaries may have been "attracted" to natural features like rivers and ridge lines, for example. A comprehensive examination of this issue is given by Ruggles and Church (1996) who further consider other shortcomings of the Thiessen tessellation. They point out that the standard approach assumes equal weight or influence between the points, but that in reality settlements vary in size, population, and economic or political influence. They use the flexibility of GIS to explore how alterations of these assumptions, through different weighting schemes, change the Thiessen tessellation for the Aztec Temascalapa-Teotihuacan survey regions [see also Stead (1995) for a similar discussion]. While this approach might seem new, Renfrew and Level (1979) actually pioneered it nearly 20 years ago in what they term "XTENT modeling."

Despite these more sensitive approaches to territoriality, the standard isotropically defined Thiessen tesselation remains frequently applied in GIS applications. Savage (1990b), for example, resorts to standard Thiessen polygons despite his close investigation of Archaic group interactions with topographic features in Georgia. Chartrand (1996) compares them between various site types in the York environs of England, and Lock and Harris (1996) use them to illustrate a lack of dispersed Neolithic long barrow distribution near Danebury, England, by the nonuniform sizes and shapes of the polygons.

Cost surfaces, a GIS concept, move beyond the assumption of a homogeneous and featureless plain that underlies the previous methods. They allow assignment of weights to individual locations across a landscape according to characteristics of terrain (e.g., slope), land cover (vegetation types), natural barriers (water bodies, cliff faces), and other factors. Costs are accumulated as one moves outward from a locus. With a uniform cost of entry *everywhere*, a cost surface mimics a simple distance surface. When nonuniform cost-of-entry rules are in place, however, widely different outcomes may be achieved that better reflect environmental influences on access and movement. This is well illustrated by Limp (1991) in the first major archaeological application of this methodology at the Rush site in Arkansas. Arguing that as slope increases it becomes significantly more difficult to traverse a location, Limp employs the square of slope in his cost-of-movement calculations and allows for riverine barriers. By defining a contour of equal accumulated cost on the resulting surface, he defines a highly irregular catchment around the Rush site that reflects actual landscape properties and can be compared with a traditional circular catchment. Agricultural potential, as reflected by soil conditions, is shown to be markedly different between the two catchment types, illustrating how unrealistic circular catchments can lead to erroneous conclusions.

Gaffney and Stančič (1991) apply a similar methodology to several periods and cultural types on the island of Hvar, in central Dalmatia. Their cost-surface-derived catchments, also a function of slope but field calibrated to walking times, show control of arable lands by Iron Age hillforts, that Bronze Age tumuli were associated with the very best soils, and that Roman settlements were located on good to very good soils (these analyses are reexamined in Gaffney *et al.*, 1995, 1996). Stančič (1994) and Stančič *et al.* (1995) compare and contrast all three spatial allocation methods (Thiessen polygons, circular catchments, and cost-surface-derived catchments) in the Dolenjska region of Slovenia, showing that territories surrounding newly established Bronze Age hillforts occur on the edges of earlier Copper Age hillfort catchments, with the same pattern repeated with Iron Age territories relative to Bronze Age ones.

Cost surfaces also have been employed as a means to investigate efficient routes of travel. Madry and Rakos (1996), for example, use the GIS technique of "optimum corridor analysis," which allows investigation of alternative travel routes on a cost surface. They investigate the siting of ancient Celtic roads in the Burgundy region of France. Similarly, Steele *et al.* (1996) employ cost surfaces on a continental scale to explore possible pathways of the first Americans in the peopling of the New World.

One limitation of the foregoing methods is that they do not consider visibility of the landscape or of rival or friendly settlements as a means for defining territories, an important dimension that GIS allows us to confront for the first time.

Intervisibility and Viewshed Analysis

Previous sections have focused on specific environmental features of locations or of local neighborhoods. They have examined methods that carve regions into territories based largely on simple geometries or on environmental properties through cost surfaces. Intervisibility studies offer an alternative to the dominance of these methodologies for examining past behaviors because there is a large social or even cognitive element involved when human constructions or settlements are sited in a landscape according to properties of view and visibility.

A line of sight (LOS) is defined between two points on a landscape if no intervening terrain, or feature on the terrain (vegetation, buildings), is higher than that line. Because terrain form is easily represented within GIS through the DTM, computation of the LOS between two points, or even between large groups of points, is a trivial undertaking. Haas and Creamer (1993), for example, determine intervisibility between more than 400 potentially defensive sites in Arizona, which they assert was a key variable in settlement choice among the Kayenta Anasazi. Ozawa *et al.* (1995) believe that beacon networks may have existed between more than 600 hillforts in southern Japan. They employed GIS to investigate intervisibility between them owing to difficulties using traditional field methods stemming from urbanization (where modern buildings often block views) and access difficulties.

Computationally more demanding is the determination of a *viewshed*, a GIS concept defined as all places visible from a defined point or points (the viewshed, obtained through numerous LOS computations, comes from the term "watershed"). The outcome is binary: a "1" indicates all locations visible and a "0" denotes places unseen. Viewsheds yield a dual perspective. They represent not only all locations visible from a locus but also all locations from which a point of interest is visible—an important distinction in certain cognitive approaches that seek to determine significant symbolic landscape features of the past (Wheatley, 1995b). Most GIS applications allow the viewer's height to be considered (whether standing on the ground or on an elevated city wall), and they can factor in potentially blocking land cover such as buildings or vegetation. The latter is accomplished through map algebra simply by adding to the DTM the heights of individual structures and typical heights of various plant cover classes. This rarely has been undertaken in archaeology, however, owing to the difficulty of detailed paleoenvironmental reconstruction of plant cover distributions. [See Wheatley (1996) for suggestions in a southern England study.]

Viewsheds have achieved great attention in archaeology. Early applications were concerned with the simple question of "what is visible?" A viewshed was determined from upper Tonto Ruin, in Tonto National Monument, Arizona, to ascertain whether an expansion of the park's boundary was warranted to preserve the view of the natural desert environment in the face of encroaching urbanization (Kvamme, 1992a). Gaffney and Stančič (1991) employ a viewshed to demonstrate intervisibility between watch towers and the early Greek colony of Pharos on the island of Hvar, Croatia.

In recent years viewsheds have received considerable attention from European scholars as a means to perceive past social or cognitive landscapes, and even territoriality. Gaffney and van Leusen (1995) argue that human communities imbued certain locations with value and that views of them were important. Visibility of monuments or features is seen as a social statement, even as a means of control, as where a view of an imposing hillfort dominates a valley below (Lock and Harris, 1996). Emphasizing the importance of the cultural over the natural, a number of researchers have shown great zeal in their quest to get at cognition through intervisibility studies and, in so doing, have developed some rather exciting approaches.

Ruggles *et al.* (1993) define a *multiple viewshed*, which represents the Boolean union of individual viewsheds computed from multiple loci of interest. Focusing on the standing stones of the island of Mull, Scotland, they are concerned with how the visibility of various features may have influenced the development of the cultural landscape and so examine the standing stones with respect to natural horizon features and their astronomical potential. Clear associations are demonstrated between lunar alignments, the landscape, and the standing stones.

Wheatley (1995b, 1996) goes a methodological step further by defining a *cumulative viewshed*, which represents the *sum* of individual viewsheds. Since any one viewshed is binary, the cumulative viewshed is a discrete layer containing $n + 1$ levels, where any locus can be rated from 0 (not visible from any viewpoint) to n (visible from all). In map form this "intensity of view" surface indeed represents a new way of looking at a landscape because it shows places that tend to be highly visible from prehistoric sites or monuments (the typical viewpoints), therefore suggesting loci of possible cultural importance. Focusing on long barrows in the vicinity of Stonehenge and Avebury, in England, Wheatley's (1995b, 1996) evidence shows that long barrows in the vicinity of Stonehenge were sited in places that were highly visible from other long barrows. He therefore argues the importance of ritual authority that required these structures to be seen. The lack of a similar pattern in the vicinity of Avebury is interpreted as pointing to clear social differences between the regions.

Gaffney *et al.* (1995, 1996) essentially copy this approach to demonstrate relationships between highly visible places and multiple rock art and ritual monument classes in Argyll, Scotland. Cumulative viewsheds made it clear that certain areas "achieved prominence" as defined by their "potential perception." For example, one valley clearly formed "the ritual cognitive focus of the area" (Gaffney *et al.*, 1995, p. 226).

Viewshed analyses also have been utilized to address other research questions. Madry and Rakos (1996) demonstrate that ancient Celtic roads in the Burgundy region of France were sited with a LOS to a maximum number of hillforts for defense of the transportation network. In the Tebenkof Bay area of Alaska, Maschner (1996b) shows that Late Phase villages possessed significantly greater viewshed areas than Middle Phase villages, suggesting that defensibility became more important through time. In contrast, Lock and Harris (1996) conclude in their analysis of Iron Age hillforts near Danebury that all-around visibility for defense was sacrificed in favor of maximizing visibility to assert visual dominance over farmsteads in certain valleys.

Viewsheds also have been claimed to relate to territoriality (Gaffney and van Leusen, 1995; Llobera, 1996). Perhaps the best demonstration of this lies in the viewshed analysis of Neolithic long barrows near Danebury (Lock and Harris, 1996), which shows that the barrows do not fall within each other's LOS. Each was located to exclude others from its viewshed. These results forced Lock and Harris (1996, p. 225) to conclude that viewshed analysis "is a more robust and useful measure for identifying territoriality . . . than Thiessen polygons."

Besides the vegetation cover or "tree" problem, there are many other potential difficulties in viewshed analyses that warrant caution. Fisher (1992) demonstrates considerable uncertainty in viewshed boundaries owing to variances in DTM that stem from differences between interpolation methods and in the viewshed algorithms themselves. Ruggles and Medyckyj-Scott (1996) show how to allow for the curvature of the earth when considering large distances. The atmospheric haze factor, which detracts from the perfect viewing conditions assumed in most analyses, also has been considered. One solution is to combine the binary viewshed with a distance decay function through map algebra to better model what might be discernable under more typical viewing conditions (Fisher, 1992; Wheatley, 1996).

On a more theoretical level, viewshed correlations are possibly only a proxy for other environmental factors that may have influenced site placement. For example, viewshed correspondences with site locations may only be an artifact of their high ridge line placements in some contexts where views were not important but certain food or other resources were. Another difficulty is the contemporaneity issue. In Wheatley's (1995b, 1996) Stonehenge analysis, for example, the long barrows were not all built on the same day. Analyzing all such sites together as if they existed at the same time can only inflate the intervisibility counts and the perceived significance of the outcome. Although viewsheds have been hailed as a means to get at "cognition" and away from the more common GIS focus on environmental correlates (see below), Maschner (1996c) observes that if the landscape of a region were flat, then viewshed relationships could not exist, making this "social mechanism" environmentally determined after all by a rolling hill country.

Simulation

GIS provides great potential in the area of regional simulation because its accurate portrayal of actual physical landscape features and environment adds a new dimension of realism. This spirit is captured in a dynamic simulation by Van West (1994) that examines whether droughts were responsible for the late 13th-century abandonment of southwestern Colorado by the Anasazi. Temperature and precipitation data recorded through the past century were used to compute Palmer

Drought Severity Indices (PDSI; a measure of annual soil moisture conditions) for multiple soil classes and elevation ranges. These PDSI values then were correlated with historic tree ring widths, yielding a regression function that made it possible to retrodict the PDSI for all soils and elevation ranges back in time on the basis of the prehistoric tree ring record. Agricultural yield studies then were linked with the PDSI on an annual basis, from AD 901–1300, allowing yearly maps of productivity (at 200 m resolution) throughout the 1,800 km^2 study region (these 400 maps were later animated in a movie). Results indicated that despite poor years, agricultural productivity always could have been high enough to support thousands of people, reducing the credibility of the drought-caused abandonment theory.

Recently, Van West and Kohler (1996) exploit this GIS database again, but this time food pooling behavior is examined through simulation. They argue that food pooling is a form of risk aversion favorable in periods of high mean and variable productivity, but that it breaks down in times of low yields. Ten unfavorable, neutral, and favorable periods for pooling are established through the paleoenvironmental simulation and are shown generally to agree with key indicators of food pooling, or the lack of it, in the archaeological record.

Many GIS-based simulations have been concerned with settlement behavior at the regional level. Kohler and Gumerman (1996), for example, utilize the southwestern Colorado database of the previous studies and loose automata, each representing a household constrained by very simple decision rules, to observe their location decision solutions as part of a broad-based study of settlement choice. GIS also has facilitated what might be the only application of location-allocation modeling in archaeology. Through it Ruggles and Church (1996) take a sophisticated look at the Aztec settlement system and the movement of goods in the Basin of Mexico. Through a modified Thiessen polygon approach based on the locations of known regional centers, they simulate a wide variety of network approximations, model assumptions, and parameter ranges that demonstrate a dendritic settlement system and a "fairly efficient pattern of collection and transport of . . . surplus and for administration of population" (Ruggles and Church, 1996, p. 173).

The spread of European populations through the waterways of New York from 1608 to 1810 is simulated by Zubrow (1990b) in a rare archaeological example of the vector-based network analysis capability of GIS. Using various initial colonization points and impedance-to-movement values assigned to each waterway segment or arc, Zubrow explored the nature and speed of patterns of migration and compared them against recorded historical circumstances. Other studies have simulated isostatic rebound to examine its effect on prehistoric settlement in Finland (Nunez *et al.*, 1995) and employed hydrological modeling and flood simulation to better understand Middle Neolithic distributions in the Tisza Valley of Hungary (Gillings, 1995).

The versatility of GIS for addressing problems at virtually any spatial scale is illustrated at one end of the spectrum in a rare intrasite simulation by Kvamme

(1996a). In this study dense debitage accumulation patterns are generated by taking experimentally produced scatters and randomly superimposing them in a confined space. The results are compared against archaeological scatters and theoretical models to support arguments for a spatial sorting phenomenon in their formation process. At quite the opposite end of the spectrum, Steele *et al.* (1996) simulate the peopling of North America under various demographic parameters, first using an isotropic surface and then with actual North American landscape features. The latter vividly illustrates the effects of landform on the cost of travel-derived pathways of the first peoples. Finally, at an even more global scale, Zubrow (1997) combines prehistoric data, navigational and content analysis of ship logs, and GIS to dynamically simulate the spread of major epidemic diseases in the New World from points of contact with Europeans during the voyages of exploration from 1492 to 1650. Several insights are gained including likely conduits and population densities necessary for disease transmission, the scheduling of depopulation, and relative magnitudes of decimation as a function of location and number of points of contact.

PROBLEMS, PROSPECTS, AND CONCLUSIONS

GIS and the Postmodern Critique

Go to, let us go down, and there confound their language, that they may not understand one another's speech.

—Genesis 11: 7, *The Holy Bible* (King James Version)

The growing dominance of GIS and its impact on anything spatial has been hailed as the "quantifier's revenge" on postmodernists (Oppenshaw, 1991, p. 621). Yet, despite the generally upbeat, positive, and even euphoric praise of its archaeological potential, the picture is not very rosy for some more seasoned practitioners. Too many archaeological GIS investigations focus only on the physical environment. This circumstance derives from the fact that maps of the environment—topography, hydrology, soils, geology—are relatively easy to obtain. It is much more difficult to acquire maps of contemporary settlements, economic or religious centers, road networks, or political spheres of influence, for example. Such data sets typically require extensive prior research or a well-developed knowledge base of a region. Van Leusen (1996, p. 182) observes: "It is not simply that cultural conditions in the past have little or no bearing . . . but that they are either largely unknown, or unmappable." Moreover, all too often the establishment of contemporaneity, a prerequisite for the investigation of a social landscape, is difficult to achieve, as when working with prehistoric hunting and gathering camps.

Environmental Determinism. In recent years the foregoing debate has become quite polarized. Many European scholars view the social landscape as central to understanding the past and either reject outright the natural for the cultural or perceive the former as mere noise that should be filtered out (Gillings and Goodrick, 1996). Indeed, Wheatley (1993) has gone so far as to suggest a "hidden agenda" behind GIS technology that encourages a functionalist perspective. Others agree (e.g., Gaffney and van Leusen, 1995; Gillings and Goodrick, 1996; Harris and Lock, 1995; Llobera, 1996), arguing that because of this bias GIS cannot be theoretically neutral. But does this bias stem from GIS or from the nature of the data we use? Did it not exist long before GIS when archaeologists worked primarily with paper maps? Maschner (1996c), for example, emphasizes that GIS is only a tool, inherently atheoretical, as is mass spectrometry or microwear analysis.

One unfortunate outcome of this debate lies in the label of "environmental determinism" that is commonly applied to studies that focus on environmental relationships (e.g., Gaffney and van Leusen, 1995; Harris and Lock, 1995; Llobera, 1996; Lock, 1995). Yet, in practice, no archaeologist today believes that everything in the past was environmentally determined, especially in contexts where one merely wants to ascertain if agriculturally based settlements in a region illustrate associations with certain soil classes, for example. Moreover, it seems silly, as one reviewer of this paper pointed out, to argue over an implicit assumption that environmental and human systems are somehow not part of the same world!

Recently, Maschner (1996c, p. 507) attempts a reconciliation by stressing the interrelationship between the social-cognitive and environmental domains. He notes, for example, that although warfare might have large cognitive and symbolic components, the choice of defensible location is due largely to landform and that a location selected only for its cognitive or symbolic value "quickly leads to a lack of symbolizers". Similarly, Kvamme (1997) discusses how a regression analysis can mollify the controversy simply by demonstrating that some portion of the variance in settlement location is explained by social variables while other portions are accounted for by environment. Yet, Gillings and Goodrick (1996), Harris and Lock (1995), Llobera (1996), and others, go a step further by suggesting that various forms of determinism are inherent to GIS and stem from the nature of the technology itself and the geographical techniques upon which it is based. As a result, they see no difference between the results of social-cognitive and environmental analyses because both are constrained by essentially the same methods. While these complaints are too numerous to fully address here, several warrant special consideration.

Wheatley (1993) originally pointed out in the archaeological literature that the Cartesian space of GIS may not be the most appropriate model for the way humans view space. In support, he observes that before modern maps the Isle of Wight, England, was originally portrayed as being much longer than it really is owing to the influence of offshore currents on local perception. These critics seem unaware of the field of "mental mapping" in human geography where dealing with warped perceptual spaces is the norm and where methods have been long around for handling them (e.g., see Gould and White; 1974). Logarithmic, polynomial, or rubber sheet transformations of space, all readily handled by GIS, might be appropriate considerations and, indeed, are utilized by Zubrow (1994) in an analysis of prehistoric Iroquoian cognitive spaces in New York.

Harris and Lock (1995) and Lock (1995) lament that GIS is spatially deterministic because all elements are required to possess exact coordinates, a circumstance not well suited for imprecisely located or fuzzy archaeological information. If archaeological data are sloppy, then we need to change our recording habits and employ appropriate technology such as global positioning systems (GPS) and laser theodolites to obtain accurate field information, as illustrated in recent landscape archaeology approaches where surface mappings of tens of thousands of artifacts are obtained across large regions (Ebert *et al.*, 1996; Holdaway, 1996; Kvamme, 1996a). For extant and traditionally recorded "site" data, dashed or dotted lines (Miller, 1995) or fuzzy or probabilistic boundaries (Fisher, 1992) might be employed.

Gaffney and van Leusen (1995) complain of the loss of detail and resolution of excavated data when archaeological sites are treated as points. Harris and Lock (1995) suggest much the same thing, arguing that it might be appropriate to treat lithic scatters in the American Southwest as points, but that in Europe the record consists of rich polygons in complex palimpsests. These are scale-dependent arguments. Zoom in enough and even artifacts have area. At the regional level we frequently can treat settlements as points or perhaps utilize site-center coordinates to exploit the rich library of point-based analysis methods. If this is not appropriate at a given scale, then a suite of area-based analysis methods exists and should be examined (see Unwin, 1981, pp. 111–152).

Prospects and Future Directions

> *Like the automobile and indoor plumbing, GIS won't be an important technology until it fades into the fabric of society and is taken for granted. It must become second nature for accessing information and translating it into knowledge. We must shift its emphasis beyond mapping to spatial reasoning.*
>
> —Berry, *Spatial Reasoning for Effective GIS*

Although predicting the future is a hazardous undertaking, there are a number of unmistakable trends that can be forecast for GIS in archaeology. Foremost among them is that GIS-driven databases will ultimately form the standard vehicle for data management and access at national, state, local, and even site levels, and these systems will not simply include data plus maps. Multimedia presentations also will offer video, sound, photographs, drawings, and animated three-dimensional views

(Harris and Lock, 1995, p. 359). Comprehensive management databases that incorporate all possible sources of knowledge about an archaeological site will become more common. Surface microtopography, mapped surface finds, data from test pits and excavations, aerial photographs, and many multispectral and geophysical remote sensing products, all combined in one place, will yield tremendous potential for understanding site content, organization, and structure. We are seeing the beginning of these trends now (e.g., Gaffney and van Leusen, 1996; Richards, 1996). With the Internet and World Wide Web (WWW), archaeological databases will be made available globally. This factor alone represents the most profound development of the future. It will change everything. In this vein Farley and Gisiger (1996) describe "corporate databases," which are shared information resources that are platform and software independent, distributed across widely separated geographic locations.

The archaeological potential of remotely sensed satellite data is about to grow rapidly. Within the next several years public domain satellites will be launched that will yield multispectral data with spatial resolutions in the 1–5 m range, completely revamping the utility of these data for archaeology (Limp, 1996). With these resolutions it will be possible to not only conduct within-site investigations from space that will be able to identify individual surface or near-surface features but also undertake such things as the periodic monitoring of important sites for the effects of erosion or vandalism. In any case, a common view in the larger GIS community is that most base maps in the future will ultimately be derived from remotely sensed satellite sources (Star and Estes, 1990).

True three-dimensional GIS applications only now are making inroads (Harris and Lock, 1996), but they are sure to form a core tool for handling within-site data ranging from artifact distributions to archaeological deposits and historic structures owing to their superior functionality over CAD. The three-dimensional environment brings forth the area of virtual reality. Already available are on-line tours of reconstructed ancient buildings or the creation of realistic, data rich, or "sensuous" landscapes (e.g., Gillings and Goodrick, 1996) within which one can immerse oneself through head-mounted stereoscopic visualization gear or other devices (Forte and Guidazzoli, 1996). Virtual reality will surely create a closer link with the past for the lay public through museum displays, the classroom, the WWW, and commercial offerings and will be a real boon to more humanistic archaeologies (e.g., see Gillings and Goodrick, 1996; Llobera, 1996; Lock, 1995).

The link between GIS and GPS is unstoppable in commercial, government, and research sectors. Archaeologists do fieldwork, they must accurately locate themselves and what they find, and they map their results. GPS has already gained large acceptance in our discipline (e.g., Estrada Belli, 1997; Lang, 1994; Limp, 1996) and will continue to do so as the technology improves and decreases in cost. In the not so distant future all survey information will be GPS-driven.

In a future facing unlimited population growth, urbanization, and scarcer resources, including cultural resources, planning and management will assume greater importance. GIS-based predictive models of archaeological location will therefore become increasingly relevant because they provide a means for making objective and testable statements, in map form, about the nature of past cultural distributions. They can provide planners and managers with a tool that results in cost savings and conservation of the resource base (Parker, 1986). We are already seeing this happening with state-sponsored modeling projects of tremendous scope in several provinces of Canada for forestry planning (Dalla Bona, 1993; Dalla Bona and Larcombe, 1996), in Minnesota with a statewide model in response to transportation planning (Hobbs, 1996), and in the Netherlands as part of a general guidance tool in one of the most densely populated countries on the planet (van Leusen, 1996).

On a more cautionary note, we are moving into a "point and click" universe where powerful tools are readily available and the potential for abuse is great. Students need to receive training in basic computer science to understand what computers and GIS do with data, in cartography to understand basic scale and representational issues, and in fundamental data analysis principles to make valid inferences from vast bodies of information in computer graphic displays. An analog of 20 years ago exists where easy access to powerful statistical software led to unprecedented abuse in the absence of formal statistical training across the social sciences.

In a prescient discussion Oppenshaw (1991, p. 625) forecast that "we are heading for an immensely data-rich but theory-poor world." Yet, through information management tools like GIS we might hope to unlock and eventually understand important patterns and relationships that lie encrypted within the world's databases. A data-rich environment with the ability to easily visualize complex relationships can only lead to improved insights that will ultimately produce better theory and understanding of the world. Indeed, perhaps a lack of sufficient data and the means to handle and visualize them has inhibited productive theory generation in the highly multidimensional social sciences, of which archaeology is only a small part. [Lave and March (1975, p. 2) may have been right when they complained that "God has chosen to give the easy problems to the physicists."] I can't wait for the future!

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REFERENCES CITED

Aberg, F. A., and Leech, R. H. (1992). The national archaeological record for England: Past, present and future. In Larsen, C. (ed.), *Sites and Monuments: National Archaeological Records*, The National Museum of Denmark, Copenhagen, pp. 157–170.

Aldenderfer, M. (1992). The state of GIS and anthropological research. *Anthropological Newsletter* 3: 14.

Aldenderfer, M. (1996). Introduction. In Aldenderfer, M., and Maschner, H. D. G. (eds.), *Anthropology, Space and Geographic Information Systems*, Oxford University Press, New York, pp. 3–18.

Allen, K. M. S. (1996). Iroquoian landscapes: People, environments, and the GIS context. In Maschner H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 198–222.

Altschul, J. H. (1990). Red flag models: The use of modelling in management contexts. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor, and Francis, London, pp. 236–238.

Andresen, J., and Madsen, T. (1992). Data structures for excavation recording. A case of complex information management. In Larsen, C. (ed.), *Sites and Monuments: National Archaeological Records*, The National Museum of Denmark, Copenhagen, pp. 23–42.

Arnold, J. B., III (1979), Archaeological applications of computer drawn contour and three dimensional perspective plots. In Upham, S. (ed.), *Computer Graphics in Archaeology*, Anthropological Research Papers, No. 15, Arizona State University, Tempe, pp. 1–15.

Arroyo-Bishop, D. (1991). The ArchaeoDATA system: Towards a European archaeological document. In Lockyear, K., and Rahtz, S. P. Q. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1990*, BAR International Series, No. 565, Oxford, pp. 61–70.

Arroyo-Bishop, D. (1992). Further structuring of the ArchéoDATA system. In Lock, G., and Moffett, J. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1991*, BAR International Series, No. S577, Oxford, pp. 89–94.

Arroyo-Bishop, D., and Zarzosa, L. (1992). The ArchaeoDATA system: A method for structuring a European archaeological information system (AIS). In Larsen, C. (ed.), *Sites and Monuments: National Archaeological Records*, The National Museum of Denmark, Copenhagen, pp. 133–156.

Arroyo-Bishop, D., and Zarzosa, L. (1995). To be or not to be: Will an object-space-time GIS/AIS become a reality or end up an archaeological entity? In Lock, G. R., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 43–54.

Baena, J., Blasco, C., and Recuero, V. (1995). The spatial analysis of Bell Beaker sites in the Madrid region. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 101–116.

Bamforth, D. B. (1994). Discussant remarks in the symposium "Albert Spaulding and the continuation of archaeological science," presented at the annual meeting of the Society for American Archaeology, Anaheim, CA.

Bampton, M., and Hamilton, N. (1996). GIS, education and stewardship in Casco Bay Estuary, Maine. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 1–58.

Beex, W. (1995). From excavation drawing to archaeological playground: CAD applications for excavations. In Wilcock, J., and Lockyear, K. (eds.), *Computer Applications and Quantitative Methods in Archaeology 1993*, BAR International Series, No. 598, Oxford, pp. 101–108.

Berry, J. K. (1995). *Spatial Reasoning for Effective GIS*, GIS World, Inc., Fort Collins, Co.

Bíro, K. T., and Fejes, I. Sz. (1995). GIS applications at the Hungarian National Museum, Department

of Information. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 261–268.
Biskowski, M. (1994). GIS and the study of grinding tools in the Teotihuacan Valley, Mexico. In Johnson, I. (ed.), *Methods in the Mountains: Proceedings of UISPP Commission IV Meeting, Mount Victoria, Australia*, Archaeological Methods Series, No. 2, Sydney University, Sydney, pp. 115–134.
Biswell, S., Cropper, L., Evans, J., Gaffney, V., and Leach, P. (1995). GIS and excavation: A cautionary tale from Shepton Mallet, Somerset, England. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 269–286.
Boaz, J. S., and Uleberg, E. (1993). Gardermoen Project: Use of a GIS system in antiquities registration and research. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 177–182.
Bosqued, C. B., Preysler, J. B., and Expiago, J. (1996). The role of GIS in the management of archaeological data: An example of application for the Spanish administration. In Aldenderfer, M., and Maschner, H. D. G. (eds.), *Anthropology, Space and Geographic Information Systems*, Oxford University Press, New York, pp. 190–201.
Brandt, R., Groenewoudt, B. J., and Kvamme, K. L. (1992) An experiment in archaeological site location: Modeling in the Netherlands using GIS techniques. *World Archaeology* **24:** 268–282.
Canouts, V. (1992). Computerized information exchange on the local and natural levels in USA. In Larsen, C. (ed.), *Sites and Monuments: National Archaeological Records*, The National Museum of Denmark, Copenhagen, pp. 231–248.
Carmichael, D. L. (1990). GIS predictive modelling of prehistoric site distributions in central Montana. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 216–225.
Carr, C. (1985). Introductory remarks on regional analysis. In Carr, C. (ed.), *For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique, and Theory*, Westport Publishers, Kansas City, MO, pp. 114–127.
Carr, T. L., and Turner, M. D. (1996). Investigating regional lithic procurement using multispectral imagery and geophysical exploration. *Archaeological Prospection* **3:** 109–128.
Chadwick, A. J. (1978). A computer simulation of Mycenean settlement. In Hodder, I. (ed.), *Simulation Studies in Archaeology*, Cambridge University Press, Cambridge, pp. 47–57.
Chadwick, A. J. (1979). Settlement simulation. In Renfrew, C., and Cooke, D. (eds.), *Transformations: Mathematical Approaches to Culture Change*, Academic Press, New York, pp. 237–255.
Chartrand, J. A. (1996). Archaeological resource visibility and GIS: A case study in Yorkshire. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 387–398.
Chartrand, J., Richards, J., and Vyner, B. (1993). Bridging the urban-rural gap: GIS and the York Environs Project. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 159–166.
Clark, G. A. (1979). Spatial association at Liencres, an early Holocene open site on the Santander coast, north-central Spain. In Upham, S. (ed.), *Computer Graphics in Archaeology*, Anthropological Research Papers, No. 15, Arizona State University, Tempe, pp. 121–43.
Copp, S. A. (1977). A quick plotting program for archaeological data. *Newsletter of Computer Archaeology* **13:** 17–25.
Cowen, D. J. (1988). GIS versus CAD versus DBMS: What are the differences? *Photogrammetric Engineering and Remote Sensing* **54:** 1551–1555.
Csáki, G., Jerem, E., and Redo, F. (1995). Data recording and GIS applications in landscape and intra-site analysis: Case studies in progress at the Archaeological Institute of the Hungarian Academy of Sciences. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 85–100.
Dalla Bona, L. (1993). A preliminary predictive model of prehistoric activity location for the western Lake Nipigon watershed. *Archaeological Computing Newsletter* **37:** 11–19.

Dalla Bona, L., and Larcombe, L. (1996). Modeling prehistoric land use in northern Ontario. In Maschner H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 252–274.

David, A. (1995). *Geophysical Survey in Archaeological Field Evaluation*, Research and Professional Services Guideline, No. 1, English Heritage Society, London.

de Lapparent, V., Geller, M. J., and Huchra, J. P. (1986). A slice of the universe. *Astrophysical Journal (Letters)* **302:** L1–L5.

Doody, M., Synnott, P., Tobin, R., and Masterson, B. (1995). A topographic survey of the inland promontory fort at Castle Gale, Carrig Henry, County Limerick. In *Discovery Programme Reports 2: Project Results 1993*, Royal Irish Academy, Dublin, pp. 39–44.

Dunnell, R. C., and Dancey, W. S. (1983). The siteless survey: A regional scale data collection strategy. In Schiffer, M. B. (ed.), *Advances in Archaeological Method and Theory, Vol. 6*, Academic Press, New York, pp. 267–287.

Ebert, J. I. (1978). Remote sensing and large-scale cultural resources management. In Lyons, T. R., and Ebert, J. I. (eds.), *Remote Sensing and Nondestructive Archaeology*, National Park Service, Washington, DC, pp. 21–34.

Ebert, J. I. (1988). Remote sensing in archaeological prospection and prediction. In Judge, W. J., and Sebastian, L. (eds.), *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling*, U.S. Department of the Interior, Bureau of Land Management, Denver, pp. 429–492.

Ebert, J. I., Camilli, E. L., and Berman, M. J. (1996). GIS in the analysis of distributional archaeological data. In Maschner H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 25–37.

Effland, R. W. (1979). Statistical distribution cartography and computer graphics. In Upham, S. (ed.) *Computer Graphics in Archaeology*, Anthropological Research Papers, No. 15, Arizona State University, Tempe, pp. 17–29.

Estrada Belli, F. (1997). GPS and GIS as aids for mapping archaeological sites. *Archaeological Computing Newsletter* **47:** 5–10.

Farley, J. A., Limp, W. F., and Lockhart, J. (1990). The archaeologist's workbench: Integrating GIS, remote sensing, EDA and database management. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 141–164.

Farley, J. A., and Gisiger, A. (1996). Managing the infrastructure: The use of a corporate metadata for archaeology. In Maschner H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 275–300.

Feder, K. L. (1979). Geographic patterning of tool types as elicited by trend surface analysis. In Upham, S. (ed.), *Computer Graphics in Archaeology*, Anthropological Research Papers, No. 15, Arizona State University, Tempe, pp. 95–102.

Fisher, P. (1992). First experiments in viewshed uncertainty: Simulating fuzzy viewsheds. *Photogrammetric Engineering and Remote Sensing* **58:** 345–352.

Fisher, P. F., and Lindenberg, R. E. (1989). On distinctions among cartography, remote sensing, and geographic information systems. *Photogrammetric Engineering and Remote Sensing* **55:** 1431–1434.

Flude, K., George, S., and Roskams, S. (1982). Uses of an archaeological database with particular reference to computer graphics and the writing-up process. In *Computer Applications in Archaeology 1981*, Institute of Archaeology, University of London, London, pp. 64–75.

Forte, M. (1995). Scientific visualization and archaeological landscape: The case study of a Terramarra, Italy. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 231–238.

Forte, M., and Guidazzoli, A. (1996). Archaeology, GIS and desktop virtual reality: The ARCTOS Project. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 443–456.

Gaffney, V., and Stančič, Z. (1991). *GIS Approaches to Regional Analysis: A Case Study of the Island of Hvar*, Znanstveni Institut Filozofske Fakultete, Ljubljana.
Gaffney, V., and van Leusen, P. M. (1995). Postscript: GIS, environmental determinism and archaeology. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 367–382.
Gaffney, V., and van Leusen, M. (1996). Extending GIS methods for regional archaeology: The Wroxeter Hinterland Project. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 297–305.
Gaffney, V., Oštir, K., Podobnikar, T., and Stančič, Z. (1996). Satellite imagery and GIS applications in Mediterranean landscapes. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 337–342.
Gaffney, V., Stančič, Z., and Watson, H. (1995). The impact of GIS on archaeology: A personal perspective. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 211–230.
Gaffney, V., Stančič, Z., and Watson, H. (1996). Moving from catchments to cognition: Tentative steps toward a larger archaeological context for GIS. In Aldenderfer, M., and Maschner, H. D. G. (eds.), *Anthropology, Space and Geographic Information Systems*, Oxford University Press, New York, pp. 132–154.
Geller, M. J. (1988). Mapping the universe: Slices and bubbles. In Cornell, J. (ed.), *Bubbles, Voids, and Bumps in Time: The New Cosmology*, Cambridge University Press, Cambridge, pp. 50–72.
Gillings, M. (1995). Flood dynamics and settlement in the Tisza Valley of north-east Hungary: GIS and the upper Tisza Project. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 67–84.
Gillings, M., and Goodrick, G. T. (1996). Sensuous and reflexive GIS: Exploring visualization and VRML. *Internet Archaeology* **1**: (http://intarch.ac.uk/journal/issue1/gillings_toc.html).
Gould, P., and White, R. (1974). *Mental Maps*, Penguin Books, New York.
Green, D. F., and Stewart, J. B. (1983), Computer generated research aids using the forest service DTIS II system. *Advances in Computer Archaeology* **1**: 4–25.
Groenewoudt, B. J., and Wiemer, R. (1993). Valkenburg-Marktveld: Analyzing the predictive potential of Roman surface scatters using GIS. In Van Dierendonck, R. M., Hallewas, D. P., and Waugh, K. E. (eds.), *The Valkenburg Excavations 1985–1988: Introduction and Detail Studies*, Rijksdienst voor het Oudheidkundig Bodemonderzoek, Amersfoort, Netherlands, pp. 47–81.
Guillot, D. (1992). The national archaeological record of France: Advances in computerization. In Larsen, C. (ed.), *Sites and Monuments: National Archaeological Records*, The National Museum of Denmark, Copenhagen, pp. 125–132.
Guillot, D., and Leroy, G. (1995). The use of GIS for archaeological resource management in France: The SCALA Project, with a case study in Picardie. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 15–26.
Haas, J., and Creamer, W. (1993). *Stress and Warfare Among the Kayenta Anasazi of the Thirteenth Century A.D.*, Fieldiana Anthropology New Series, No. 21, Field Museum of Anthropology, Chicago.
Hall, S. S. (1992). *Mapping the Next Millenium: How Computer-Driven Cartography Is Revolutionizing the Face of Science*, Random House, New York.
Hansen, H. J. (1993). European archaeological databases: Problems and prospects. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 229–238.
Harris, T. M., and Lock, G. R. (1990). The diffusion of a new technology: A perspective on the adoption of a geographic information system within UK archaeology. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 33–53.
Harris, T. M., and Lock, G. R. (1992). Toward a regional GIS site information retrieval system: The Oxfordshire sites and monuments record (SMR) prototype. In Larsen, C. (ed.), *Sites and*

Monuments: National Archaeological Records, The National Museum of Denmark, Copenhagen, pp. 185–199.

Harris, T., and Lock, G. (1995). Toward an evaluation of GIS in European archaeology: The past, present and future of theory and applications. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 349–366.

Harris, T. M., and Lock, G. R. (1996). Multi-dimensional GIS: Exploratory approaches to spatial and temporal relationships within archaeological stratigraphy. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol.* 2, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 307–316.

Hasenstab, R. J. (1983). *A Preliminary Cultural Resource Sensitivity Analysis for the Proposed Flood Control Facilities Construction in the Passaic River Basin of New Jersey*, Report submitted to the Passaic River Basin Special Studies Branch, Department of the Army, New York District Army Corps of Engineers, Soil Systems, Inc., Marietta, GA.

Hasenstab, R. J. (1996). Settlement as adaptation: Variability in Iroquois village site selection as inferred through GIS. In Maschner H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 223–241.

Hasenstab, R. J., and Resnick, B. (1990). GIS in historical predictive modelling: The Fort Drum project. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 284–306.

Hinshelwood, A., and Dalla Bona, L. (1994). GIS and intrasite analysis: An example from northwestern Ontario. *Archaeological Computing Newsletter* **40:** 12–20.

Hobbs, E. (1996). Preliminary results from Mn/Model. *Mn/Model Newsletter* **2:** 1–3.

Hodder, I., and Orton, C. (1976). *Spatial Analysis in Archaeology*, Cambridge University Press, Cambridge.

Holdaway, S. (1996). GIS and open site archeology in western New South Wales, Australia. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, p. 218.

Hunt, E. D. (1992). Upgrading site-catchment analyses with the use of GIS: Investigating the settlement patterns of horticulturists. *World Archaeology* **24:** 283–309.

Johnson, J. K. (1996). Delta digitizing: GIS and remote sensing in northwest Mississippi. In Maschner H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 242–251.

Johnson, J. K., Madry, S. L. H., and Sever, T. (1988). Remote sensing and GIS analysis in large scale survey design in north Mississippi. *Southeastern Archaeology* **7:** 124–131.

Jones, J. (1996). TMAPPER! High quality map production with IDRISI vector data. *Archaeological Computing Newsletter* **45:** 5–11.

Judge, W. J., and Sebastian, L. (eds.) (1988). *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling*, U.S. Bureau of Land Management, Department of the Interior, Denver.

Kirkinen, T. (1996). Center in the wilderness area using a geographical information system (GIS) in modelling the Late Iron Age settlement in eastern Finland. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 93–100.

Kohler, T. A., and Gumerman, G. J. (1996). Beyond GIS: Populating worlds with agents. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 101–106.

Kohler, T. A., and Parker, S. C. (1986). Predictive models for archaeological resource location. In Schiffer, M. B. (ed.), *Advances in Archaeological Method and Theory, Vol. 9*, Academic Press, New York, pp. 397–452.

Kotsakis, K., Andreau, S., Vargas, A., and Papoudas, D. (1995). Reconstructing a Bronze Age site with CAD. In Huggett, J., and Ryan, N. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1994*, BAR International Series, No. 600, Oxford, pp. 181–188.

Kuna, M., and Adelsbergerová, D. (1995). Prehistoric location preferences: An application of GIS to the Vinorsky Potok project, Bohemia, the Czech Republic. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 117–132.

Kvamme, K. L. (1984). Models of prehistoric site location near Pinon Canyon, Colorado. In Condie, C. J. (ed.), *The Archaeology of Northeastern New Mexico*, New Mexico Archaeological Council, Albuquerque, pp. 347–370.

Kvamme, K. L. (1989). Geographic information systems in regional archaeological research and data management. In Schiffer, M. B. (ed.), *Archaeological Method and Theory, Vol. 1*, University of Arizona Press, Tucson, pp. 139–202.

Kvamme, K. L. (1990a). One-sample tests in regional archaeological analysis: New possibilities through computer technology. *American Antiquity* **55:** 367–381.

Kvamme, K. L. (1990b). The fundamental principles and practice of predictive archaeological modeling. In Voorrips, A. (ed.), *Mathematics and Information Science in Archaeology: A Flexible Framework*, Studies in Modern Archaeology, Vol. 3, Holos-Verlag, Bonn, Germany, pp. 257–295.

Kvamme, K. L. (1992a). Geographic information systems and archaeology. In Lock, G., and Moffett, J. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1991*, BAR International Series, No. S577, Oxford, pp. 77–84.

Kvamme, K. L. (1992b). Terrain form analysis of archaeological location through geographic information systems. In Lock, G., and Moffett, J. (eds.), *Computer Applications and Quantitative Methods in Archaeology 1991*, BAR International Series, No. S577, Oxford, pp. 127–136.

Kvamme, K. L. (1992c). A predictive site location model on the High Plains: An example with an independent test. *Plains Anthropologist* **37:** 19–40.

Kvamme, K. L. (1992). Spatial statistics and GIS: An integrated approach. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 91–103.

Kvamme, K. L. (1994). Ranter's corner—GIS graphics vs. spatial statistics: How do they fit together? *Archaeological Computing Newsletter* **38:** 1–2.

Kvamme, K. L. (1995). A view from across the water: The North American experience in archaeological GIS. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 1–14.

Kvamme, K. L. (1996a). Investigating chipping debris scatters: GIS as an analytical engine. In Maschner H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 38–71.

Kvamme, K. L. (1996b). A proton magnetometry survey at Navan Fort. *Emania* **14:** 83–88.

Kvamme, K. L. (1996c). Randomization methods for statistical inference in raster GIS contexts. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 107–114.

Kvamme, K. L. (1997). Ranter's corner—Bringing the camps together: GIS and ED. *Archaeological Computing Newsletter* **47:** 1–5.

Kvamme, K. L., and Jochim, M. A. (1989). The environmental basis of Mesolithic settlement. In Bonsall, C. (ed.), *The Mesolithic in Europe: Papers Presented at the Third International Symposium*, John Donald Publishers, Edinburgh, pp. 1–12.

Ladefoged, T. N., McLachlan, S. M., Ross, S. C. L., Sheppard, P. J., and Sutton, D. G. (1995). GIS-based image enhancement of conductivity and magnetic susceptibility data from Ureturituri Pa and Fort Resolution, New Zealand. *American Antiquity* **60:** 471–481.

Lang, L. (1994). GPS on the right trail. *Government Technology* **7:** 28–31.

Lang, N. A. R. (1993). From model to machine procurement and implementation of geographical information systems for county sites and monuments records. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 167–175.

Larsen, C. (ed.) (1992). *Sites and Monuments: National Archaeological Records*, The National Museum of Denmark, Copenhagen, pp. 185–199.

Larson, P. (1975). Trend analysis in archaeology: A preliminary study of intrasite patterning, *Norwegian Archaeological Review* **8:** 75–80.

Lave, C. A., and March, J. G. (1975). *An Introduction to Models in the Social Sciences*, Harper and Row, New York.

Limp, W. F. (1989). *The Use of Multispectral Digital Imagery in Archeological Investigations*, Research Series No. 24, Arkansas Archeological Survey, Fayetteville.

Limp, W. F. (1991). Continuous cost movement models. In Behrens, C. A., and Sever, T. L. (eds.), *Applications of Space Age Technology in Anthropology*, National Aeronautics and Space Administration, Science and Technology Laboratory, John C. Stennis Space Center, MS, pp. 237–250.

Limp, W. F. (1992). The challenge of automated systems in archaeology. *Federal Archeology Report* **5:** 1–2.

Limp, W. F. (1996). Developing methodologies in the analysis of spatially referenced data and their impacts on archaeological method and theory. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 115–126.

Limp, W. F., and Gisiger, A. (1992). Continental scale archaeology studies using GIS. *Federal Archeology Report* **5:** 3–6.

Llobera, M. (1996). Exploring the topography of mind: GIS, social space and archaeology. *Antiquity* **70:** 612–622.

Lock, G. R. (1993). GIS or CAD: What's in a name? *Archaeological Computing Newsletter* **37:** 1–2.

Lock, G. (1995). Archaeological computing, archaeological theory and moves toward contextualism. In Huggett, J., and Ryan, N. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1994*, BAR International Series, No. 600, Oxford, pp. 13–18.

Lock, G., and Harris, T. (1992). Visualizing spatial data: The importance of geographic information systems. In Reilly, P., and Rahtz, S. (eds.), *Archaeology and the Information Age: A Global Perspective*, Routledge, London, pp. 81–96.

Lock, G. R., and Harris, T. M. (1996). Danebury revisited: An English Iron Age hillfort in a digital landscape. In Aldenderfer, M., and Maschner, H. D. G. (eds.), *Anthropology, Space and Geographic Information Systems*, Oxford University Press, New York, pp. 214–240.

Madry, S. L. H. (1990). The realities of hardware. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 173–183.

Madry, S. L. H., and Crumley, C. L. (1990). An application of remote sensing and GIS in a regional archaeological settlement pattern analysis: The Arroux River Valley, Burgundy, France. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 364–380.

Madry, S. L. H., and Rakos, L. (1996). Line-of-sight and cost-surface techniques for regional research in the Arroux River Valley. In Maschner H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 104–126.

Madsen, T. (1996). GIS and Scandinavian archaeology: A tale from the real world. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 127–136.

Marble, D. F. (1984). Geographic information systems: An overview. In *Spatial Information Technologies for Remote Sensing Today and Tomorrow, Proceedings of Pecora 9*, IEEE, Silver Springs, MD, pp. 18–24.

Maschner, H. D. G. (1996a). Geographic information systems in archaeology. In Maschner, H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 1–24.

Maschner, H. D. G. (1996b). The politics of settlement choice on the Northwest coast: GIS, cognition, and coastal landscapes. In Aldenderfer, M., and Maschner, H. D. G. (eds.), *Anthropology, Space and Geographic Information Systems*, Oxford University Press, New York, pp. 175–189.

Maschner, H. D. G. (1996c). Review of *Archaeology and Geographical Information Systems: A*

European Perspective [Lock. G., and Stančič, Z. (eds.), 1995, Taylor and Francis, London]. *Geoarchaeology* **11:** 505–507.

Maschner, H. D. G., and Stein, J. (1995). Multivariate approaches to site location on the northwest coast of North America. *Antiquity* **69:** 61–73.

Massagrande, F. A. (1995). Using GIS with non-systematic survey data: The Mediterranean evidence. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 55–66.

McClung de Tapia, E., and Tapia-Recillas, H. (1996). Statistical analysis using GIS in the study of Prehispanic settlement location in the Teotihuacan region, Mexico. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 137–148.

Meffert, M. (1995). Spatial relations in Roman Iron Age settlements in the Assendelver polders, the Netherlands. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 287–300.

Middleton, R., and Winstanley, D. (1993). GIS in a landscape archaeology context. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 151–158.

Mikkelson, D. M., and Larsen, J. H. (1992). Recording archaeological sites in Norway. In Larsen, C. (ed.), *Sites and Monuments: National Archaeological Records*, The National Museum of Denmark, Copenhagen, pp. 71–80.

Miller, P. (1995). How to look good and influence people: Thoughts on the design and interpretation of an archaeological GIS. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 319–334.

Miller, P. A. (1996). Digging deep: GIS in the city. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol.* 2, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 369–376.

Murray, D. M. (1995). The management of archaeological information: A strategy. In Wilcock, J., and Lockyear, K. (eds.), *Computer Applications and Quantitative Methods in Archaeology 1993*, BAR International Series, No. 598, Oxford, pp. 83–88.

Mušič, B. (1995). On-site prospection in Slovenia: The case of Rodik. *Archaeological Computing Newsletter* **43:** 6–15.

Newman, C. (1993). The Tara survey: Interim report. In *Discovery Programme Reports 1: Project Results 1992*, Royal Irish Academy, Dublin, pp. 70–93.

Nunez, M., Vikkula, A., and Kirkinen, T. (1995). Perceiving time and space in an isostatically rising region. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 141–152.

Oppenshaw, S. (1991). A view on the GIS crisis in geography, or, using GIS to put Humty-Dumpty back together again. *Environment and Planning A* **23:** 621–628.

Oswald, A. (1996). Restoring a thirteenth century castle wall using GIS. *ARCNews* **18:** 26.

Ozawa, K., Kato, T., and Tsude, H. (1995). Detection of beacon networks between ancient hill-forts using a digital terrain model based GIS. In Huggett, J., and Ryan, N. (eds.), *Computer Applications and Quantitative Methods in Archaeology*, 1994, BAR International Series, No. 600, Oxford, pp. 157–162.

Palumbo, G. (1993). JADIS (Jordan Antiquities Database and Information System): An example of national archaeological inventory and GIS applications. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 183–188.

Parker, S. (1985). Predictive modeling of site settlement systems using multivariate logistics. In Carr, C. (ed.), *For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique, and Theory*, Westport Publishers, Kansas City, MO, pp. 173–207.

Parker, S. (1986). The role of geographic information systems in cultural resource management. In Opitz, B. K. (ed.), *Geographic Information Systems in Government, Vol. I*, A. Deepak Publishing, Hampton, VA, pp. 133–140.

Peterman, G. L. (1992). Geographic information systems: Archaeology's latest tool. *Biblical Archaeologist* **55:** 162–167.

Petrie, L., Johnson, I., Cullen, B., and Kvamme, K. L. (1995). *GIS in Archaeology: An Annotated Bibliography*, Archaeological Methods Series, No. 1, Sydney University, Sydney.

Plog, F. T., and Hill, J. N. (1971). Explaining variability in the distribution of sites. In Gumerman, G. J. (ed.), *The Distribution of Prehistoric Population Aggregates, Anthropological Reports*, No. 1, Prescott College Press, Prescott, AZ, pp. 7–36.

Potts, R., Jorstad, T., and Cole, D. (1996). The role of GIS in the interdisciplinary investigations at Olorgesailie, Kenya, a Pleistocene archaeological locality. In Aldenderfer, M., and Maschner, H. D. G. (eds.), *Anthropology, Space and Geographic Information Systems*, Oxford University Press, New York, pp. 202–213.

Preysler, J. B., and Blasco, C. (1996). Application of GIS to images and their processing: The Chiribiquete Mountains Project. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 353–358.

Raper, J., (1989). *Three Dimensional Applications in Geographic Information Systems*, Taylor and Francis, London.

Renfrew, C., and Level, E. V. (1979). Exploring dominance: Predicting polities from centers. In Renfrew, C., and Cooke, K. L. (eds.), *Transformations: Mathematical Approaches to Culture Change*, Academic Press, New York, pp. 145–167.

Reynoso, C., and Castro, D. (1994). VB-GIS 3D: A GIS specifically designed for archaeology. In Johnson, I. (ed.), *Methods in the Mountains: Proceedings of UISPP Commission IV Meeting, Mount Victoria, Australia*, Archaeological Methods Series, No. 2, Sydney University, Sydney, pp. 135–142.

Richards, J. D. (1996). Putting the site in its setting: GIS and the search for Anglo-Saxon settlement in Northumbria. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 377–386.

Robinson, H. (1993). The archaeological implications of a computerized integrated national heritage information system. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 139–150.

Romano, D. G., and Tolba, O. (1995). Remote sensing, GIS and electronic surveying: Reconstructing the city plan and landscape of Roman Corinth. In Huggett, J., and Ryan, N. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1994*, BAR International Series, No. 600, Oxford, pp. 163–174.

Roorda, I. M., and Wiemer, R., (1992a). Towards a new archaeological information system in the Netherlands. In Lock, G., and Moffett, J. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1991*, BAR International Series, No. S577, Oxford, pp. 85–88.

Roorda, I., and Wiemer, R. (1992b). The ARCHIS Project: Towards a new national archaeological record in the Netherlands. In Larsen, C. (ed.), *Sites and Monuments: National Archaeological Records*, The National Museum of Denmark, Copenhagen, pp. 117–124.

Ruggles, A. J., and Church, R. L. (1996). Spatial allocation in archaeology: An opportunity for reevaluation. In Maschner H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 147–176.

Ruggles, C. L. N., Medyckyj-Scott, D. J., and Gruffydd, A. (1993). Multiple viewshed analysis using GIS and its archaeological application: A case study in northern Mull. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 125–131.

Ruggles, C. L. N., and Medyckyj-Scott, D. J. (1996). Site location, landscape visibility, and symbolic astronomy: A Scottish case study. In Maschner, H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 127–146.

Sanz, F. Q., Preysler, J. B., and Bosqued, C. B. (1995). An application of GIS to intra-site spatial analysis: The Iberian Iron Age cemetery of El Cigarralejo (Murcia, Spain). In Huggett, J., and

Ryan, N. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1994*, BAR International Series, No. 600, Oxford, pp. 137–146.
Savage, S. H. (1990a). GIS in archaeological research. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 22–32.
Savage, S. H. (1990b). Modelling the Late Archaic social landscape. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 330–355.
Scollar, I. (1966). Computer treatment of magnetic measurements from archaeological sites. *Archaeometry* **9:** 61–71.
Scollar, I., Tabbagh, A., Hesse, A., and Herzog, I. (1990). *Archaeological Prospecting and Remote Sensing*, Cambridge University Press, Cambridge.
Sebastian, L., and Judge, J. W. (1988). Predicting the past: Correlation, explanation, and the use of archaeological models. In Judge, W. J., and Sebastian, L. (eds.), *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling*, U.S. Department of the Interior, Bureau of Land Management, Denver, pp. 1–18.
Shennan, S. (1988). *Quantifying Archaeology*, Academic Press, San Diego.
Shermer, S. J., and Tiffany, J. A. (1985). Environmental variables as factors in site location: An example from the upper Midwest. *Midcontinental Journal of Archaeology* **10:** 215–240.
Snow, D. R. (1994). Using MapInfo to map archaeological data. In Johnson, I. (ed.), *Methods in the Mountains: Proceedings of UISPP Commission IV Meeting, Mount Victoria, Australia*, Archaeological Methods Series, No. 2, Sydney University, Sydney, pp. 143–148.
Snow, D. R. (1996). GIS applications in North America. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 159–168.
Stančič, Z. (1994). Locational analysis and settlement studies with GIS. In Johnson, I. (ed.), *Methods in the Mountains: Proceedings of UISPP Commission IV Meeting, Mount Victoria, Australia*, Archaeological Methods Series, No. 2, Sydney University, Sydney, pp. 73–80.
Stančič, Z., and Gaffney, V. (1996). GIS based analysis of the population trends on the island of Brač in Central Dalmatia. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 169–184.
Stančič, Z., Dular, J., Gaffney, V., and Tecco-Hvala, S. (1995). A GIS-based analysis of later prehistoric settlement patterns in Dolenjska, Slovenia. In Wilcock, J., and Lockyear, K. (ed.), *Computer Applications and Quantitative Methods in Archaeology, 1993*, BAR International Series, No. 598, Oxford, pp. 161–164.
Star, J., and Estes, J. E. (1990). *Geographic Information Systems: An Introduction*, Prentice-Hall, Englewood Cliffs, NJ.
Stead, S. (1995). Humans and PETS in space. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 313–318.
Steele, J., Sluckin, T. J., Denholm, D. R., and Gamble, C. S. (1996). Simulating hunter-gatherer colonization of the Americas. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 223–227.
Thomas, D. H., and Bettinger, R. L. (1976). *Prehistoric Pinon Ecotone Settlements of the Upper Reese River Valley, Central Nevada*, Anthropological Papers, Vol. 53, No. 3, American Museum of Natural History, New York.
Unwin, D. (1981) *Introductory Spatial Analysis*, Methuen, London.
van Leusen, P. M. (1993). Cartographic modelling in a cell-based GIS. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 105–122.
van Leusen, P. M. (1996). GIS and location modeling in Dutch archaeology: A review of current approaches. In Maschner, H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 177–197.

Van West, C. (1994). *Modeling Prehistoric Agricultural Productivity in Southwestern Colorado: A GIS Approach*, Department of Anthropology Reports of Investigations, No. 67, Washington State University, Pullman.

Van West, C., and Kohler, T. A. (1996). A time to rend, a time to sew: New perspectives on Northern Anasazi sociopolitical development in late prehistory. In Aldenderfer, M., and Maschner, H. D. G. (eds.), *Anthropology, Space and Geographic Information Systems*, Oxford University Press, New York, pp. 107–131.

Vikkula, A. (1994). Stone Age environment and landscape changes on the eastern Finnish Lake District. In Johnson, I. (ed.), *Methods in the Mountains: Proceedings of UISPP Commission IV Meeting, Mount Victoria, Australia*, Archaeological Methods Series, No. 2, Sydney University, Sydney, pp. 91–98.

Vita-Finzi, C., and Higgs, E. S. (1970). Prehistoric economy in the Mount Carmel area of Palestine: Site catchment analysis. *Proceedings of the Prehistoric Society* **36:** 1–37.

Wansleeben, M. (1988). Applications of geographical information systems in archaeological research. In Rahtz, S. P. Q. (ed.), *Computer and Quantitative Methods in Archaeology, 1988, Vol. 2*, BAR International Series, No. 446 (ii), Oxford, pp. 435–451.

Wansleeben, M., and Verhart, L. B. M. (1995). GIS on different spatial levels and the Neolithization process in the south-eastern Netherlands. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 153–170.

Warren, R. E. (1990a). Predictive modelling in archaeology: A primer. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 90–111.

Warren, R. E. (1990b). Predictive modeling of archaeological site location: A case study in the Midwest. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 201–215.

Wheatley, D. (1993). Going over old ground: GIS, archaeological theory and the act of perception. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 133–137.

Wheatley, D. (1995a). The impact of information technology on the practice of archaeological management. In Cooper, M. A., Firth, A., Carman, J., and Wheatley, D. (eds.), *Managing Archaeology*, Routledge, London, pp. 163–174.

Wheatley, D. (1995b). Cumulative viewshed analysis: A GIS-based method for investigating intervisibility, and its archaeological application. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 171–186.

Wheatley, D. (1996). The use of GIS to understand regional variation in Earlier Neolithic Wessex. In Maschner, H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 75–103.

Wiemer, R. (1995). Another way to deal with maps in archaeological GIS. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 301–312.

Williams, I., Limp, W. F., and Briuer, F. L. (1990). Using geographic information systems and exploratory data analysis for archaeological site classification and analysis. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 239–273.

Zubrow, E. B. W. (1990a). The fantasies of GIS software. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 184–194.

Zubrow, E. B. W. (1990b). Modelling and prediction with geographic information systems: A demographic example from prehistoric and historic New York. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 307–318.

Zubrow, E. B. W. (1994). Knowledge representation and archaeology: A cognitive example using

GIS. In Renfrew, C., and Zubrow, E. B. W. (eds.), *The Ancient Mind: Elements of Cognitive Archaeology*, Cambridge University Press, Cambridge, pp. 107–118.
Zubrow, E. (1997). Clusters of death, pockets of survival: Dynamic modelling and GIS. In van der Leeuw, S., and McGlade, J. (eds.), *Time, Process and Structured Transformation in Archaeology*, Routledge, London, pp. 216–253.
Zubrow, E. B. W., and Harbaugh, J. W. (1978). Archaeological prospecting: Kriging and simulation. In Hodder, I. (ed.), *Simulation Studies in Archaeology*, Cambridge University Press, Cambridge, pp. 109–122.

BIBLIOGRAPHY OF RECENT LITERATURE

Ackerly, N. W. (1994). Analyses of historic New Mexican acequia systems using GIS technology. *Geo Info Systems* **4:** 20–21.
Aldenderfer, M., and Maschner, H. D. G. (eds.) (1996). *Anthropology, Space and Geographical Information Systems*, Oxford University Press, New York.
Allen, K. M. S. (1990). Manipulating space: A commentary on GIS applications. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 197–200.
Allen, K. M. S. (1990). Modelling early historic trade in the eastern Great Lakes using geographic information systems. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 319–329.
Allen, K. M. S., Green S. W., and Zubrow, E. B. W. (eds.) (1990). *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London.
Andresen, J. T., Masden, T., and Scollar, I. (eds.) (1993). *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA1992*, Aarhus University Press, Aarhus, Denmark.
Baena, F. J., Quesada, F., and Blasco, M. C. (1996). An application of GIS intra-site analysis to museum display. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 465–471.
Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.) (1996). *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy.
Bíro, K. T. (1996). Simple fun: Interactive computer demonstration program on the exhibition of the Szentgal-Tuzkoveshegy prehistoric industrial area. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 429–432.
Boaz, J. S., and Uleberg, E. (1995). The potential of GIS-based studies of Iron Age cultural landscapes in eastern Norway. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 249–260.
Bomba, P. E., Carstens, K., and Brown, A. K. (1993). A cartographic geographic information system for the archaeological study of Fort Jefferson, Kentucky. In *Proceedings of the 13th Annual ESRI User Conference, Palm Springs, California*, Environmental Systems Research Institute, Redlands, CA, pp. 169–181.
Califano, A. (1994). Rome links ancient cartographic data with GIS technology. *Geo Info Systems* **4:** 48–51.
Castleford, J. (1992). Archaeology, GIS, and the time dimension: An overview. In Lock, G., and Moffett, J. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1991*, BAR International Series, No. S577, Oxford, pp. 95–104.
Chittenden, B. (1990). GIS technology used in American battlefield protection program. *CRM Bulletin* **13:** 4.
Christopherson, G. L., Guertin, D. P., and Borstad, K. A. (1996). Increasing our understanding of ancient Jordan with ARC/INFO. *ARCNews* **18:** 27.
Claxton, J. B. (1995). Future enhancements to GIS: Implications for archaeological theory. In Lock,

G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 335–348.

Crumley, C. L., and Marquardt, W. H. (1990). Landscape: A unifying concept in regional analysis. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 73–79.

Dann, M. A., and Yerkes, R. W. (1994). Use of geographic information systems for the spatial analysis of Frankish settlements in the Korinthia, Greece. In Kardulias, P. N. (ed.), *Beyond the Site: Regional Studies in the Aegean Area*, University Press of America, Lanham, MD, pp. 289–311.

Doganis, T. (1996). Parthenon renovation gets a big boost with GIS. *ARCNews* **18:** 24.

Ebert, J. I. (1996). Human origins investigated with digital mapping and GIS. *ARCNews* **18:** 25.

Flyg, P., and Bodin, U. (1996). GIS-applications in Swedish archaeology. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 67–68.

Futato, E. M. (1991). GIS modelling of archaeological site locations: A low-tech approach. In Behrens, C. A., and Sever, T. L. (eds.), *Applications of Space Age Technology in Anthropology*, National Aeronautics and Space Administration, Science and Technology Laboratory, John C. Stennis Space Center, MS, pp. 95–110.

Gaffney, V., and Stančič, Z. (1991). Predicting the past: GIS and archaeology. *Geo-Information-Systeme* **4:** 27–32.

Gaffney, V., and Stančič, Z. (1992). Diodorus Siculus and the island of Hvar, Dalmatia: Testing the text with GIS. In Lock, G., and Moffett, J. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1991*, BAR International Series, No. S577, Oxford, pp. 113–123.

Gaffney, V., and Stančič, Z. (1994). GIS and historical archaeology: The case of the island of Hvar in Croatia. *Archeologia E Calcolatori* **5:** 257–268.

Gaffney, V., Stančič, Z., and Farley, J. (1993). Geographical information systems, territorial analysis and prehistoric agriculture on the island of Hvar, Dalmatia. In Fabis, M., Kuzma, I., and Markova, K. (eds.), *Actes du XIIe Congres International des Sciences Pre- et Proto-Historiques, Bratislava, 1–7 Septembre 1991*, Institut Archeologique de l'Academie Slovaque des Sciences a Nitra, Bratislava, pp. 407–415.

Gillings, M. (1996). Not drowning but waving? Re-humanizing GIS, the Tisza flood plain revisited. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 69–84.

Goodchild, M. (1996). Geographic information systems and spatial analysis in the social sciences. In Aldenderfer, M., and Maschner, H. D. G. (eds.), *Anthropology, Space and Geographical Information Systems*, Oxford University Press, New York, pp. 241–250.

Green, S. W. (1990). Sorting out settlement in southeastern Ireland: Landscape archaeology and geographic information systems. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 356–363.

Hall, N. K., and Sale, K. (1994). Where art thou? The AIATSIS rock art database and GIS project 1993. In Johnson, I. (ed.), *Methods in the Mountains: Proceedings of UISPP Commission IV Meeting, Mount Victoria, Australia*, Archaeological Methods Series, No. 2, Sydney University, Sydney, pp. 53–60.

Huggett, J. W. (1992). Integrating databases and graphics: A prelude to geographic information systems. *Archaeological Computing Newsletter* **30:** 4–7.

Jackson, J. M. (1990). Building and historic settlement database in GIS. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 274–283.

Jacobson, E., Meachan, J., and Cutting, D. (1994). Patterns on the steppe: Applying GIS to the archaeology of the Altay Mountains. *Geo Info Systems* **4:** 32–45.

Johnson, I. (1996). Desktop mapping and raster GIS: Best of both worlds? In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 85–92.

Johnson, J. K. (1990). Settlement patterns, GIS, remote sensing and the late prehistory of the Black

Prairie in east central Mississippi. In Behrens, C. A., and Sever, T. L. (eds.), *Applications of Space Age Technology in Anthropology*, National Aeronautics and Space Administration, Science and Technology Laboratory, John C. Stennis Space Center, MS, pp. 111–119.

Katsaridis, P., and Tsigourakos, P. (1993). The use of GIS in land use planning for the protection of the Delfi hinterland (Greece). In *Proceedings of the 13th Annual ESRI User Conference, Palm Springs, California*, Environmental Systems Research Institute, Redlands, CA pp. 321–327.

Knapp, A. B., and Johnson, I. (1994). Quantifying survey data from Cyprus: The use of aerial photos for field recording and GIS input. In Johnson, I. (ed.), *Methods in the Mountains: Proceedings of UISPP Commission IV Meeting, Mount Victoria, Australia*, Archaeological Methods Series, No. 2, Sydney University, Sydney, pp. 157–164.

Knoerl, J. J. (1995). Mapping history using geographic information systems. *The Public Historian* **13:** 97–108.

Krist Jr., F. J., and Brown, D. G. (1995). GIS modelling of Paleo-Indian period caribou migration and viewsheds in northeastern lower Michigan. *Photogrammetric Engineering and Remote Sensing* **60:** 1129–1137.

Kvamme, K. L. (1990). GIS algorithms and their effects on regional archaeological analysis. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 112–126.

Kvamme, K. L. (1990). Predictive cultural resource modeling at Pinon Canyon: 1984–85. In Andrefsky, W. (ed.), *An Introduction to the Archaeology of Pinon Canyon, Southeastern Colorado, Volume I: Background and Methods*, National Park Service, Rocky Mountain Regional Office, Denver, pp. 6–83.

Kvamme, K. L. (1993). Computer methods: Geographic information systems (Appendix. B). In Haas, J., and Creamer, W., *Stress and Warfare Among the Kayenta Anasazi of the Thirteenth Century A. D.*, Fieldiana Anthropology New Series, No. 21, Field Museum of Anthropology, Chicago, pp. 171–180.

Lock, G., and Stančič, Z. (eds.) (1995). *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London.

Marozas, B. A., and Zack, J. A. (1990). GIS and archaeological site location. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 165–172.

Martlew, R. (1996). The contribution of GIS to the study of landscape evolution in the Yorkshore Dales, UK. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 293–296.

Maschner, H. D. G. (ed.) (1996). *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Maschner, H. D. G. (1996). Theory, technology, and the future of geographic information systems in archaeology. In Maschner, H. D. G. (ed.), *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research*, Occasional Paper, No. 23, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 301–308.

Massagrande, F. A. (1995). A GIS approach to the study of non-systematically collected data: A case study from the Mediterranean. In Huggett, J., and Ryan, N. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1994*, BAR International Series, No. 600, Oxford, pp. 147–156.

Massagrande, F. (1996). The Romans in southwestern Spain: Total conquest or partial assimilation? Can GIS answer? In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 325–330.

Mytum, H. (1996). Intrasite patterning and the temporal dimension using GIS: The example of Kellington churchyard. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 363–367.

Nuestupny, E. (1995). Beyond GIS. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 133–140.

Ogleby, C. (1994). Geographic information systems in archaeology and anthropology: A case study from the Arawe Islands, Papua New Guinea. In Johnson, I. (ed.), *Methods in the Mountains: Proceedings of UISPP Commission IV Meeting, Mount Victoria, Australia*, Archaeological Methods Series, No. 2, Sydney University, Sydney, pp. 99–114.

Peterman, G. L. (1993). GIS and archaeology in Jordan. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA92*, Aarhus University Press, Aarhus, Denmark, pp. 189–192.

Peterson, J., and Smith, V. J. R. (1995). A GIS study of potential traces of a Roman cadastre and soil types in Romney marsh. In Wilcock, J., and Lockyear, K. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1993*, BAR International Series, No. 598, Oxford, pp. 155–158.

Phillips, J. C., and McKenzie, C. L. (1992). *Archaeology and the Geographic Analysis Support System: An Evaluation of a Soil Conservation Service Model of Archaeological Site Locations in Santa Rosa County, Florida*, Report of Investigations, No. 47, Archaeology Insitute, University of West Florida, Pensacola.

Rahtz, S. P. Q. (1992). GISsing the henge and making it cry. *Archaeological Computing Newsletter* **30:** 8–9.

Reynoso, C., (1994). VB-GIS 3D: A development report on a GIS model for archaeology. *Archaeological Computing Newsletter* **38:** 3–7.

Romano, D. G., and Tolba, O. (1996). Remote sensing and GIS in the study of Roman centuriation in the Corinthia, Greece. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol.* 2, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 457–463.

Ross, W., Dallas, A., Parker, D., and Hilder, D. W. (1995). GIS principles to an English country house: The Brodsworth Hall project. In Wilcock, J., and Lockyear, K. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1993*, BAR International Series, No. 598, Oxford, pp. 259–262.

Ruggles, C. (1992). Abstract data structures for GIS applications in archaeology. In Lock, G., and Moffett, J. (eds.), *Computer Applications and Quantitative Methods in Archaeology, 1991*, BAR International Series, No. S577, Oxford, pp. 107–112.

Saile, T., and Zimmermann, A. (1996). Cattle or crops. Applications of GIS in central Germany. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 149–158.

Smith, N. (1995). Towards a study of ancient Greek landscapes: The Perseus GIS. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 239–248.

Spikins, P. (1995). 'Vitual landscapes': GIS and lithic scatters. In Schofield, A. J. (ed.), *Lithics in Context*, Lithic Studies Society Occasional Paper, No. 5, British Museum, London, pp. 95–104.

Stine, L. F., and Stine, R. S. (1990). GIS, archaeology, and freedom of information. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 54–64.

Stine, R. S., and Decker, T. D. (1990). Archaeology, data integration and GIS. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 134–140.

Stine, R. S., and Lanter, D. P. (1990). Considerations for archaeology database design. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 80–89.

Stoddart, S., Belcher, M., and Harrison, A. (1996). L'applicazione del GIS all'Etruria meridionale. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 185–192.

van Leusen, P. M. (1995). GIS and archaeological resource management: A European agenda. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 27–42.

van Waarden, N., and Wilson B. (1994). Developing a hydrological model of the Lake Condah fish traps in western Victoria using GIS. In Johnson, I. (ed.), *Methods in the Mountains: Proceedings of UISPP Commission IV Meeting, Mount Victoria, Australia*, Archaeological Methods Series, No. 2, Sydney University, Sydney, pp. 81–90.

Verhagen, P. (1996). The use of GIS as a tool for modelling ecological change and human occupation in the Middle Aguas Valley (S. E. Spain). In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 317–324.

Verhagen, P., and Mc Glade, J. (1996). Spatialising dynamical modelling: A new opportunity for GIS. In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 193–208.

Verhagen, P., McGlade, J., Risch, R., and Gili, S. (1995). Some criteria for modelling socio-economic activities in the Bronze Age of south-east Spain. In Lock, G., and Stančič, Z. (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor and Francis, London, pp. 187–210.

Voorrips, A. (1996). Archaeological theory and GIS, any relations? In Bietti, A., Cazzella, A., Johnson, I., and Voorrips, A. (eds.), *The Colloquia of the XIII International Congress of Prehistoric and Protohistoric Sciences, Vol. 1: Theoretical and Methodological Problems*, ABACO, Forli, Italy, pp. 209–214.

Wheatley, D. (1996). Between the lines: The role of GIS-based predictive modelling in the interpretation of extensive survey data. In Kamermans, H., and Fennema, K. (eds.), *Interfacing the Past: Computer Applications and Quantitative Methods in Archaeology, CAA95, Vol. 2*, Analecta Praehistorica Leidensia, No. 28, University of Leiden, Leiden, pp. 275–292.

Williams, I., Parker, S., and Limp, W. F. (1990). The integration of GRASS, GIS, S, and regional database management: A comprehensive interactive environment for spatial analysis. In Voorrips, A., and Ottaway, B. (eds.), *New Tools from Mathematical Archaeology*, Polish Academy of Sciences, Cracow, pp. 91–106.

Winterhalder, B., and Evans, T. (1991). Preliminary GIS analysis of the agricultural landscape of Cuyo Cuyo. In Behrens, C. A., and Sever, T. L. (eds.), *Applications of Space Age Technology in Anthropology*, National Aeronautics and Space Administration, Science and Technology Laboratory, John C. Stennis Space Center, MS, pp. 195–225.

Zubrow, E. B. W. (1990). Contemplating space: A commentary on theory. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 67–72.

Zubrow, E. B. W., and Green, S. W. (1990). Coping with space: Commentary on data sources, hardware and software. In Allen, K. M. S., Green, S. W., and Zubrow, E. B. W. (eds.), *Interpreting Space: GIS and Archaeology*, Taylor and Francis, London, pp. 129–133.