Using ARC/GRID to Calculate Topographic Prominence in an Archaeological Landscape

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Abstract

Topographic prominence can be defined as the perceived difference in height between an individual and their surroundings within a defined neighborhood. Because this difference can be seen as an element of visual/political control, topographic prominence may provide clues to perceived social hierarchy and rank. This study uses ARC/GRID to discover topographic prominence in a landscape at a variety of neighborhood scales. Within these landscapes archaeological sites have been introduced to determine their relative topographic prominence. Data for this study comes from the hinterland surveys of the Madaba Plains Project at Tall al-Umayri, Jordan.

Introduction

In an archaeological context, topographic prominence can be simply defined as whether a site sticks up or sticks down; i.e., whether it was found up on top of a ridge or down in a drainage. The importance of topographic prominence is that it may offer clues about perceived social hierarchy of sites within an archaeological landscape. Marcus Llobera introduces GIS into the discussion of topographic prominence in his 2001 article. In this paper, Llobera used relative height to measure prominence. In this study an alternative to Llobera's measurement of prominence will be developed and applied to data from the region of Tall al-Umayri, Jordan. In the following paragraphs, the project region will be introduced, Llobera's method for the measurement of topographic prominence will be briefly discussed, and an alternative will be suggested and tested. Special attention will be paid to questions of social hierarchy as they relate to topographic prominence.

Data

Both archaeological and topographic data were necessary for the completion of this project. The following is a brief discussion of the data.

Archaeological Data

The Madaba Plains Project (MPP) has been involved in the archaeology of Jordan since 1968. It is a large, multidisciplinary project that has concentrated its efforts on the excavation of three regionally important sites: Tall Hisban, Tall Jalul, and Tall al-Umayri. Extensive archaeological surveys were conducted in the hinterland of each excavated site. Data for this study was taken from the Tall al-Umayri hinterland survey.

Tall al-Umayri is located just a few kilometers south and west of Amman, Jordan (lat/lon coordinates 31 52 07N, 35 53 14E – Palestine Grid coordinates 234200E, 142000N). The site covers approximately 16 acres (6.5 hectares) (Ibach 1987) and has been extensively excavated over the course of eight field seasons (1984, 1987, 1989, 1992, 1994, 1996, 1998, and 2000). Habitation at the site stretches from the Early Bronze Age through the Hellenistic period. To date, these excavations have revealed substantial occupation during the Early Bronze Age, Iron Age I, and Iron Age II. Additionally, while exposure of Middle Bronze Age material has been limited, the presence of massive MB IIC defensive structures indicates a significant presence during this period. (Herr et al. 1994, Herr et al. 1991, Younker et al. 1996).

The Umayri regional survey began in 1984 as a component of the Madaba Plains Project's excavation at Tall al-Umayri. Operating within a five-kilometer radius around Tall al-Umayri, its stated objective was "to gather data pertinent to reconstructing changes over time in patterns of food production in the hinterlands" (LaBianca 1989: 23-24). In order to achieve this goal, the survey was divided into four main emphases: a random sample survey, a judgment survey, an environmental survey, and an ethnographic survey (LaBianca 1989: 24).

Of these four surveys, the random survey and judgment survey are most important to this discussion. The random sample survey was carried out during the first three field seasons and has provided a baseline, against which many of the results from the other surveys can be measured. This survey visited 100 randomly selected survey parcels, 200 x 200 meters in size, collected pottery and recorded various environmental data in an effort to collect a representative sample of the survey region's environment, ceramics, and antiquity sites (Figure 1). The random nature of the survey was designed to accomplish two main goals: first, to force investigators into areas that might otherwise be overlooked because of access difficulty; and second, to increase the validity of various statistical analyses concerning the environmental and archaeological characteristics of the region (Christopherson 1997a, Cole 1989).

The judgment survey was intended to provide the primary archaeological component to the survey database. Employing traditional methodology, the judgment survey followed roads and wadis to examine areas thought likely to produce antiquity sites. In addition, this survey team was responsible for recording archaeological sites discovered by the other components of the hinterland survey, principally the random and environmental surveys. Finally, it should be noted that although discussed separately here, all four components of the survey were highly integrated, often traveling and recording together. In fact, most of the sites recorded by the judgment survey were actually discovered by the random sample and environmental surveys.

Through the efforts of these survey components, the Umayri regional survey recorded 139 sites over five field seasons (Figure 2). These sites ranged from small, single feature sites to mid-sized urban centers, and from the Lower Palaeolithic to the Late Islamic periods. The final publication of these sites is in its early stages but brief descriptions can be found in several preliminary reports (Boling 1989, Christopherson 1991, Christopherson 1997b, Christopherson et al. 1998, Geraty et al. 1986, Geraty et al. 1990, Geraty et al. 1991, Krug 1991, Younker 1989, Younker 1991a, Younker 1991b).

In both the random and judgment surveys, a cyclic pattern of settlement density was found (Figure 3). This pattern offered the opportunity to examine social stratification, as evidenced by topographic prominence, within the context of changing settlement density. For the purposes of this paper, data was limited to the Iron Age I, Iron Age II, Byzantine, and Umayyad periods. These four periods represent change from sparse to dense settlement (Iron Age I to Iron Age II) and from dense to sparse settlement (Byzantine to Umayyad).

Topographic Data

An extensive GIS was developed for the Umayri region. Data for hypsography, hydrography, physical, and cultural features were captured from the Jordan 1:25,000 series of topographic maps. Elevation, roads, and wadi channels were taken from the following sheets: Amman, Sheet 225/145 and Naur, Sheet 225/135 (D. Survey 1958a, D. Survey 1958b). Additionally, geology and soil maps were created in 1992 specifically for the Umayri hinterland survey by the MPP geologist, Douglas W. Schnurrenberger.

The coordinates for all environmental and archaeological data were based on the Palestine Grid and Transverse Mercator projection of the Jordan 1:25,000 series maps. The unit of measure for this coordinate system is the meter, and the point of origin is 035° 12' 43.490" E. longitude, 31° 44' 02.749" N. latitude. The coordinate grid was shifted 70251.555 meters East, and 126876.909 North. The digitized area was contained within the following coordinates: Minimum X = 228000 meters East, Maximum X = 240000 meters East, Minimum Y = 136000 meters North, Maximum Y = 148000 meters North, representing an area of 144 square kilometers. This area was gridded, with a cell size of 20 X 20 meters, creating a matrix of 600 rows and 600 columns, or 360,000 cells. Of the cells in the grid, 195,356 were contained within the five kilometer radius of the Umayri survey region. Although the raster surfaces made in this study were not confined to the survey area, all statistical analysis was.

Derived from the captured data, a variety of environmental data themes were developed in this GIS. Most important for this study was the digital elevation model (DEM). The DEM for the Umayri region was interpolated in ARC/INFO using the TOPOGRID algorithm (ESRI 1998, Hutchinson 1989). This DEM can be seen in Figure 4. A series of surfaces describing a variety of topographic measures was created from this DEM. Two of these surfaces, view potential and an exposure index were used in this study to discern topographic prominence. These will be discussed in greater detail below.

Topographic Prominence

The discussion of topographic prominence must begin with Marcus Llobera's insightful article, Building Past Landscape Perception With GIS: Understanding Topographic Prominence (Llobera 2001). Llobera clearly and persuasively lays out a case for pursuing topographic prominence as a means for understanding certain aspects of past landscape perception. Although a full discussion of Llobera's paper is not possible in this forum, some aspects must be treated before we can proceed. In the next few paragraphs this paper will briefly discuss Llobera's treatment of affordances, his description of topographic prominence, and his use of GIS to measure prominence.

For Llobera, discussion of topographic prominence begins with environmental affordances. As Gibson put it, "the affordances of the environment are what it offers the animal, … either for good or ill … It implies the complementarity of the animal and the environment" (Gibson 1986). For Llobera, this indicates that in every environment there are areas that will aid humans, or other animals, in their quest for survival, aesthetics, domination, etc., and areas that will hinder that pursuit. It is the human's prerogative to select areas that will help them achieve their goals. Detecting these affordances within a landscape can serve the archaeologist as reflections of past social structures, social change, and perhaps even processes of socialization (Llobera 2001).

One affordance identified by Llobera is topographic prominence. Depending on individual or societal goals, habitation sites are selected that are more, or less prominent within the context of local topography. As Llobera defines it, topographic prominence is the "height differential between an individual and his/her surroundings, as apprehended from the individual's point of view." (Llobera 2001) For Llobera, social hierarchy can be discovered in the relative level of topographic hierarchy found between sites.

Llobera measured topographic prominence as "the percentage of locations that lie below the individual's location … within a certain radius." (Llobera 2001) In a raster environment, this translates to the percentage of cells that lie below the target cell within a defined radius. The larger this percentage is, the higher the topographic prominence of the target cell. This is an elegantly simple measurement that is easily understood. The higher you are on the slope, the more cells in the neighborhood will be below you, and therefore the more prominent will be your position.

The main weakness with this measurement is that relative height does not necessarily translate to local prominence. For example, it is possible to be higher than most of the surrounding area but, because of local terrain, remain invisible to much, if not all of that area. A better measure of topographic prominence would take into account not just relative height but also some measure of visibility.

Measuring Topographic Prominence in the Umayri Region

Measuring prominence seems a natural avenue for GIS based analysis of archaeological data. Llobera used relative height to determine relative prominence. As discussed above, this measure by itself would not necessarily provide a complete picture of prominence. In order to more comprehensively measure model both the height and the visibility aspects of topographic prominence, this paper is proposing a combination of two terrain algorithms developed by Ken Kvamme. These algorithms use elevation data from a DEM to measure exposure and view potential.

Exposure Index

The exposure index is an algorithm designed by Kvamme to aid in the identification of cliff dwellings in the American southwest. Based on his description of the index (Kvamme calls it the Rim Index), the author wrote an AML that passed an imaginary cylinder over the DEM. The radius of the cylinder was variable but the height was set at 20 meters above the target cell. The measured volume of the cylinder provided a relative index for shelter (Kvamme 1988: 335-336, Kvamme 1990: 12, Kvamme 1992a: 26-27). For example, a site located on an exposed hilltop will increase the height of the cylinder, and in turn its volume, while a site located in a valley will decrease the height of the cylinder and its volume providing a relative index for exposure in the region (Figure 5).

Changing the size of the neighborhood by increasing the radius of the cylinder had a profound effect on the exposure index. In experiments with different neighborhood sizes, the radius was increased in steps from a single cell to 15 cells (Figure 6). With each increase in the radius there were visible changes in the index. Smaller neighborhoods tend to lend importance to individual cells while larger neighborhoods increase the importance of areas. This phenomenon is best illustrated in Figure 7, a closeup of two surfaces, one using a radius of 1 and the other of 5 meters. In this figure, the circle on both surfaces surrounds the main excavation site of Tall al-Umayri.

To compare exposure of archaeological sites at a variety of neighborhood sizes, the index values were converted to z-scores and Kolmogorov Smirnov (KS) tests were carried out. The KS is a non-parametric statistical test that measures the difference between the cumulative proportions of two samples. In Figure 8, cumulative proportions for an exposure surface with a radius of 5 cells are displayed for archaeological sites and the random sample. The KS test locates the point at which the two samples are farthest apart. (In this particular case that occurs near a z-score of 1.) It then subtr r proportion from the greater proportion and returns this number as the test statistic e at the five percent level is reached if the difference between the samples is greater than $d = \frac{1.36}{\sqrt{n}}$. Because the square root of *n* serves as the denominator, sample size greatly affects the point at which the difference between samples becomes significant. A large sample size lessens the difference necessary for significance to be reached, while a small sample increases it. In this case, with a sample of 133 archaeological sites, the difference must be greater than 0.1179 for significance at the 5% level. In fact the difference between these samples was 0.2750, indicating that exposure was a significant factor in site location strategies in the Umayri region.

Figure 8 also provides details about the type of exposure preferred by the inhabitants of the Umayri region. Because the cumulative proportion of sites is to the right of the random sample, it indicates that they preferred values higher than would be expected if the site selection process were random. That is, they were seeking areas of greater exposure when deciding on locations for their sites.

Given the visual differences between surfaces based on different neighborhood radii, it was surprising that the relative exposure of archaeological sites within these surfaces changed little. Figure 9 shows the results of a series of KS tests on exposure surfaces of increasing neighborhood size. Test statistics for this group were surprisingly similar, ranging between 0.275 and 0.315, with all of them highly significant. Further, in all cases the preference was for areas where exposure was greater than expected.

The final question with regard to exposure was whether or not there were differences from one archaeological period to another. To test this, exposure index scores, based on a 5 cell radius, were compared for archaeological sites from Iron Age I, Iron Age II, Byzantine, and Umayyad periods. KS tests and Cumulative proportion graphs revealed that the exposure index for all periods was highly significant, and that during all periods there was a preference to be located in areas of high exposure (Figure 10). These findings may indicate that topographic prominence was not restricted to elites in the Umayri region during the four periods in question.

View Potential

Because it would be possible for an archaeological site to be located in an area of relatively high exposure yet, because of local terrain, remain invisible to other sites in the vicinity, an additional topographic measure was included in the study. Kvamme's Ridge Index was used because it is a measure of view potential. The algorithm that calculates this index is designed to measure the "angle of unobstructed horizontal view from a given location" (Kvamme 1983: 28). First discussed by Brown (1979) as a way to measure view potential for Late Prehistoric sites in Kansas, this index is based on the 360 degrees of a compass. Written in C by Kvamme and George Ball to work with ARC/INFO files, this algorithm passes a local neighborhood window over the surface of a DEM. At each cell, it uses the elevation of the center, or target cell, as the vertex of an elevation contour. Extending the contour to the edge of the 3 X 3 window, it calculates the angle of this contour and writes this value into the target cell of the new raster (Figure 11a). High scores indicate hilltop and ridge locations with their wide viewing angles, low scores correspond to drainages and their reduced viewing angles, and scores around 180 are indicative of sites located mid-slope or in plains settings (Figure 11b) (Kvamme 1992b). The view potential map for the Umayri region can be seen in Figure 12. Here the dark cells are ridges with their wide viewing angles, and the light cells are drainages with their restricted view potential.

Combined Shelter/View

Merging the surfaces for exposure and view potential allows the placement archaeological sites in a combined measure of topographic prominence. To get the combined model, the two surfaces were divided in the middle and joined. To do this, the exposure surface was divided between areas with Z-scores greater than 0, and and those with less than 0, and the view potential surface into areas with scores greater than 180 and those with scores less than 180. These new surfaces were then converted to vector polygons and combined using Arc/INFO's UNION command. Based on these two measures, the polygons in the new coverage were then classified into four categories:

- High Exposure and Wide Viewing Angles
- High Exposure and Narrow Viewing Angles
- Low Exposure and Wide Viewing Angles
- Low Exposure and Narrow Viewing Angles

A map of these four categories can be seen in Figure 13. In this model areas of the greatest topographic prominence are those with high exposure and wide viewing angles, while those areas that are sheltered with narrow viewing angles would have the least topographic prominence.

The Model and Topographic Prominence in the Umayri Region

This model was used to test topographic prominence for archaeological sites in the Umayri region. Table 1 contains a summary of the four categories of topographic prominence. Placing archaeological sites within the context of this landscape, one could assume that, given a random distribution, their distribution would approximate the proportions found in Table 1. That is, that about 42% of archaeological sites would be found in areas that were sheltered with limited view potential, 28% in exposed areas with wide view angles, 23% in exposed areas with narrow view angles, and 7% in sheltered areas with wide view angles.

Table 1: Total area by exposure and view potential

Exposure and View Type	Total Area	Proportion
Exposed and Ridge	22021200	0.281810038
Exposed and Drainage	17831200	0.228189706
Sheltered and Ridge	5799600	0.074218730
Sheltered and Drainage	32490000	0.415781526

A chi-square test was used to evaluate this assumption for all four archaeological periods. The forumla for calculating chi-squre is:

$$\chi^2 = \sum_{i=1}^{4} \frac{(O_i - E_i)^2}{E_i}$$

where *O* is the observed number of archaeological sites and *E* is the expected number of archaeological sites (Hays 1988: 770). The Chi-square statistic for Iron Age I sites can be seen in Table 2. In this table, observed numbers of sites, expected numbers of sites, and chi-square scores for each of the four categories are found, along with totals for chi-squares. The two most important cells in this table are those for exposed areas with wide viewing angles, and sheltered areas with narrow viewing angles (these represent the areas of greatest topographic prominence, and the areas of least topographic prominence respectively). This table indicates that there were more Iron Age I sites in areas of high topographic prominence and fewer in areas of low topographic prominence than would be expected given a random distribution of sites. This is especially true for the areas of lowest topographic prominence. With one degree of freedom, the chi-square statistic must be greater than 3.84146 in order to be significant at the 5% level. At 3.97, the distribution of Iron Age I sites in this topographic prominence model is statistically significant. Further, this significance was created primarily by a lower than expected number of sites in areas of low topographic prominence, and higher than expected number of sites in areas of high prominence.

Table 2: Topographic Prominence for Iron Age I Sites

	Exposed	**Sheltered**	**Totals**
Ridge	Observed 11 Expected 8.17 Chi-Square 0.98	Observed 2 Expected 2.15 Chi-Square 0.01	0.99
Drainage	Observed 9 Expected 6.62 Chi-Square 0.86	Observed 7 Expected 12.06 Chi-Square 2.12	2.98
Totals	1.84	2.13	**3.97**

A similar pattern was found for each of the remaining periods of interest. Table 3 has the numbers for Iron Age II sites. In this table, there was again a shift of expected numbers from areas of low to areas of high topographic prominence, and the chi-square statistic of 9.19 was highly significant. This indicates that during this period, there was again a general trend to locate in areas of high topographic prominence.

Table 3: Topographic Prominence for Iron Age II Sites

	Exposed	**Sheltered**	**Totals**

Ridge	Observed 36 Expected 28.46 Chi-Square 2.00	Observed 9 Expected 7.50 Chi-Square 0.30	2.30
Drainage	Observed 29 Expected 23.05 Chi-Square 1.54	Observed 27 Expected 41.99 Chi-Square 5.35	6.89
Totals	3.54	5.65	**9.19**

Table 4 contains the numbers for sites from the Byzantine Period. Again the pattern was one of fewer than expected sites in areas of low prominence and more than expected in areas of high topographic prominence. The chi-square statistic, 10.95 was once again highly significant, with most of the difference found in the small number of sites found in areas of low prominence.

Table 4: Topographic Prominence for Byzantine Sites

	Exposed	**Sheltered**	**Totals**
Ridge	Observed 39 Expected 31.00 Chi-Square 2.07	Observed 12 Expected 8.16 Chi-Square 1.80	3.87
Drainage	Observed 30 Expected 25.10 Chi-Square 0.96	Observed 29 Expected 45.74 Chi-Square 6.12	7.08
Totals	3.03	7.92	**10.95**

The trend toward locating sites in areas of high prominence continued during the Umayyad period. In Table 5, a lower than expected number of sites were found in areas of low topographic prominence, and a higher than expected number of sites were found in areas of high topographic prominence. The chi-square statistic was once again significant at the 5% level.

Table 5: Topographic Prominence for Iron Umayyad Sites

	Exposed	**Sheltered**	**Totals**

Ridge	Observed 17 Expected 12.12 Chi-Square 1.97	Observed 4 Expected 3.19 Chi-Square 0.20	2.17
Drainage	Observed 10 Expected 9.81 Chi-Square 0.00	Observed 12 Expected 17.88 Chi-Square 1.93	1.93
Totals	1.97	2.13	**4.10**

These tables leave a very clear picture of settlement trends in the Umayri region. There was a marked preference for areas of high topographic prominence, at the expense of areas of low topographic prominence. The chi-square statistic for each of the four periods examined were significant at the 5% level. During the Iron Age I, Iron Age II, and Byzantine periods, the bulk of the statistic was supplied by the fewer than expected number of sites in areas of low topographic prominence. During the Umayyad period, this shifted slightly with the statistic distributed more-or-less evenly between more than expected sites in areas of high prominence and less than expected sites in areas of low prominence.

Although these trends are clear, their meaning is less clear. When this study was undertaken, it was expected that the results would lead in the opposite direction. That is, that there would be fewer sites in areas of high topographic prominence and more in areas of low topographic prominence. This was based on two assumptions: first, that topographic prominence was related to social hierarchy; and second, that there were a smaller number of elites controlling a larger number of non-elites.

Of the possible explanations for these unexpected results, four seem most plausible:

- The model used did not adequately measure topographic prominence
- The sites used in this study were not representative of the periods in question
- The social structure of the Umayri region was non-hierarchical
- Topographic prominence is not a good measure of social hierarchy in the Umayri region

Of these, the first seems unlikely to explain the results of the study. Although the combination of exposure and view potential discussed here do not provide a perfect measure of topographic prominence, it seems that together they do explain enough to provide a strong measure of prominence.

More likely is whether or not the sites used provide a representative sample of sites from the study area. The survey methodology employed a random sampling strategy to provide a representative sample, but there were factors beyond the control of the researchers and any methodology they might have employed. Most importantly, the introduction of mechanized agriculture in the area has forever changed the face of the region. Because mechanized equipment is most productive in large fields, a premium has been placed on field size. Manmade impediments to large fields are routinely bulldozed, destroying evidence of past and present culture in the process. This may mean that numbers of sites in areas where fields remain, sheletered areas, were under represented in the archaeological database, while areas on slopes and ridges, where fieilds are too small to allow mechanized agriculture, unjustly dominate the data set.

The question about whether or not the results indicate a more egalitarian society than had been expected is the most difficult to answer. The evidence shown here is certainly suggestive of this position, but there are other data that seem to contradict it. Most notably there are a few very large, heavily fortified sites in the region; Tall al-Umayri and Tall Jawa during the Iron Age, and Tall Umayri East and Umayri Survey Site 57 during the Byzantine and Umayyad periods. These sites dominate the landscape in ways that are clear to researchers in the area, yet they may not be the most topographically prominent locations. This is especially true of Tall al-Umayri which is lower than any of the surrounding hills. For these sites, their large size, their control of water and transportation resources, and their heavy fortifications are better indicators of their domination of the region than is topographic prominence. While this speaks to a clear hierarchy of the largest sites over the rest of the sites in the region, it does not rule out a certain egalitarianism among the remaining sites.

Finally, it may be that topographic prominence is not a good measure of social hierarchy in the Umayri region. As noted above, the largest sites in the area clearly represent a different social level than the smaller sites, but this hierarchy is demonstrated by their size and by their control of resources and not necessarily by their position in local topography. Hierarchies among smaller sites are less clear. It is nearly impossible to differentiate size in a meaningful way for these sites, and it may not be possible to establish social position for them based on control of resources.

The evidence suggests that there was a simple social hierarchy in the Umayri region that is partially explained by topographic prominence. The region was dominated by large sites during each period examined, with the remaining sites interacting in an egalitarian way. The importance of the large sites was demonstrated by size, fortifications, and control of the water and communication resources. The difference between these sites and the rest of the material culture in the region was so great that differences between the remaining sites seem relatively insignificant. A high proportion of them chose to settle in areas of topographic prominence at the expense of the areas of lowest prominence. This preference for topographic prominence indicates a preference for this affordance, as well as an egalitarian approach to settlement patterns among the smaller sites in the region.

Conclusions

There are several conclusions that can be drawn from this exercise. First, it is possible to use GIS to measure topographic prominence. Second, these measures can be as simple, or as sophisticated as the user wants them to be. Third, the application of exposure and view potential to the data from the Umayri regional survey showed a statistically significant preference for areas that had both high exposure and high view potential, and a clear desire to avoid areas of low exposure and low view potential. Fourth, the results of this study indicate a simple hierarchy at work in the Umayri region. Although the region was dominated by large sites, smaller sites existed in a relatively egalitarian social structure.

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References Cited

Boling, R. G. 1989. "Site Survey in the el-Umeiri Region," in *Madaba Plains Project 1: The 1984 Season at Tell el-Umeiri and Vicinity and Subsequent Studies*. Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, and R. W. Younker, pp. 98-188. Berrien Springs, Michigan: Andrews University/Institute of Archaeology.

Brown, K. L. 1979. Late Prehistoric Settlement Patterns in Southwestern Kansas. *Plains Anthropologist* 43:482-486.

Christopherson, G. L. 1991. "Limekilns from the Regional Survey," in *Madaba Plains Project 2: The 1987 Season at Tell el-Umeiri and Vicinity and Subsequent Studies*. Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, and R. W. Younker, pp. 343-352. Berrien Springs, Michigan: Andrews University/ Institute of Archaeology.

—. 1997a. "The 1989 Random Square Survey in the Tall al-Umayri Region," in *Madaba Plains Project 3: The 1989 Season at Tell el-Umeiri and Vicinity and Subsequent* Studies. Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, R. W. Younker, and D. R. Clark, pp. 250-290. Berrien Springs, Michigan: Andrews University/Institute of Archaeology.

—. 1997b. "Madaba Plains Project: Regional Survey Sites, 1989," in *Madaba Plains Project 3: The 1989 Season at Tell el-Umeiri and Vicinity and Subsequent Studies*. Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, R. W. Younker, and D. R. Clark, pp. 291-302. Berrien Springs, Michigan: Andrews University/Institute of Archaeology.

Christopherson, G. L., R. G. Boling, J. A. Cole, D. C. Hopkins, G. L. Mattingly, D. W. Schnurrenberger, and R. W. Younker. 1998. "Summary Descriptions of Archaeological Sites from the Survey at Tall al-Umayri, Jordan." http://www.casa.arizona.edu/MPP/mpp_pub

Cole, J. A. 1989. "Random Square Survey in the el-Umeiri Region," in *Madaba Plains Project 1: The 1984 Season at Tell el-Umeiri and Vicinity and Subsequent Studies.* Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, and R. W. Younker, pp. 51-97. Berrien Springs, Michigan: Andrews University/ Institute of Archaeology.

D. Survey. 1958a. "Amman," *Series K 835, Sheet 225/145,* Edition 3 edition. Amman, Jordan: War Office and Air Ministry.

—. 1958b. "Naur," *Series K 835, Sheet 225/135,* Edition 2 edition. Amman, Jordan: War Office and Air Ministry.

ESRI. 1998. "ARC/INFO," 7.2.1 edition. Redlands, CA: Environmental Systems Research Institute.

Geraty, L. T., L. G. Herr, Ø. S. LaBianca, J. R. Battenfield, R. G. Boling, D. R. Clark, J. I. Lawlor, L. A. Mitchel, and R. W. Younker. 1986. Madaba Plains Project: A Preliminary Report of the 1984 Season at Tell el-Umeiri and Vicinity. *Bulletin of the American Schools of Oriental Research, Supplement* 24:117-144.

Geraty, L. T., L. G. Herr, Ø. S. LaBianca, J. R. Battenfield, G. L. Christopherson, D. R. Clark, J. A. Cole, P. M. Daviau, L. E. Hubbard, J. I. Lawlor, R. Low, and R. W. Younker. 1990. Madaba Plains Project: A Preliminary Report of the 1987 Season at Tell El-Umeiri and Vicinity. *Bulletin of the American Schools of Oriental Research, Supplement* 26:59-88.

Geraty, L. T., L. G. Herr, Ø. S. LaBianca, and R. W. Younker. 1991. "An Overview of the 1987 Season of Excavation and Survey in the Madaba Plains," in *Madaba Plains Project 2: The 1987 Season at Tell el-Umeiri and Vicinity and Subsequent Studies.* Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, and R. W. Younker, pp. 3-7. Berrien Springs, Michigan: Andrews University/Institute of Archaeology.

Gibson, J. J. 1986. *The Ecological Approach to Visual Perception.* New Jersey: Lawrence Erlbaum Associates Inc.

Hays, W. L. 1988. *Statistics,* Fourth edition. New York: Harcourt Brace Jovanovich College Publishers.

Herr, L. G., L. T. Geraty, O. S. LaBianca, and R. W. Younker. 1994. Madaba Plains Project: The 1992 Excavations at Tell el-Umeiri and Vicinity. *Annual of the Department of Antiquity of Jordan* XXXVIII:147-172.

Herr, L. G., L. T. Geraty, Ø. S. LaBianca, and R. W. Younker. Editors. 1991. *Madaba Plains Project: The 1987 Season at Tell el-Umeiri and Vicinity and Subsequent Studies. Vol. 2*. Berrien Springs, Michigan: Andrews University Press.

Hutchinson, M. F. 1989. A New Procedure for Gridding Elevation and Stream Line Data with Automatic Removal of Spurious Pits. *Journal of Hydrology* 106:211-232.

Ibach, R. D. 1987. *Archaeological Survey of the Hesban Region: Catalogue of Sites and Characterization of Periods. Vol. 5*. Hesban. Berrien Springs, Michigan: Andrews University/Institute of Archaeology.

Krug, H. P. 1991. "The Necropolis at Tell el-Umeiri (East)," in *Madaba Plains Project 2: The 1987 Season at Tell el-Umeiri and Vicinity and Subsequent Studies*. Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, and R. W. Younker, pp. 356-369. Berrien Springs, Michigan: Andrews University/Institute of Archaeology.

Kvamme, K. L. 1983. Computer Processing Techniques for Regional Modeling of Archaeological Site Locations. *Advances in Computer Archaeology* 1:26-52.

—. 1988. "Development and Testing of Quantitative Models," in *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling*. Edited by W. J. Judge and L. Sebastian, pp. 325-428. Washington, D. C.: U.S. Government Printing Office.

—. 1990. "Terrain Pac," 1.6 edition. Tucson: Laboratory of GIS & Spatial Analysis Arizona State Museum.

—. 1992a. A Predictive Site Location Model on the High Plains: An Example with an Independent Test. *Plains Anthropologist* 37:19-50.

—. 1992b. "Terrain Form Analysis of Archaeological Location Through Geographic Information Systems," in *Computer Applications and Quantitative Methods in Archaeology 1991*, BAR International Series. Edited by G. Lock and J. Moffett, pp. 127-136. Oxford: TEMPVS REPARATVM Archaeological and Historical Associates Limited.

LaBianca, Ø. S. 1989. "Introduction to the Hinterland Survey," in Madaba Plains Project 1: *The 1984 Season at Tell el-Umeiri and Vicinity and Subsequent Studies*. Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, and R. W. Younker, pp. 23-26. Berrien Springs, Michigan: Andrews University/Institute of Archaeology.

Llobera, M. 2001. Building Past Landscape Perception With GIS: Understanding Topographic Prominence. *Journal of Archaeological Science* 28:1005-1014.

Younker, R. W. 1989. "Towers in the Region Surrounding Tell Umeiri," in Madaba Plains Project 1: *The 1984 Season at Tell el-Umeiri and Vicinity and Subsequent Studies.* Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, and R. W. Younker, pp. 195-198. Berrien Springs, Michigan: Andrews University/ Institute of Archaeology.

—. 1991a. "Architectural Remains from the Hinterland Survey," in *Madaba Plains Project 2: The 1987 Season at Tell el-Umeiri and Vicinity and Subsequent Studies.* Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, and R. W. Younker, pp. 335-342. Berrien Springs, Michigan: Andrews University/Institute of Archaeology.

—. 1991b. "The Judgment Survey," in *Madaba Plains Project 2: The 1987 Season at Tell el-Umeiri and Vicinity and Subsequent Studies.* Edited by L. T. Geraty, L. G. Herr, Ø. S. LaBianca, and R. W. Younker, pp. 269-334. Berrien Springs, Michigan: Andrews University/Institute of Archaeology.

Younker, R. W., L. T. Geraty, L. G. Herr, O. LaBianca, and D. Clark. 1996. Preliminary Report of the 1994 Season of the Madaba Plains Project: Regional Survey, Tall Al-Umayri, and Tall Jalul Excavations. *Andrews University Seminary Studies* 34:65-92.

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