13 PREDICTING LATE CLASSIC MAYA SETTLEMENT PATTERNS

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At El Pilar, the Belize River Archaeological Settlement Survey investigates the significance of agricultural resources to the Maya settlement and land use patterns in the Late Classic using the analytic capabilities of geographic information systems (GIS) and the recently developed UCSB Maya Forest GIS (ADL 2005). The data have allowed the application of weights-of-evidence statistical techniques to explore the Maya settlement patterns based on known archaeological sites.

Introduction

At the peak of the Maya civilization, between 600 and 900 AD, the population density of the greater Peten region of Northeastern Guatemala and Western Belize has been estimated to be up to nine times that of today with densities speculated to be 1000 persons per sq km and growth rates up to 2.5% per annum. A vast and complex system of "urban" centers developed that included the huge city of Tikal at one end to the continuum of settlement down to thousands of household farms with isolated buildings interspersed across the landscape. Today, our incomplete record focuses on only a fraction of the Maya settlements that have been mapped and analyzed. This record provides a base for understanding Maya patterns of land use and based on this record, we apply research methods that use the data, and combine the power of GIS and statistical modeling to predict the distribution and number of Maya settlements from the subset of known sites from the Belize River Archaeological Settlement Survey. Our modeling exercise allows us to test the model in the field, to evaluate environmental constraints on Maya settlement, and to create a map showing those regions worth conserving with numerous Maya settlements.

The ancient Maya were an agrarian society with a well-documented development process that transformed the Maya forest into a sustained human landscape (Beach 1998; Culbert 1998; Dunning 1996; Fedick 1996, 1989; Flannery 1982; Harrison and Turner 1978; McAnany 1995; Miles 1957; Pope et al. 1996; Rice 1978; Sanders 1962, 1978; Turner 1993; Voorhies 1998). Yet while the evolution of the ancient Maya is renowned, there is considerable speculation on the nature of their subsistence and settlement distribution (Chase 1987; Ford 1991; Haviland 1972; Rice 1991; Turner 1990; Tourtellot 1990; Dunning et al. 2002). Data on settlement distribution, civic center locations, and the importance of natural and cultural influences fuel the debates on the population for the Maya area. We have found that these debates have ignored the relationship between the spatial distributions of Maya settlements and interaction with the environment that controlled aspects of daily life. We investigate the significance of agricultural resources to the Maya settlement and land use patterns in the Late Classic using the analytic capabilities of geographic information systems (GIS) and the recently developed UCSB Maya Forest GIS (ADL 2005). The data have allowed the application of weights-of-evidence statistical techniques to explore the Maya settlement

Research Reports in Belizean Archaeology, Vol. 3, 2006, pp. 193-212 .

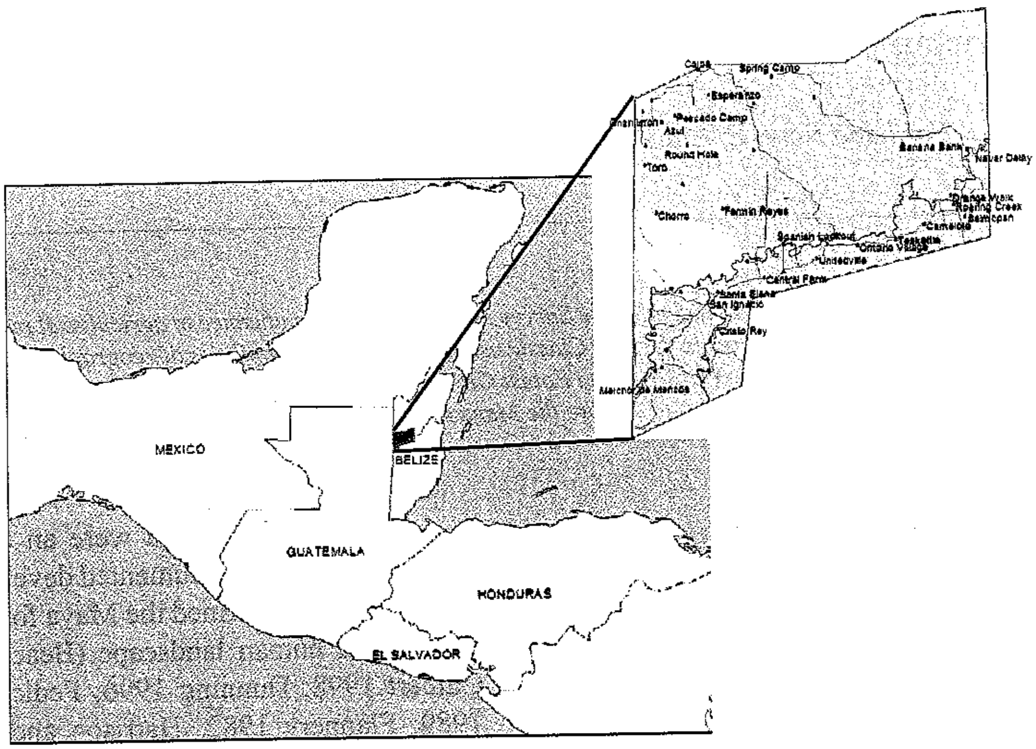

Figure 1: The location of the Belize River Area

patterns based on known archaeological sites.

Research on the Maya has produced a large corpus of information on Maya settlement and interpretations of patterns founded on focused surveys around the region (e.g., Bullard 1960; Willey 1965; Puleston 1973; Rice 1976; Ashmore 1981; Ford 1986; Fedick 1988; Webster 1988; De Montmillion 1989; McAnany 1995; Pyburn 1990; Smyth 1995; Tourtellot 1996). Settlements identified in these studies have demonstrated that intensive occupations were strongly influenced, if not fully determined by, geographic factors. It is widely acknowledged that settlement densities were high in the well-drained areas of the region and that distributions are related to Maya farming choices, suggesting a wide diversity in agricultural pursuits. (Adams et al. 1980; Coultas et al. 1994) demonstrated that intensive occupations were strongly influenced, if not fully determined by, geographic factors. It is widely acknowledged that settlement densities were high in the well-drained areas of the region and that distributions are related to Maya farming choices, suggesting a wide diversity in agricultural pursuits (Adams et al. 1980; Coultas el al. 1994; Cowgill 1962; Dunning 1992, 1994; Fedick 1989, 1994; Fedick and Ford 1990; Gliessman 1983 Harrison 1990; Mazzarelli 1976; Miksecek 1991; Pohl 1990; Sanders; Voorhies 1982). These data have been used to measure settlement densities and as a proxy for population and land use.

On the low end, population estimates for the ancient Maya ranges from 3 to 9 times greater than contemporary densities of 10-25 persons per sq km (see Culbert and Rice 1990). Suggested densities for major centers such as Tikal and Caracol have been set at c. 1000-2000 people per sq km (Culbert and Rice 1990). Further, calculations of annual growth rates have been suggested to be as great as 2.5% (cf. Adams1996; Chase and Chase 1995) similar to the fastest growing nations of Africa today where populations double every 20-30 years (Population Reference Bureau; UK Government). These numbers do not correspond to comparable pre-industrial settings and are greater than modern Japan, China and India (Boserup 1981).

It is universally acknowledged that the archaeological record is incomplete. While there are many reasons for this to be true, the foremost among them are: archaeology's bias toward research on the largest settlements; the difficulty of exploring the isolated settlement sites of largely forested region; and the lesser likelihood of survival of smaller settlements. If we wish to interpolate the whole patterns from our partial foundation, we need to consider the potential of statistical probabilistic spatial modeling. We initiate a test of the predictive model for the patterns of Maya settlement using the GIS at one geographic scale: the local 1:50,000 scale (Figure 1). We use the weights-of-evidence method to convert maps for the examined area into probabilities of settlement using known archeological sites. Field data were collected to validate the model.

The Geography of the Maya Forest

The Maya forest region is characterized by rolling limestone ridges (Turner 1978) covered by a deciduous hardwood forest. This verdant jungle thrives on an annual rainfall of 1000 to 3000 mm that falls mainly from June to January. The dry-season runs from January to June. Activities today are impacted by this wet/dry seasonal deluge and drought sequence, as they were in the Maya prehistory (Ford 1986, 1996; Fedick and Ford 1990; Lucero 2002; Haberland 1983; Rice 1993; Scarborough 1998). Today the area remains mostly forested, including the Maya Biosphere Reserve, but both slash-and-burn and commercial farming are pushing the development frontier inland and into the margins of the protected areas. About 85% (30,000 km²) of the Peten of Guatemala was, until recently, covered with semi-deciduous subtropical moist forest of which less than 50% now remains. Land clearing often reveals the location of archeological sites, and leads to their destruction by erosion, looting, and over plowing. While the larger sites are developed for tourism, and some rank among the greatest existing views of the ancient world, the impact of ecotourism and conservation have been slight in comparison to the agricultural extensions.

Mapping of archaeological sites is incomplete, and varies by country, yet a surprising amount of GIS data can be accumulated from existing sources and surveying agencies. What is clear is that during the Late Classic Period (AD 600-900), the number of inhabitants of the region as a whole was greater than that of today, with no difference in resources or climate. The settlement and land use pattern, however, was far from uniform over the landscape. What are the underlying associations creating the distribution?

A composite mosaic of regional land resources underwrites the foundation of Late Classic Period settlement distribution and intensity in the Maya forest. Settlement densities were the highest in the well-drained ridges across the region (Fedick 1989, 1992; Fedick and Ford 1990; Ford 1996, 1991; Puleston 1973; Rice 1976 see Bullard 1960, 1964). Ridge lands are concentrated in the interior (Turner 1978) and are characterized by shallow, fertile, mollisol soils of excellent quality (Dunning 1996; Fedick 1988, 1989, 1995), representing only 1% of the world's tropics yet up to 50% of the Maya forest. These soils are superior for hand cultivation methods but are inappropriate for contemporary industrial methods (Jenkins et al. 1976), which relate to the conservation risks in the region today. Thus today's most productive farming areas are almost a spatial compliment of the Maya's.

The well-drained soil zones preferred

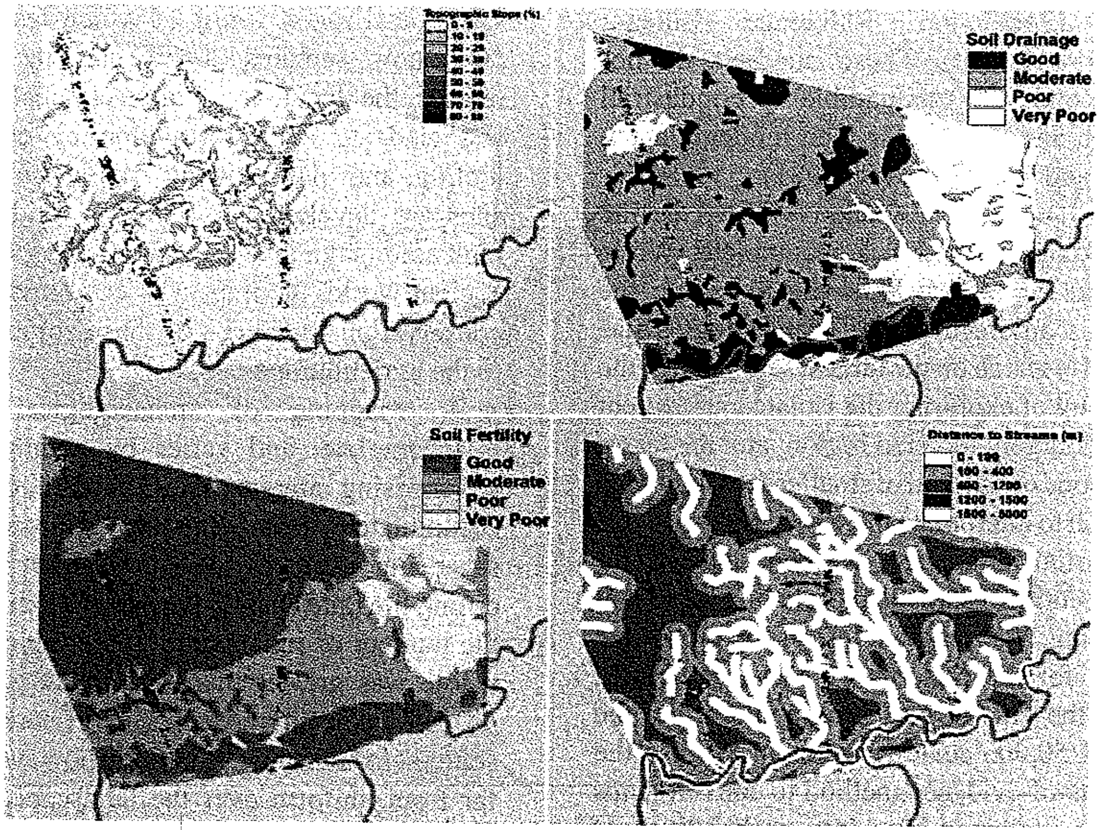

Figure 2: Geographic evidence for the initial predictive model test

for Maya settlement are unevenly distributed across the region, resulting in dispersed settlement patterns (Ford 1986; Ford 1991a, (Culbert and Rice 1990; Sanders 1981; see also Freidel 1981). There is a distinct relationship between the availability of well-drained ridges, settlement density, and the regional Maya hierarchy (Fedick and Ford 1990; Ford 1994, 1996, 1998). This is evident in the local settlement around El Pilar, where extensive field work and settlement surveys have taken place (Fedick 1988; Ford et al. 2000, 2001; Kamp and Whitacre 2002).

There is ample evidence that the greater Peten area around Tikal dominated the region in the Late Classic Period, AD 600-900 (Coe 1965; Culbert et al. 1990; Fedick and Ford 1990; Ford 1986, 1990; Martin and Grube 1995; Haviland 1972; Mathews 1985; 1991; Marcus 1993, Jones 1991; Chase and Chase 1992; Culbert 1991; Schele and Mathews 1991). During this time period, Maya settlement expansion and construction was at its maximum (Abrams 1994; Andrews 1977; Wernecke 1994). Yet Maya cites do not fit traditional notions of urbanism (Ashmore 1991; Bacon 1976; Duncan 1987; Graham 1996; Hardoy 1964, 1968; Haviland 1969; Kubler 1958; Marcus 1983; Sanders and Webster 1988; Wilford 2000), suggesting a value for "green space" that would allow for a more forested landscape (Graham 2003). Even visual metaphors expressed values they placed on nature (Peterson 1983, 1990, Towsend 1992). Jaguars (Benson 1997; Houston and Stuart 1989; Saunders 1989), three species of monkey including the Capuchin, now locally extinct (Baker 1992), and cacao (Peterson 1990) figures prominently in Maya art and iconography. The presence and pervasiveness of these animals, as well as a myriad of water loving creatures (Solari 2002) have habitat implications for the Maya forest in ancient times.

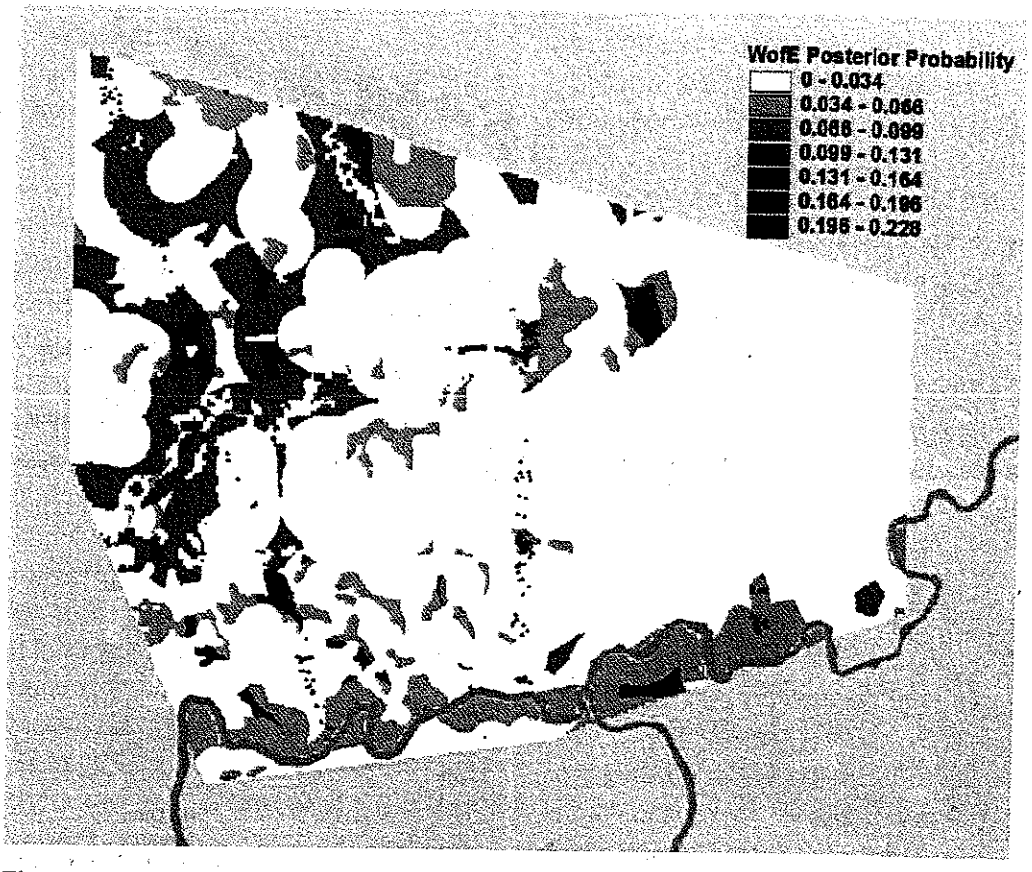

Figure 3: The BRASS area predictive model

Many scholars focus on the dramatic Classic Maya and the search for the causes of the collapse has generated a substantial literature (e.g., Culbert 1973, 1988; Culbert and Rice 1990; Dunning et al., 2002 Redman 1999). Regardless of the causes, the evolution of social complexity of the Maya were founded in gradual rise in population and concomitant land use intensification, including farming of marginal land (cf. Fletcher 1995; Boserup 1965, 1981; Cohen 1977; Stone 1996). Early investments in settlement development also endured over time. This centralization process integrated the populations over a span of more than 1700 years, based on the development and management of the assets of the Maya forest (Fedick 1996; Ford 1990, 1998; Ford and Rose 1995; Graham 1987; Sanders 1977; Pyburn 1996; McAnany 1989). Environmental dimensions constrained subsistence strategies and cultural developments mediated those constraints (Fletcher 1995). The result was clearly one of agricultural diversity to sustain the evidence of steady growth of Maya civilization, and reflecting considerable adaptation to the environment, including the development of robust strategies to survive periods of disturbance, such as hurricanes and drought.

Throughout the entire Maya sequence, there are a series of environmental factors that have been identified and interpreted through geological, paleoecological, tephrochonological, archaeological, and historical sources (e.g. Deveey et al 1979; Andrews and Hammond 1990; Espindola et al 2000; Beach 1998; Jones 1998; Schwartz 1990). For example, volcanic eruptions and intensity of volcanic activity in Mesoamerica is of particular interest in the evaluation of environmental inputs as local impacts (Sheets 1992) and ability to distribute large amounts of volcanic ash to stratospheric levels (See

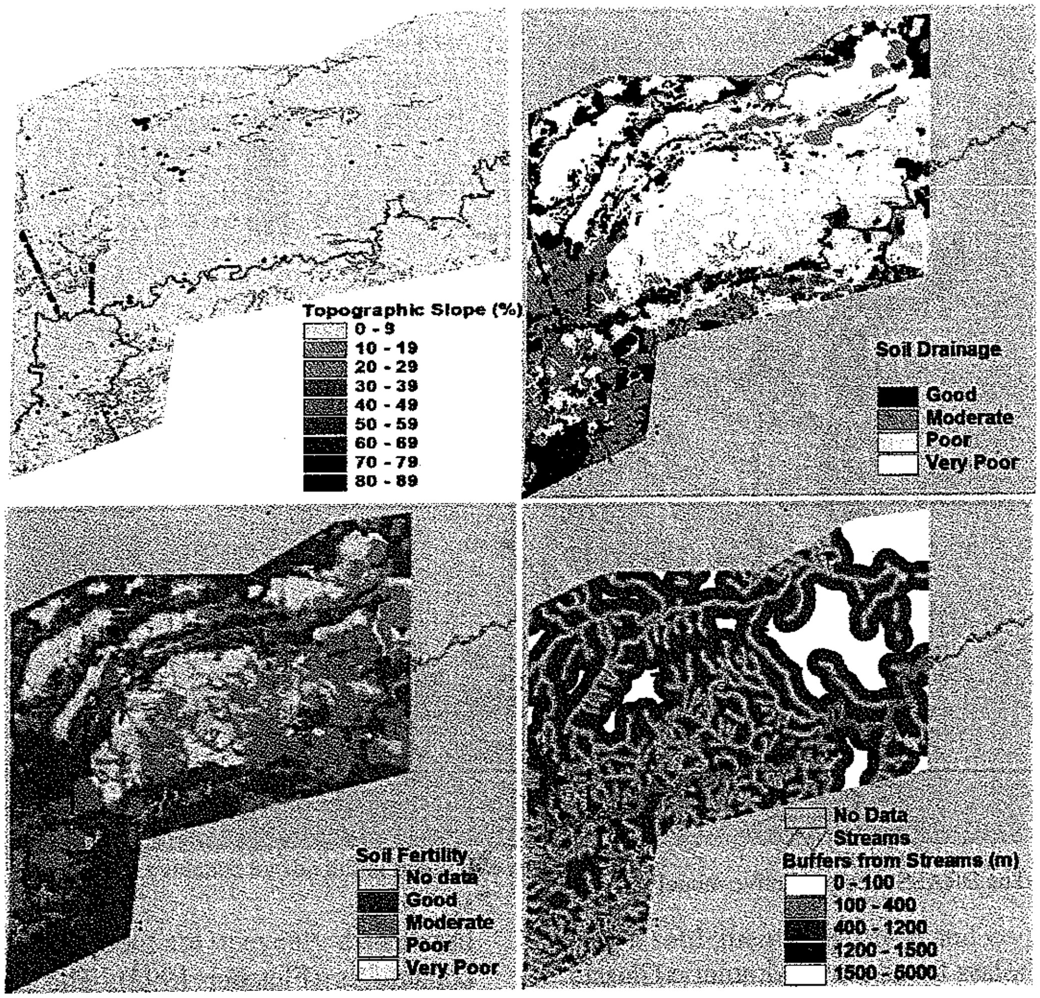

Figure 4: the evidential geographic themes for the great Belize River area

Drexler et al 1980; Espindola et al. 2000; Rose et al. 1999; Sarna et al. 1981) have distinct impacts (Ford and Glicken 1987, Ford and Rose 1995; Voorhies and Thomassion 1979), particularly in the Late Classic Period.

It appears that regional settlement distribution and density are related to land use intensity through 900 AD (see Fletcher 1995; Boserup 1965, 1981; Stone 1996; Turner 1990; Johnson and Earle 1987). Regional land use patterns hold constant at the local level, as seen in the Belize River area around El Pilar (Fedick 1988, 1989), yet have not been rigorously tested. The influence of subsistence and relative impact of cultural dimensions should be most pronounced at the local level, yet testable data at those scales are scant (see Fedick 1989). Despite the evidence of high settlement densities in the past that would be based on a long sustained land use strategy, little effort has been made to identify the balance that was attained by the ancient Maya pattern. Instead, modern industrial strategies are proposed that bear no resemblance to the past and can be seen as destructive short-term trajectory in process (Sever 1999; Turner 1990). The success of the past strategies, the needs of contemporary local populations, and the conservation demands underscore the imperative to understand the past success of Maya agriculture.

Weights-of-Evidence Analysis

The premise of our model is that the unknown map of Late Classic Maya settlement distribution consists of a set of unknown locations that are a subset of known locations where archeological surveys have located settlements. While the actual distribution cannot be known, it can be modeled probabilistically. The settlement distribution is assumed to spatially reflect mapped distributions of major environmental features. Among these are topographic slope, soil fertility, soil drainage, and proximity to water bodies. These factors each contribute independently to the location of all settlements, but in different amounts. These amounts, or weights, are the basis for the use of Weights of Evidence (WofE) analysis (Monts-Homkey 2000; Ford and Clarke 2001, Raines 2002; Sijean 2003; Monthus 2004). *WofE* origins are in mining geology (Bonham Carter 1999). The essential tools have been integrated into a GIS software package, ESRI's ArcView 3.2 (Kemp et al. 1999; Raines et al. 2000), and extended into a broader analysis package called ArcSDM.

WofE analysis follows six steps: (1) select known points of some feature such as farming sites that are to be modeled; (2) select thematic maps that contribute to the explanation of a distribution; (3) using the correlation analysis tools of *WofE*, convert selected map layers to binary or categorical form; (4) test for conditional independence comparing prior and posterior probabilities by class combinations, eliminating those maps which do not contribute explanatory power; (5) create a set of weights to use for each layer using Bayesian methods; and (6) develop posterior probability and the associated uncertainty maps using the weighted layers (Bonham-Carter 1994; Raines 1999). The probabilities can then be used as environmental weights in a settlement simulation.

Any model is only as good as its ability: (1) to be calibrated and validated to reflect past and existing data; (2) to summarize and simplify a real system so as to allow experiments and test hypotheses; (3) to allow aggregate investigations that would not be possible by testing parts in isolation; and (4) to be transportable. Our *WofE* model is designed to allow us to predict where to expect and not expect Maya settlements, allowing an independent means of validation. The model allows us to see the relative importance of environmental factors in Maya settlement location choices. It also allows cross scale comparison of the weights. While the actual application is not directly transportable since the weights are derived for each case separately, the approach is applicable universally and the posterior probability layer can be input into further models.

In practical terms, each result map is converted into two or more categories. Of the numerous soils classes on the ODA survey of the Belize Valley (Jenkin et al. 1976), for example, each was condensed into characteristics of drainage and fertility weighting of good, moderate, poor and very poor, for four categories. The number of categories for a more continuous variable, such as percent slope, can be determined using the software and some simple measures. *WofE* then combines layers and categories spatially and determines which points in the evidential theme (in our case, archeological sites) fell inside and outside of the regions on the map. The weights are computed both as layer/class contributors to a distribution and the opposite, i.e. they "repel" the evidential theme. Positive weights ($W+$) reflect the possibility of the presence of sites if the class is present. If the positive weight is positive ($W+>0$), in the presence of the class or theme, we will find more sites than chance would determine. If the positive weight is negative ($W+<0$), then presence of the class or theme, means fewer sites than what the chance would determine. If $W+$ is equal to zero, the class does not influence the location of, it is not an evidential class, and should be excluded from the model. Negative weights ($W-$) are the complement: if the negative weight is

Theme	Scale and Extent	Map Source	Resolution	Classification	Transform
Soil Fertility	Belize River Valley	Digitized paper map-Jenkin et al. 1976	1:50,000 vector	4 classes	4 classes
Soil Drainage Capability	Belize River Valley	Digitized paper map-Jenkins et al. 1976	1:50,000	4 classes	4 classes
Topography	Belize River Valley	Paper official topo 40 meter Belize data	1:50,000vector	40 meter contours	DEM
Rivers and Streams	Belize River Valley	Paper official topo 40 meter Belize data	1:50,000 vector	Perennial and Intermittent streams	Buffers 400m
Lakes and Water Bodies	Belize River Valley	Paper official topo 40 meter	1:50,000vector	all	Buffers 400m
Archaeological Sites	Site	BRASS surveys	1:2000 vector	Major/minor, center, house sites Inconsistent nomenclature	1 class

Table 1. GIS Data employed in the Predictive Modeling of Ancient Maya Settlement

negative (*W-<0*), the class is a good negative indicator while if (*W->0*), that would expect that the absence of the class or theme, we will find more sites than what the chance would suggest. Contrast is the difference between the positive and the negative weights (C = W+-W -) and is a measurement of the correlation between a particular theme and the training points, in our case the known archeological sites. If contrast for a theme is high, then that theme in general is a good predictor. Weights are log ratios of conditional probabilities.

The *WofE* software allows computation of a table of class weights, the contrast, and an estimate of the variance of the contrast. This allows statistical tests of significance of the evidential themes, allows the computation of uncertainty, and permits trial and error testing of classes and layer combinations to build stronger models. A final output is the sum of the posterior probabilities for all contributing classes and layers, in the form of a map showing their spatial distribution.

UCSB Maya Forest GIS

Our research began with identifying a need to build a method to incorporate the collection, integration, harmonization, preservation, and distribution of the scattered environmental and settlement data from the Maya forest region. The result was the UCSB Maya Forest Geographic Information System (GIS), a data repository for the greater Maya forest region of Belize, Guatemala, and Mexico. Data contributed by agencies and scientists have been combined into a regional GIS (Ford and Clarke 2000) and encoded with Federal Geographic Data Committee standard metadata for archiving and redistribution via the Alexandria Digital Library (Smith and Frew 1995), and now available through the

ADL (2005).

The original compilation on CD (2000) was based on the GIS developed at the regional scale by the Paseo Pantera Consortium for the US Agency for International Development. Integrated with this is a digitized maps of topography and soils, Sader's (1999) land use data for the Petén, geo-referenced MSS satellite images, the local GIS database developed by Fedick on soils (1989) for the Belize River area (topography, soils, geology) as well as settlement data of Ford' BRASS project (1983-2003), and a 1998 1:6 000 photo-mosaic of the El Pilar Archaeological Reserve for Maya Flora and Fauna (Girardin 1999). This first version (UCSB Maya Forest GIS 2000) has been shared with collaborators in Belize and Guatemala, and published on the Internet by the SCS Belize Country Conference (Ford and Clarke 2002). A key recent addition has been 90m-resolution digital topography from NASA's Shuttle Radar Topographic Mapping program. Many of these data provided the input weighting layers for the weights-of-evidence modeling.

The Data, Geographic Methods, and Procedures

From the numerous data contained in the GIS, a subset of environmental data layers were extracted and clipped to the various study zones. The input layers selected at the local scale and extents are listed in Table 1. We combine traditional archaeological field research data with new geographic predictive methods using weights-of-evidence WofE approaches. Environmental components of the settlement location model include soils, geology, topographic variables, and surface hydrology as independent environmental layers with their spatial transforms, such as buffers. These environmental layers will be combined with known archaeological Maya settlements from the BRASS surveys as actual locations for the analysis. The strength of associations that the model will provide will help to assess environmental contributions to settlement patterns and can be evaluated against cultural factors, such as location of civic centers and settlement exclusion areas, to provide a map of settlement and environmental relationships.

Settlement Patterns: By the Late Classic, all the well-drained uplands should evidence high settlement, resulting in dispersed patterns. Occupation is found in many zones and the influence of several geographic variables is present. Evaluating the dependence of known settlement sites on the fundamental geographic variables constraining farming, we can assess the importance of farming in explaining Maya land use patterns. We use the data base from the BRASS survey transects as the evidential theme for Maya settlement. With the statistical probability model we develop a basis for predicting Maya settlements. Detailed field validation and re-examination at the local scale has enhanced the predictive settlement base and provide the foundation for our model.

Distribution of Water, Slope, and Soil:

Given continuity in climate regime and geology, the major impact on the environment is human land use. The ancient system of agriculture depended on rainfall. Manipulations of landscapes were oriented toward minimizing limitations. Consequently, where lands may be consistently wet, there have been drainages recorded. Where the land is too steep terraces are noted. The porous limestone of the Maya forest leaks water to subsurface aquifers. Since annual rainfall distribution is seasonal, agricultural and land use cycles will respond to these constraints. Slope is also a consideration in the sighting of settlements. Most of the settlements will avoid areas that are consistently wet or steep. For the farming settlements, soil quality is a major issue. Overall characteristics of fertility are critical for

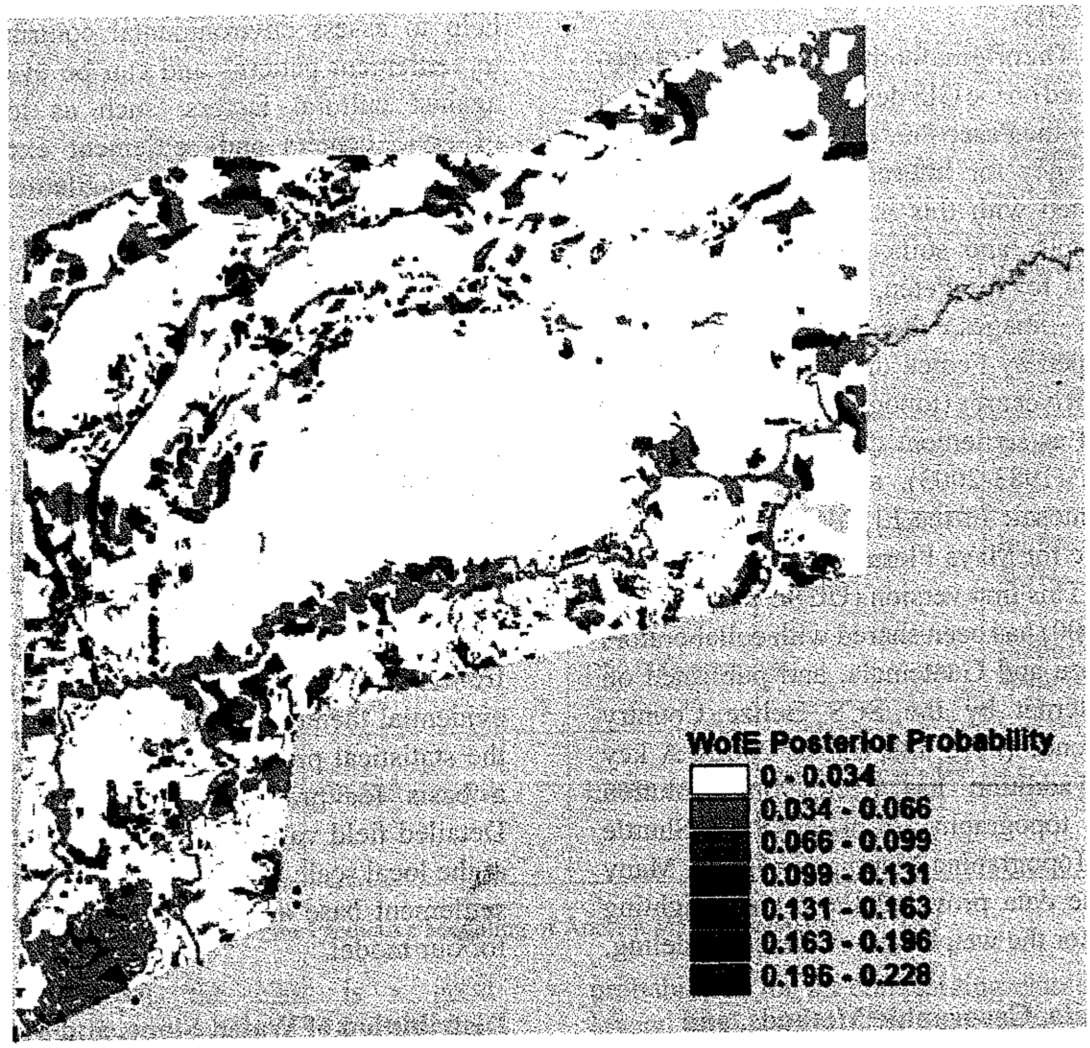

Figure 5: The predictive model for the Belize River area.

domesticated crops and issues of drainage qualities influence the ability of specific plants to respond to variations in rainfall. For the local scale, we focus on spatial distributions of water and soil, along with topography to associate with Maya settlement distribution

Modeling Ancient Maya Patterns

The UCSB Maya forest GIS is our modeling base for examining the ancient Maya landscape in relationship to the settlements of Late Classic Maya. We assess land use hypotheses presented in the vast literature on the Maya with the GIS, using tools available in standard GIS packages such as ArcView and ArcGIS. We will simulate the actual spatial distribution using landscape weighting factors developed in our work using Weights of Evidence (WofE) analysis (Ford and Clarke 2001, Raines 2002; Sijean 2003; Monthus 2004). Gary Raines, who helped build the ArcView extensions for WofE analysis (Raines et al. 2000) has worked on the Columbia River Basin Ecosystem Management Project (Raines et al. 1996, Raines and Johnson 1996; Raines and Smith 1996) and in the development of GIS data standards (geology.usgs.gov/dm/). Raines has collaborated extensively in our WofE predictive modeling to the Maya forest, and is willing to continue this collaboration.

The initial tests were conducted with

the BRASS study area of three settlement transects covering the western end of the Belize River area. The settlement data are representative of the western uplands and the eastern valley. The El Pilar transect provides a sample of the densest settlement areas associated with the major center. The Yaxox transect flanks the well-drained uplands and includes areas of the marl foothills, similar to the greater Spanish Lookout area. The eastern Bacab Na transects provides a sample of the alluvial valley similar to the area of Barton Ramie with unoccupied savanna to the north. The BRASS area served as the source of the first examination of the dependent geographic variables of slope, soil fertility and drainage, as well as distance to water bodies. These are the significant variables contemporary farmers use in the location of cultivations and are known worldwide to influence agricultural investment.

The four independent variables were classified with the aid of the *WofE* model and the graphic image of each variable is shown in Figure 2. The *Weights of Evidence WofE* program builds each theme individually, weighting them based on their distribution. The cumulative combinations of each then are weighted against each other for their contribution to explaining the dependent variable, in our case Maya settlement. This formed the foundation of our investigation and the basis of our results.

Methodology

The results of our investigation of the predictive model have proven illuminating, supporting the view that agricultural strategies are at the foundation of Maya development. We developed the geographic themes of topography, soil drainage, soil fertility, and distance to water bodies for the test area of the BRASS surveys. For the initial test a random sample of 50% of the known sites are used. This sample is used to predict the remaining 50% of actual sites. The evidential themes are presented in Table 1 and represent the independent variables in the predictive model. Using the random sample, the *WofE* program generated the predictive model by combining the weights and prioritizing them statistically for the model. Then the results of the samples are generated as visuals for comparison to the whole (Figure 3). Comparing the random sample to the whole of the settlement data we found that we could predict 75% of the settlements for the BRASS area. Then the test case was expanded to the whole Belize River area.

The model was then applied across the Belize River area (Figure 4) and the *WofE* model was propagated based on the results of the test case (Figure 5). The results were then field validated for verification and to calibrate the model. This involved travel to target destinations across the study area with a GPS and mapping residential sites where found. Travel on rural roads throughout Spanish Lookout, south of Soccutz and Benque Viejo, and into the north of the El Pilar area provided a number of cleared areas for survey and recording of residential sites. Data were collected from the 2003 and 2004 seasons and used for the validation of the expanded model. The results of the field verification provided added sites for the model, independent corroboration of the model and an increase in predictive confidence of 80% (Monthus 2004).

Results and Conclusions

Our results point to the singular importance of smallholder farmer choice in the selection of residential settlement. While all geographic factors were contributors to the model, we discovered that:

- The predictive model explains 75% of settlement locations from the study area and 80% for the local area as a whole
- For water bodies: eliminated lakes, Strahler order, Belize River as contributory factors verified importance of streams important up to 400m

- Validation with GPS field data
- Provided a basis for extending model to regional data for the whole Maya area

The selections for farming sites is associated with a combination of attributes that point to intensive cultivation of the forest as a garden, comparable to traditional farmers in the region today. This provides a link from the ancient Maya settlement pattern and land use to the contemporary forest gardeners whose hand cultivation of unplowed tree dominated plots conserve soil productivity, retain water, promote biodiversity, and support the requirements of birds and other animals. The traditional forest garden techniques provide a basis for understanding the Maya settlement patterns that strive to maximize access to a variety of good agricultural areas and vary the intensity of land use across a wide area. The different land use areas provide alternative zones for open sun drenched poly-cultivated milpas to shaded tree orchards with understory cover crops and emergent palms. Future work will explore the nature of the settlement distribution with an effort to develop population estimates and model thresholds of land use intensity that could contribute to the Classic Maya collapse.

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