6 *CALCULATING LATE CLASSIC LOWLAND MAYA POPULATION FOR THE UPPER BELIZE RIVER AREA*

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The problem of estimating ancient Maya populations has vexed archaeologists since the first temples were discovered, and existing best estimates range considerably. Using a probability map of Maya settlement patterns derived from predictive Bayesian modeling of the Upper Belize River Area, we have developed a means of estimating populations in the unknown areas. Using the ancient land use patterns of residential units revealed in surveyed areas, we expanded our model across a greater area, creating a probability map of all Maya sites of the area, discovered or not. Based on a classification of the sites and demographic assumptions about the average family, we derive estimates and their ranges of population for the Late Classic Maya that reveal an intensive land use system.

Introduction

Estimating Maya population numbers throughout their settlement history in Central America has been a preoccupation of Maya archaeologists for nearly a century. Contemplating the abandoned, forest-covered temples and the numerous smaller platforms that appeared to be everywhere, gave rise to a rich variety of interpretations. Yet it was the focused attention on the major architecture and the abundance of the smaller structures that led researchers to envision a dense and widespread system of Maya settlement.

As first noted by Bullard, as one looks beyond the temples and plazas variation in Maya settlement forms and configurations can be recognized (1960; see also Fedick 1995; Fedick and Ford 1990; Ford 1991; Iannone and Connell 2003; Isendahl 2002; Sabloff 1992; Smyth et al 1995; Webster 2008). Still, the perception remains of vast cities surrounded by their sustaining rural hinterland habitations (Rice and Culbert 1990 following Redfield 1967). Estimates for Late Classic settlement densities also appear to reflect this division (Rice and Culbert 1990:30-31). Yet this distinction is possibly more structured by our own experiences of contemporary urbanization, and not by actual evidence from the ancient Maya landscape, where the perceived urban/rural dichotomy falls short of describing the diversity of Maya settlement (Ford 1991; Levi 2002). It is hard to evaluate the efficacy of the dichotomy, however, since archaeological surveys are

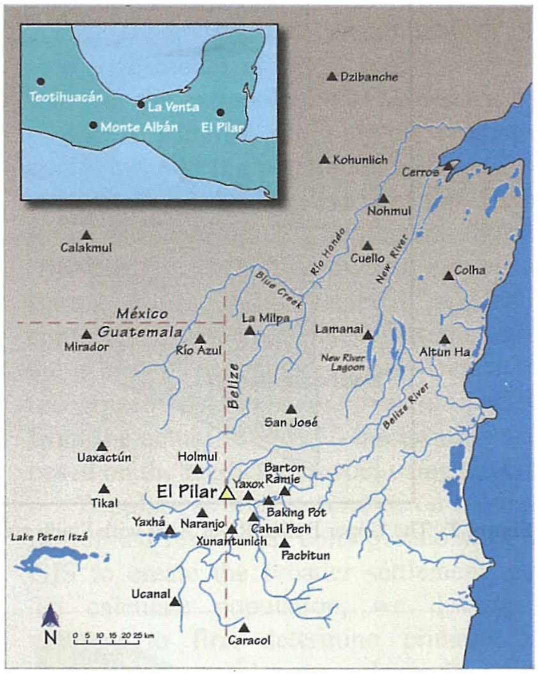

Figure 1. The Central Maya Lowlands with Sites indicated.

obstructed by the density and isolation of the Maya forest itself. Centers ranging in size from the large site of Tikal to the residential community of Barton Ramie (Figure 1) relied on the landscape for their subsistence needs. In this research we sought answers to questions of how the Maya used their land, and consequently, how they chose to settle and farm the landscape. With answers to these questions, estimates of ancient populations become feasible.

The nature of settlement patterns and densities suggests nuances that can only be revealed by a more detailed examination of

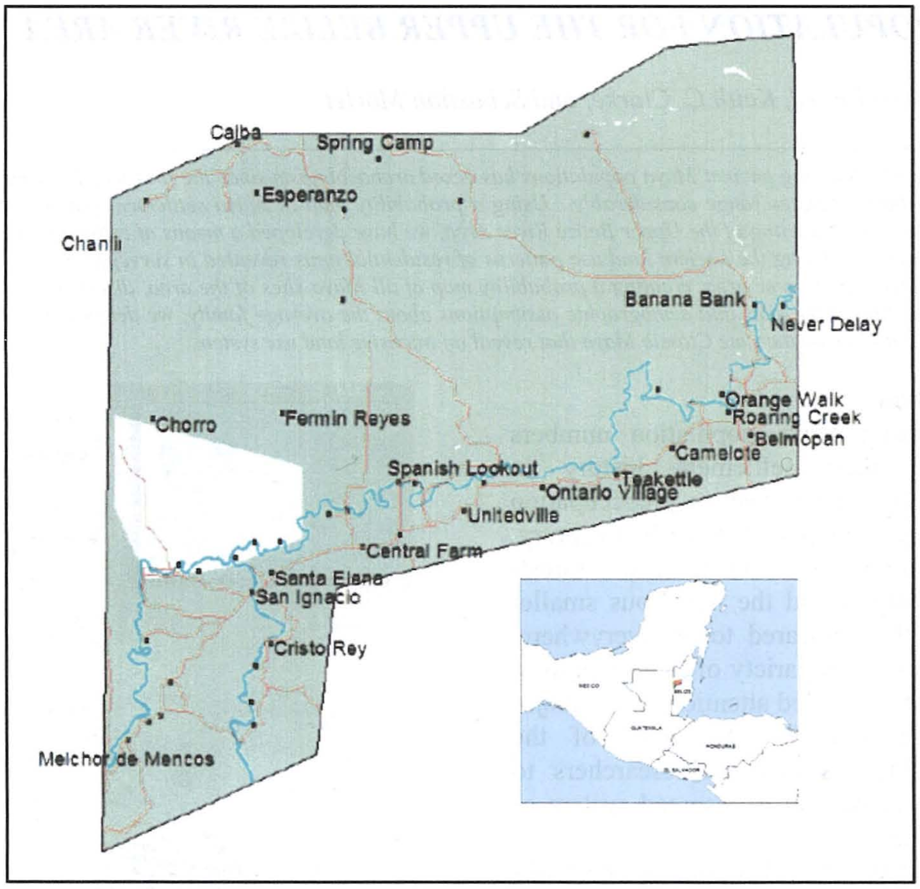

Figure 2. The Upper Belize River Area with Study area indicated.

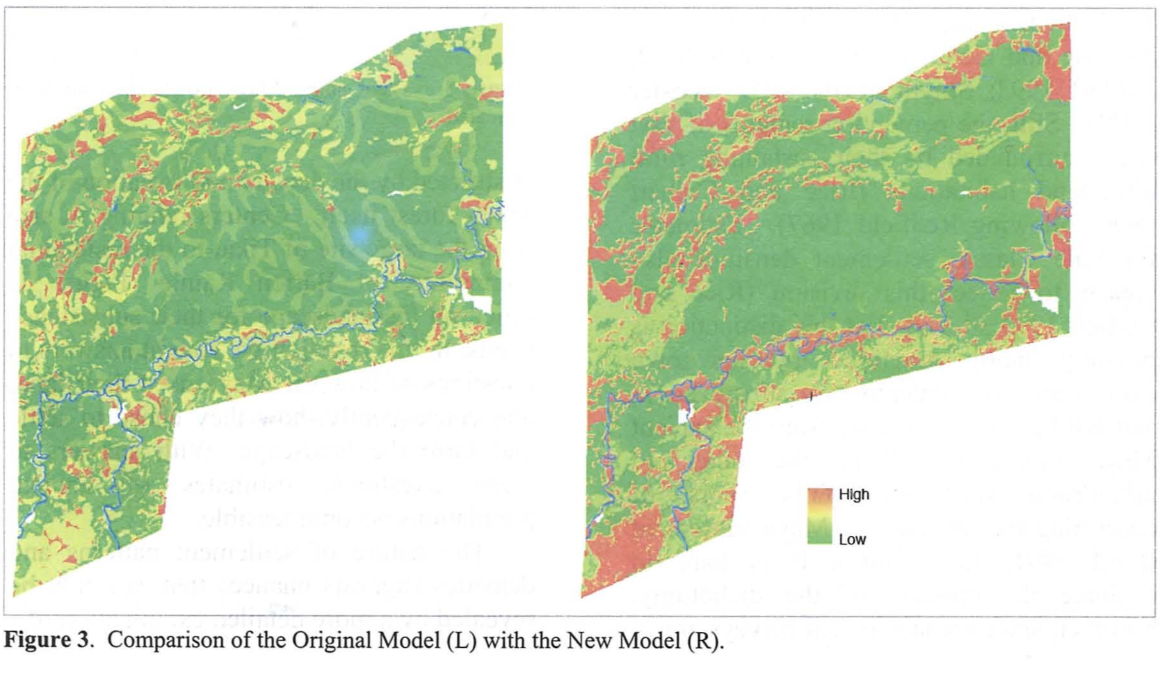

Figure 3. Comparison of the Original Model (L) with the New Model (R).

the Maya landscape. In prior work, we created an assessment for Maya sites of the Upper Belize River Area with the development of a predictive model using geographic variables (Ford and Clarke 2006; Ford et al. 2009). This research involved extensive data correlation, building a model based on Weight-of-Evidence (Bayesian) predictive methods, application of the model, and its validation through field testing. The model proved highly successful in predicting both the greater and lesser presence of Maya settlements (Ford, Clarke, and Raines 2009).

Our work with Maya settlement patterns offers a new perspective that builds on the constellation of environmental characteristics commonly associated with ancient patterns of settlement (Campbell et al. 2006). Put simply and in local terms, well-drained ridges within the tall canopy forests had high settlement densities (Ford 1986:68-69, 88, 1991); poor-drained lowlands with short forest had low settlement densities; and seasonally inundated and perennial wetlands had no settlement (Fedick and Ford 1990). Given that the Maya civic centers are perched within well-drained areas and that the general non-central surveys incorporate the variety of landforms, it may be that the proportions of varied environmental characteristics explain the differences in densities. High densities around major centers such as Tikal were located in areas with a high proportion of well-drained terrain; archaeological surveys that surround such centers will therefore represent well-drained ridges and high settlement densities. Broader estimates based on these densities if extended will overestimate populations. Intersite areas, such as those located between Tikal and Yaxhá, incorporate different environmental zones ranging from ridges to wetlands (Ford 1986; 2003) and yield average settlement densities lower than that of Tikal, for example.

When the environmental characteristics are taken into account, there is a wide variation. These variations may be difficult to appreciate from the perspective offered via a survey transect, but Geographic Information Systems (GIS) offers a means to identify patterns and produce maps based on samples of identified settlements and patterns. This is how we constructed a predictive model of Maya settlement for the Upper Belize River Area (Ford and Clarke 2006, Ford et al 2009). The results of the GIS research forms the basis of this further effort to calculate Maya population density and distribution.

We begin with an assessment of the predictive model of Maya settlements as a basis for the extrapolation of settlement and residential patterns. Refining our predictive model to build the population estimates, we used the transect surveys for the Belize River Archaeological Settlement Survey (BRASS), along with additional surveys of Barton Ramie, to characterize residential configurations and settlement patterns across the wider Upper Belize River Area. The recognized patterns are then propagated from the actual surveys to the broader map, based on the predictive model using the GIS.

Populations were estimated on the basis of defined residential units plotted with the GIS to create the broader settlement map. To calculate population, we develop a strategy to first determine primary and secondary residence derived from ethnohistoric and ethnographic cases. The results provide both a view of how settlement and population vary across the landscape and also present a picture of high population levels and intense land use for the Late Classic Maya.

Predictive Model Map of Ancient Maya Settlement Patterns

Over the past several years, we have been working with the results of a predictive model of Maya sites drawing on data gathered in the GIS (Ford and Clarke 2006, Ford et al. 2009; Merlet 2009, 2010). Focused on the data gathered by the BRASS research, where three basic transects in the western portion and targeted quadrants to the east were designed to gain an

Tool	Parameter	Result
Training sites for	Training points	Random Sampling of Training Points
Calculate Weights	Raster of Training Points	Table of Weights for Evidential Layers
Calculate Probabilities	Raster of Weights	Calculated Posterior Probabilities
Logistic Regression	Raster of Weights	Calculated Regression Statistic
Weights of Evidence (WofE)	Raster of Weights	Calculated Weights of Evidence
Agterberg-Cheng Test	Posterior Probability Standards	Test Conditional Independence
Area/Frequency Tables	Posterior Probability Training Points	Table of the Predictive Model

Table 1. Geographic Information System Database for the Predictive Model of Maya Settlement (Merlet 2009).

appreciation for the variation of settlements in the alluvial valley, the rolling marl foothills and the well-drained ridges to the north. Before the BRASS study, Maya studies concentrated in the valley suggested that settlement was a ribbon line pattern only along the river (Coe and Coe 1956; Thompson 1942; Willey et al. 1965). This view is now altered and we have a more complex understanding of settlement patterns today. Thus we can compensate for the sampling bias of prior sites selected too close together.

Based on the BRASS research, we have developed a predicted map of the c. 1300 sq km of the Upper Belize River Area that predicts sites and their density at a 96% confidence level (Figure 2 and 3). Based on the known sites and their relationship to the geographic variables of soil fertility, soil drainage, distance from rivers, and topographic slope, we constructed a predictive map based on the steps outlined in Table 1.

The original tests (Ford et al. 2009) applied a model training mask that bounded all the transect areas (Ford et al 2009:8) for the Upper Belize River Area and included rivers as a geographic theme. In our present model, we have refined the focus by recreating the training mask coverage to bound precisely around only those areas with survey coverage, thus we control for locations with sites as well as for those areas without sites (Merlet 2009:16-17). The results provide a more powerful model with the quality of predicting not only the presence of sites but also the absence of sites.

In the final model refinements, experiment results were compared with and without the coverage of rivers. We found that the interaction of the river coverage was clouding patterns of land use, especially where there was a low probability of settlement (Ford et al. 2009: 12-13). The relation between rivers and sites was found to be complex, positive at some distances and negative at others. Evaluating the reliability of the models with and without the river coverage, we determined that we had better predictive results without the rivers.

The validation of the predictive model used successive field tests based on the initial models (Monthus 2004; Ford and Clarke 2006; Ford et al. 2009). Unsurveyed areas were field visited and site locations were plotted with a Global Positioning System (GPS) receiver and mobile GIS. These site validations were used to refine a final model and provide the new probability map (Figure 3). Our current model results use the detailed mask of the actual survey areas and only three geographic variables: soil fertility, soil drainage, and topographic slope. With these, our predictive map is statistically both highly explanatory and robust.

Domestic Architecture and Residential Units in the Upper Belize River Area

From the outset, ancient structures have been used as a proxy for houses and their

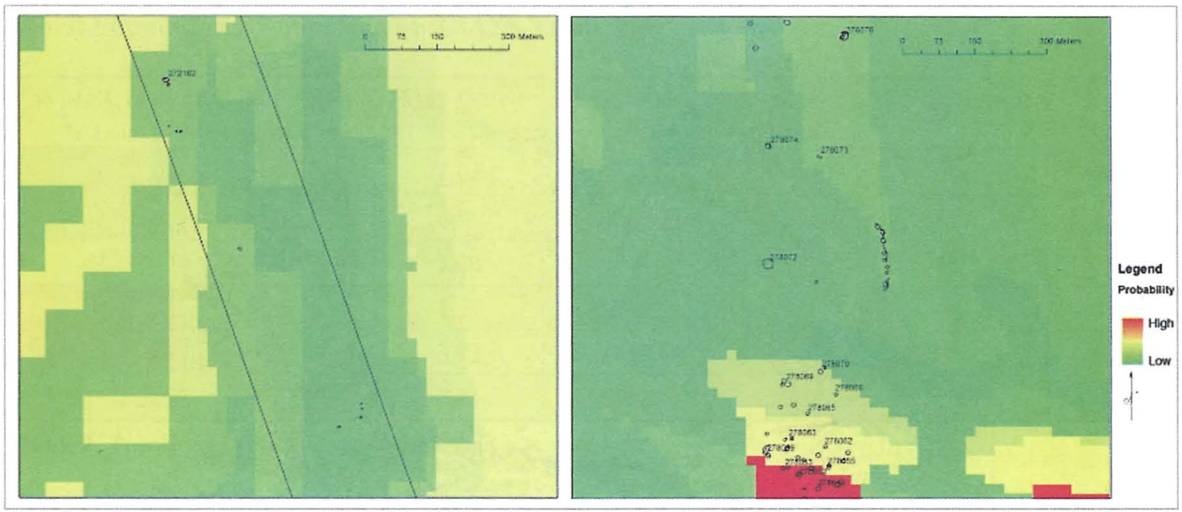

Figure 4. Results of the Predictive Model for Low Priority Zones on the BRASS River (Pilar (L) and Yaxox Transect (R)).

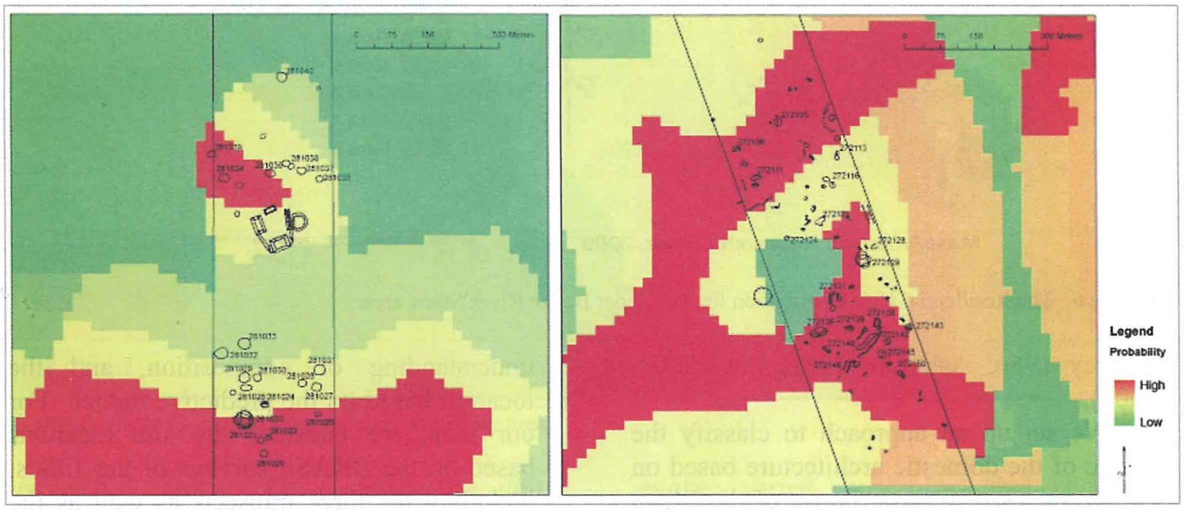

Figure 5. Results of the Predictive Model for High Priority Zones on the BRAa Transect: Valley and Ridges (Bacab Na (L) and El Pilar Transect (R)).

inhabitants, linking to the obvious relationship of residential structures and families. The move from domestic architecture to homes and people has vexed archeologists and caused much discussion in the archaeological literature (see Culbert and Rice for a bibliography). Any estimation system is fraught with problems and assumptions that influence the results (Turner 1990). Our attempt here is to incorporate the standard system of calculation based on a new strategy of defining permanent residential units. We feel that the traditional survey data are a fundamental starting point, and are both valid and comparable (Helay et al. 2007).

At present, we do not concern ourselves with the invisible remains for precisely that reason, they are invisible. This does not discount the many issues raised about such a problem (see Johnston 1992, 2002), but does emphasize that we are basing the estimates on visible remains only. Indeed, we see the variety of visible residential configurations and their spatial distribution as important, considering groups as distinct from solitary structures a critical point and considered in our definition of primary residential units

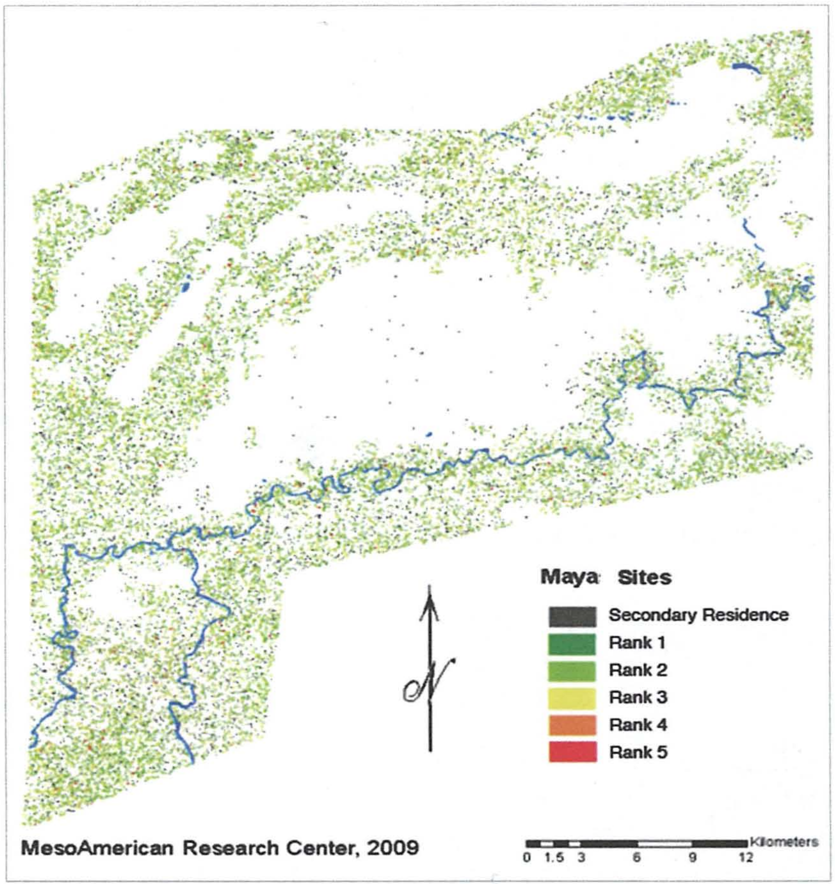

Figure 6. The Residential Unit Distribution for the Upper Belize River Study area.

(Willey 1956; Ashmore 1981; Levi 2002, 2003).

We set up an approach to classify the nature of the domestic architecture based on the requisites of a basic house of the Maya area (see Wachope 1938 as an example). We take the position that the recorded surface remains provide a foundation for estimations of land use intensity and population density in and of themselves. We are comparing similar features when we discuss visible architectural remains, as surface remains provide a common comparative base.

We use the recorded remains of domestic architecture from the archaeological surveys of the BRASS program (Ford 1985, 1990; Ford and Fedick 1992), along with the Barton Ramie map (Willey et al. 1965) to generalize over the whole Upper Belize River Area. This required the identification of residential sites, the consideration of size, the understanding of composition, and the location based on the predictive model. For our map, we consider the site locations based on the BRASS surveys of the 1980s, including the three transects as well as the ancillary surveys conducted in peripheral areas (Fedick 1988) and the Barton Ramie map (Willey et al. 1965). Based on these site locations and their association with the predictive values generated by our GIS model, we have been able to propagate predicted patterns of settlement across the landscape. These patterns have been validated at the 96% confidence level (Ford et al. 2009:13).

With the BRASS residential database, we used recorded data on structure size (diagonal length in m), residential unit composition (number of structures and evidence of plaza), labor investment (calculated based on Arnold and Ford 1980), and the location to compute the weights of

Total Population Distribution of BRASS Transects						
WofEClass	Residential Units	Area (km²)	Population	Density	% Population	% Area
1	0	2.01	0	0	0%	22%
2	11	0.51	64	124	3%	06%
3	28	1.20	154	129	8%	13%
4	53	1.57	298	190	15%	17%
5	259	3.72	1452	390	74%	41%
Total	352	9.01	1968	218	100%	100%

Table 2. Population Distribution of BRASS Transects.

Total Population for the Study Area						
WofEClass	Late Classic Residences	Area (km²)	Population	Density	% Population	% Area
1	0	485	0	0	0%	38%
2	5403	243	30255	124	17%	19%
3	1753	76	9818	129	5%	6%
4	7643	225	42800	190	23%	18%
5	17808	256	99727	390	55%	20%
Total	32607	1284	182600	142	100%	100%

Table 3. Total estimated Population for the Study area.

evidence statistic. These residential unit variables were then used to propagate the patterns on the map.

Using the labor investment calculation (LI) originally developed for the Tikal map (Arnold and Ford 1980), sites were ranked from 1-5 based on a calculation that takes into account the size and number of structures and the presence or absence of a plaza. This provides the basis for distributing sites and considering their overall impact on the landscape.

While the presumed house sites have been accepted as such, how to use the house sites as a proxy for population has been fraught with problems. Patterns of subsistence agriculture have demonstrated that families that occupy residential units evoke varied strategies that typically involved several residences (Farris 1984; Fedick 1992, 1996; Zetina and Faust In Press; Netting 1977; Redfield and Villa Rojas1962; Steggerda 1941; Villa Rojas 1945; Zetina 2007). In fact, recent ethnographies of the Maya suggest an average of three residences per family based on the seasonal round of agricultural activities (Zetina and Faust In Press; Zetina 2007), thus creating a pattern of multiple residence based on agricultural demands in the field.

Based on the ethnographic studies, we consider that the very small structures would have served secondary domestic services and should be excluded from the estimation of population. Thus, solitary structures with an LI less than 500 with diagonals averaging c. 10 m, were designated as secondary residences. These secondary residential units composed 41% of the BRASS sample, but only c. 26% of mapped structures. The residential units with LI greater than 500 and an average unit diagonal of c. 24 m were designated as primary residential units and provided the basis for our population calculation. The primary residential units composed 59% of the domestic architecture of the BRASS surveys.

Propagating Maya Settlements Across the Upper Belize River Area

The identification of primary and secondary residential units in the BRASS and Barton Ramie surveys were used to propagate patterns of residential settlements proportionally across the entire Upper Belize River Area. The propagation used the probabilities of our predictive model as the foundation. We used the residential site classification by labor investment rank (LI; Ford and Arnold 1980) as they patterned in the surveys. Figures 4 and 5 provide a sample of the relationship of the predictive model and the Maya settlement in the Upper Belize River area. The first pair of images (Figure 4) shows the low priority areas and the nature of settlement in those areas. The second pair of images (Figure 5) shows the high priority areas and the patterns of those areas. The variations in the densities, the composition of the residential units, and their size and configurations, were categorized and schematically coded for the propagation to the larger mapped area. Based on the nature of residential settlement in these surveyed areas, we propagated residential sites to the larger map of the Belize River Area using random simulation.

Based on the predictive map, we tallied residential sites that qualified as primary residential units and then used the standard proportion of occupation in the Late Classic period of 95% to build the map. This is consistent with the BRASS data (Ford 1985; Ford et al. 2009:14). From this we were able to associate the residential units with the predictive zones (classed from the WofE or Weights of Evidence model predictive probabilities) to create a table of the population distribution (Table 2). To generate our population estimation for the Upper Belize River Area, we use the generally accepted standard of 5.6 persons per residential unit (Narroll 1962; Puleston 1973; Turner 1990; Healy et al. 2007). Turner (1990) argued that this is a conservative estimation for "paleotechnic agrarian economies" (Turner 1990:305).

The result of this process produced a map that provides a picture of the distribution and a view of the concentrations of settlements and populations in the Belize River Area (Figure 6). Distributions are diverse and we can see how areas of concentrated settlements in the east, south, and the northwest demonstrate where elite controls should be manifest.

Using the tools of the GIS and the predictive model, we were able to use the distribution map (Figure 6) to develop a table of residential distribution for the entire study area of the Upper Belize River area (Table 3). The distributions of the BRASS surveys are the basis of the new map that is the foundation of the population estimations. This new map provides the probability distribution of Maya sites at the 96% confidence level. The landforms and predictive zones are of different proportions in the whole study area when compared with the BRASS transects. The predictive zones, however, are represented in the BRASS transects and the validation of the model includes the Upper Belize River Area (see Ford et al. 2009:14-15).

The population estimates for the Upper Belize River Area are substantial. The range is extreme: 0 persons per sq km in areas of lowest probability (38% of the area) to 390 persons per sq km in the highest probability zones (55% of the area). The overall average is 142 persons per sq km, a density that is significantly greater than the early estimates (Turner 1990:317) but within the range that has been estimated for the Late Classic period (Culbert and Rice 1990). This is relatively dense by Boserup's (1981:9-11) reckoning. The density estimated for Ming

Dynasty China at 1500 AD? is estimated at only 64 persons per sq km and pre-modern Japan at 1750 AD is roughly 128 persons per sq km. Rosenberg (2010) summarizes our world's current population density by continent:

North America - 83 people per square kilometer
South America - 189 people per square kilometer
Europe - 347 people per square kilometer
Asia - 525 people per square kilometer
Africa - 168 people per square kilometer
Australia - 17 people per square kilometer

Boserup (1981:9), in her synthetic treatise on population and technology, evaluated population densities worldwide and determined that density greater than 64 are dense and over 256 very dense. She presented a table of continental densities based on the conditions in 1975. The dense and very dense categories are only found in Europe and Asia (Boserup 1981:11).

Reviewing our population estimates for the Late Classic Maya of the Upper Belize River Area suggests a very intensive use of the landscape. In the c. 1300 sq km that was studied, 182, 600 people must have lived and farmed. Yet while areas of the greatest density reach 390 per sq km, very dense by Boserup's calculations (1981:9), this encompasses only 20% of the area. Consequently the most intense land use takes in only one-fifth of the terrain. This small percentage would be a complex mosaic of houses, varied open sunlit areas of maize fields and home orchard gardens, as described in the ethnographic literature (Redfield and Villa Rojas 1962; Zetina 2007). These dense settlement zones found throughout the study area are both near and far from major and minor centers. They contrast with the virtually unoccupied areas of low settlement priority making up 38% of the study area. These extensive unoccupied zones, encompassing nearly two-fifths of the study area, would have been woodlands, thus supporting the natural resource needs of the Maya.

Summary

There have been many strategies used to develop population estimates for prehistoric societies. The Maya have presented one of the more difficult cases as the tropical forest cover limits surveys. New satellite and geospatial technologies have sought to overcome these obstacles (e.g. Garrison et al. 2008), and in the future we may have an opportunity to test our land use model with these more sophisticated capabilities. Our predictive model provides one way to address land use based on statistical probabilities (Ford and Clarke 2006; Ford et al. 2009).

With the new population density map based on our predictive model, we demonstrate in this paper a means to create a settlement map using archaeological surveys and their patterns against a predictive model map that may have used beyond our context. While it has been recognized that settlements are not evenly distributed, our map is based on geographic variables on which the settlements are dependent. By enumerating the proportions of residential units and propagating their distribution across the landscape from the known areas to the predicted areas, we have derived the patterns of primary and secondary residential sites. Our total estimates project 142 persons per sq km for the whole study area, with a range of 0-390 persons per sq km. The estimates we have come up with are approximately ten times the population density of Belize today.

These population estimates are founded on a series of assumptions. We recognize the subsistence farmer's strategy of using primary and secondary residences, and have made our calculations based on the primary residential units alone. We use 95% occupation commonly used for the Maya area in the Late Classic period, comparable to Late Classic occupation in the area. With all these considerations taken into account, we have discovered that the density of occupation of the Upper Belize River Area was potentially very high. We believe the results of our research provide an understanding of how the landscape was used. We present a mosaic of intensity based on the geographic variables of the Upper Belize River Area. We show areas of intense use and areas that are largely unoccupied. This variation is acknowledged but had not been well appreciated. Our model demonstrates that high settlement and population densities are not something confined to the urban civic centers, but occur where the constellation of geographic variables coincide: well drained fertile soil areas with moderate slope (Ford et al. 2009). Access to natural water sources was only a minor factor (Merlet 2009). Settlements with high predictive values would be good candidates for civic center presence. This could be tested by further field surveys.

To support an estimated population of 142 persons per sq km, a successful subsistence economy was required. The investments that began to take shape in the Preclassic before 1000 BC and grew over two millennia must be able to account for this intense land use pattern. We propose that the *forest garden milpa cycle* (Ford and Nigh 2009) was the subsistence base that could provide a long-term sustainable subsistence base for the Upper Belize River Area Maya. Our next step will be to build a model of Maya land use based on the Forest Garden Milpa cycle and the food and resources it could supply.

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References Cited

Arnold, Jeanne E. and Anabel Ford
1980 A statistical examination of settlement patterns at Tikal, Guatemala. *American Antiquity* 45(4):713-726.

Ashmore, W.
1981 Some Issues of Method and Theory in Lowland Maya Settlement Archaeology. In *Lowland Maya Settlement Patterns*, edited by W. Ashmore, pp. 37-69. University of New Mexico Press, Albuquerque.

Billie Lee Turner, II
1976 Population Density in the Classic Maya Lowlands: New Evidence for Old Approaches. *The Geographical Review* 66(1):73-82.

Boserup, Ester
1981 *Population and Technological Change: A Study of Long-Term Trends*. University of Chicago Press, Chicago.

Brown, Clifford T. and Walter R.T. Witschey
2003 The fractal geometry of ancient Maya settlement30:1619–1632.

Chase, Arlen F. and Diane Z. Chase
1998 Scale and Intensity in Classic Period Maya Agriculture: Terracing and Settlement at the "Garden City" of Caracol, Belize. *Culture & Agriculture* 20(2/3).

Cowgill, Ursula M.
1960 Soil fertility, population, and the ancient Maya. *Proceedings of the National Academy of Sciences* 46:1009-1011.

Culbert, T. Patrick and Don S. Rice (editors)
1990 *Precolumbian Population History in the Maya Lowlands*. University of New Mexico Press, Albuquerque.

Fedick, Scott L.
1988 *Prehistoric Maya Settlement and Land Use Patterns in the Upper Belize River Area, Belize, Central America*. Ph. D. Dissertation, Arizona State University.

Fedick, Scott L
1989 The Economics of Agricultural Land Use and Settlement in the Upper Belize River Valley. In *Prehistoric Maya Economies of Belize*, edited by P. A. McAnany and B. L. Isaac, pp. 215-254. *Research in Economic Anthropology, Supplement* no. 4. JAI Press, Greenwich.

Fedick, Scott L.
1992 An Agricultural Perspective on Prehistoric Maya Household Location and Settlement Density. In *Memorias Del Primer Congreso Internacional de Mayistas; Mesas Redondas, Arquelogía, Epigrafía*, pp. 87-108. Universidad Nacional Autónoma de México, Mexico D.F.

Fedick, Scott L
1995 Land Evaluation and Ancient Maya Land Use in the Upper Belize River Area, Belize, Central America. *Latin American Antiquity* 6(1):16-34.

Fedick, Scott L. (editor)
1996 *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*. University of Utah Press, Salt Lake City.

Fedick, Scott L. and Anabel Ford
1990 The prehistoric agricultural landscape of the central Maya lowlands: An examination of local variability in a regional context. *World Archaeology* 22(1):18-33.

Ford, Anabel
1985 Maya Settlement Pattern Chronology in the Belize River Area and the Implications for the Development of the Central Maya Lowlands. *Belcast Journal of Belizean Affairs* 2:13-32.

1990 Maya Settlement in the Belize River Area: Variations in Residence Patterns of the Central Maya Lowlands. In *Prehistoric Population History in the Maya Lowlands*, edited by T. P. Culbert and D. S. Rice, pp. 167-181. University of New Mexico Press, Albuquerque.

1991 Problems with the Evaluation of Population from Settlement Data: Examination of Ancient Maya Residential Patterns in the Tikal-Yaxhá Intersite Area. *Estudios de Cultura Maya* (18):157-186.

2003 *Crecimiento de Población y Complejidad Social: Asentamiento y Medio Ambiente en las Tierras Bajas Mayas*. Translated by E. H. Gaytan Monográfica 14. Plumsock Mesoamerican Studies/CIRMA, Miami.

Ford, Anabel and Keith C. Clarke
2006 Predicting late classic Maya settlement patterns. In *Archaeological Investigations in the Eastern Maya Lowlands: Papers of the 2005 Belize Archaeology Symposium*, pp. 193-212. Research Reports in Belizean Archaeology. vol. 3. Institute of Archaeology, Belmopan.

Ford, Anabel, Keith C. Clarke and Gary Raines
2009 Modeling settlement patterns of the Late Classic Maya with Bayesian methods and Geographic Information Systems. *Annals of the Association of American Geographers* 99:496-520.

Ford, Anabel and Scott L. Fedick
1992 Prehistoric Maya Settlement Patterns in the Upper Belize River Area: Initial Results of the Belize River Archaeological Settlement Survey. *Journal of Field Archaeology* 19:35-49.

Ford, Anabel and Ronald Nigh
2009 Origins of the Maya forest garden: Maya resource management after the Holocene thermal maximum. *Journal of Ethnobiology* 29:213-236.

Garrison, Thomas G., Stephen D. Houston, Charles Golden, Takeshi Inomata, Zachary Nelson and Jessica Munson
2008 Evaluating the use of IKONOS satellite imagery in lowland Maya settlement archaeology. *Journal of Archaeological Science* 35:2770–2777.

Haviland, William Arthur
1969 A New Population Estimate for Tikal, Guatemala. *American Antiquity* 34(4):429-433.

Haviland, William A.
1972 Family Size, Prehistoric Population Estimates, and the Ancient Maya. *American Antiquity* 37(1):135-139.

Healy, Paul F., Christophe G. B. Helmke, Jaime J. Awe and Kay S. Sunahara
2007 Survey, Settlement, and Population History at the Ancient Maya Site of Pacbitun, Belize. *Journal of Field Archaeology* 32(1):17-39.

Hendon, Julia A.
1992 The Interpretation Of Survey Data: Two Case Studies From The Maya Area. *Latin American Antiquity*, 3(1):22-42.

Iannone, Gyles and Samuel V. Connell (editors)
2003 *Perspectives on Ancient Maya Rural Complexity*. The Cotsen Institute of Archaeology, University of California, Los Angeles, Los Angeles.

Isendahl, Christian
2002 *Common Knowledge: lowland Maya urban farming at Xuch.* thesis, Uppsala University.

Johnston, Kevin, Fernando Moscoso Moller and Stefan Schmitt
1992 Casas No-Visibles De Los Mayas Clásicos: Estructuras Residenciales Sin Plataformas Basales En Itzan, Petén. In *V Simposio de Investigaciones Arqueológicas en Guatemala*, edited by J.P. Laporte. Museo Nacional de Arqueología y Etnología, Guatemala.

Johnston, Kevin J.
2002 Protrusion, Bioturbation, and Settlement Detection during Surface Survey: The Lowland Maya Case. *Journal of*

Archaeological Method and Theory 9(1):1-67.

2003 The intensification of pre-industrial cereal agriculture in the tropics: Boserup, cultivation lengthening, and the Classic Maya. *Journal of Anthropological Archaeology* 22(2):126-161.

2004 The "Invisible" Maya: Minimally Mounded Residential Settlement at Itzán, Petén, Guatemala. *Latin American Antiquity* 15:145-179.

Levi, Laura J.
2002 An Institutional Perspective on Prehispanic Maya Residential Variation:Settlement and Community at San Estevan, Belize. *Journal of Anthropological Archaeology,* 21:120–141.

2003 Space and the limits to community. In *Perspectives on Ancient Maya Rural Complexity*, pp. 89-93. vol. 49.

Merlet, Sébastien
2009 A study on the use of Geographic Information Systems (GIS) in a multi-scale archaeological project. MA, Ecole Superieure des Geometres et Topographes.

2010 Détermination des besoins d'une population Maya durant la période du Classique Tardif au moyen d'un modèle prédictif. *Revue XYZ* 123:17-24.

Monthus, Florent
2004 *Weights of Evidence and Maya Settlement.* MA, Ecole Superieure des Geometres et Topographes

Moriarty, Mathew D.
2004 Settlement Archaeology at Moltul de San José, Petén, Guatemala: Preliminary results from the 1998-2003 Seasons. *Mayab* 17:21-44.

Netting, Robert McC.
1977 Maya subsistence: Mythologies, analogies, possibilities. In *The Origins of Maya Civilization*, edited by R. E. W. Adams, pp. 299-333. University of New Mexico Press, Albuquerque.

Puleston, Dennis Edward
1973 *Ancient Maya Settlement and Environment at Tikal, Guatemala: Implications for Subsistence Models.* PhD dissertation, University of Pennsylvannia.

Redfield, Robert
1967 *A Village that Chose Progress: Chan Kom Revisited.* The University of Chicago Publications in Anthropology. Social Anthropological Series. University of Chicago Press, Chicago.

Redfield, Robert and Alfonso Villa Rojas
1962 *Chan Kom, A Maya Village*. University of Chicago Press, Chicago.

Rice, Don S.
1978 Population Growth and Subsistence Alternatives in a Tropical Lacustrine Environment. In *Pre-Hispanic Maya Agriculture*, edited by P. D. Harrison and B. L. Turner, pp. 35-61. University of New Mexico Press, Albuquerque.

Rosenberg, Matt
2010 Population Density. 2010. About.com Guide. Access 6 December 2010 http://geography.about.com/od/populationgeography/a/popdensity.htm

Sabloff, Jeremy A. and Gair Tourtellot
1992 Beyond Temples and Palaces: Recent Settlement Pattern Research at the Ancient Maya City of Sayil (1983-1985). *New Theories on the Ancient Maya* 77:77.

1992 Beyond Temples and Palaces: Recent Settlement Pattern Research at the Ancient Maya City of Sayil (1983-1985). *New Theories on the Ancient Maya* 77:77.

Smyth, Michael P., Christopher D. Dore and Nicholas P. Dunning
1995 Interpreting Prehistoric Settlement Patterns: Lessons from the Maya Center of Sayil,Yucatan. *Journal of Field Archaeology* 22(3):321-347.

Thompson, J. Eric S.
1971 Estimates of Maya Population: Deranging Factors. *American Antiquity* 36(2):214-216.

Tourtellot, Gair, Jeremy A. Sabloff and Michael P. Smyth
1990 Room Counts and Population Estimation for Terminal Classic Sayil in the Puuc Region, Yucatan, Mexico. In *Precolumbian Population History in the Maya Lowlands*, edited by T. P. Culbert and D. S. Rice, pp. 245-261. University of New Mexico Press, Albuquerque.

Turner, Bill Lee
1990 Population Reconstruction of the Central Maya Lowlands: 1000 B.C. to A.D. 1500. In *Precolumbian Population History*

in the Maya Lowlands, edited by T. P. Culbert and D. S. Rice, pp. 301-324. 1st ed. University of New Mexico Press, Albuquerque.

Villa Rojas, Alfonso
1945 *The Maya of East Central Quintana Roo* 559. Carnegie Institution, Washington, D.C.

Wauchope, Robert
1938 *Modern Maya houses: A study of their archaeological significance*. Carnegie Institution of Washington, Washington DC.

Webster, David
2008 Three Maya settlement projects and their implications. In *6th Palenque Mesa Redonda*, pp. 28, Palenque.

Webster, David, Timothy Murtha, Kirk D. Straight, Jay Silverstein, Horacia Martinez, Richard E. Terry and Richard Burnett
2007 The Great Tikal Earthworks Revisited. *Journal of Field Archaeology* 32:41-64.

Willey, Gordon R.
1956 The Structure of Ancient Maya Society: Evidence from the Southern Lowlands. *American Anthropologist* 58:777-782.

Willey, Gordon R., Jr. William R. Bullard, John B. Glass and James C. Gifford
1965 *Prehistoric Maya Settlements in the Belize Valley*. Peabody Museum, Cambridge.

Zetina Gutiérrez, María de Guadalupe
2007 *Ecología humana de las rancherías de Pich, Campeche: un análisis diacrónic*. MS, Centro de Investigación Y Estudios Avanzados del Instituto Politècnico Naciona.

Zetina-Gutierrez, M. G. and B. Faust.
In Press ¿Cuántas casas cada familia? Un reto para la arqueología maya de la agricultura nómada. *Estudios de la Cultural Maya Universidad Nacional Autónoma de México*.