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PRAGIS: a test case for a web-based archaeological GIS

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Abstract

Archaeology, like many disciplines, has employed GIS as a tool which allows a diversity of new research agendas, from predictive site modeling to combining of spatial data sets, which were once too cumbersome to be handled in entirety. With the explosion of web mapping applications over the past decade, the opportunity now exists to bring these capabilities, which once required specialized education and software, to the entire archaeological community. The Puuc Region Archaeological Geographic Information System (PRAGIS) is a methodological foray into bringing spatial analysis to professionals regardless of their computer mapping experience. With the combination of data sets pertaining to site location, landforms, modern features, recent land use patterns, as well as several basemaps, it is intended that this type of program will provide the intermediary functionality between the options of static viewing of sites and the full suite of spatial tools, and corresponding knowledge base for their implementation.

<http://egis.artsci.uc.edu/PRAGIS/>

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1. Introduction

As archaeology is a field inherently concerned with locating sites within a landscape, GIS has offered a perfect opportunity to allow the rapid mapping and dissemination of site and settlement pattern information. Digital geodatabases allow the accumulation of vast amounts of information which can be readily accessed with simple tools, such as overlay, or utilized in spatial analysis. One of the most daunting tasks in approaching any archaeological project is understanding how various elements relate, as well as the extent of work done by prior investigators. Such problems can be greatly ameliorated by the compilation of information within a single resource allowing users to compare known relationships and develop future directions for research in the area. Though GIS systems offer the capability to compile many sources of information into a single source, which can be referenced on demand for basic data prior, during, and after a study, they have traditionally been restricted in access to only a few users. The now commonplace nature of web-based mapping applications offers the opportunity to bring GIS out of the realm of limited user groups and into the field of archaeology as a whole.

1.1 GIS and Archaeology

Digital mapping developed as a tool for archaeology slowly, starting first with specialists working in conjunction with archaeologists and later with a select few archaeologists learning all of the necessary methods. It was in this environment that many of the cornerstones of GIS applications in archaeology were developed, such as viewshed analysis (Wheatley, 1995; Lake et al., 1998), regional settlement pattern analysis (Kvamme, 1989), and predictive site modeling (Kvamme, 1999). Increased usage of GIS by archaeologists can be seen in the number of texts that introduce the topic to new or old professionals (eg. Gillings & Wheatley, 2005; Wheatley & Gillings, 2005; Westcott & Brandon, 2005; Conolly & Lake, 2010; Renfrew & Bahn, 2012). During a survey of 140 archaeologists in the late 1990s it was found that over 90% of the respondents

utilized a GIS in their work (Gourad, 1999). It should be noted that this survey was conducted online with the intention of reaching those archaeologists most likely to utilize GIS.

The combination of an increase in general computer proficiency coupled with more user friendly application interfaces has allowed GIS to move from the purview of specialists and into the hands of any archaeologist willing to devote the time to learning a new skill. Common products used include both open source software such as GRASS or Oxford Archaeology's release of gvSIG, and private software packages such as ESRI's ArcGIS. Unfortunately, ESRI's software, the more intuitive of the programs listed, has a rather high price tag that can make it a divisive investment potentially precluding its inclusion for smaller archaeological projects (one-time fees of \$1,500 for a single use basic license or \$7000 for a standard license, which has many of the necessary tools for archaeology such as spatial analyst, as listed on ESRI's website as of 28 April 2012). Even after acquiring the software capability, obtaining access or knowledge of the appropriate use of the information can be a challenge for those not accustomed to working with spatial data.

Some archaeological projects have incorporated GIS development and analysis as part of their project design, but the information available from such work is typically only in the form of static maps or visualizations. Some projects that have made GIS a key aspect of study provide the ability to download their data for personal use, in addition to the formal presentation of maps prepared by the project itself (eg. Belli, 2010; Hammond, 2003). Centers for the collection, analysis, and redistribution of information relevant for archaeologists have been set up at a number of institutions (e.g. CAMEL, 2010; AERA, 2011). Such data sources offer valuable opportunities to increase a project's resources, but they do not provide a universal system available to the archaeological community as a whole.

1.2 Web Mapping/Web GIS and Archaeology

Within the past twenty years, the way that many people conceptualize and consume spatial information has been revolutionized. Where it was once common to have a static map displaying locations over a base of imagery, land surface classification, or hypsography, now a user often expects to have the ability to vary the scale, type of location data displayed, as well as base layer to overview the data. Web-based mapping officially began in 1993 with the release of PARC map viewer by the Xerox Corporation, but it was the exponential growth of internet usage and companies such as MapQuest and Google that turned the technology into an everyday tool for many in countries well served by internet access (Fu & Sun, 2011).

Availability of high resolution satellite imagery through Google Earth brought an unprecedented opportunity for archaeological projects to engage in thorough prospection prior to ever setting foot in the field (Klokočník & Kostecký, 2010). Such access has also led some researchers to obtain data directly by digitizing structures from this imagery for further analysis (Sadr & Rodier, 2012). Though the benefit offered by imagery of this quality is enormous, the web offers greater capabilities for knowledge dissemination and interaction that provide an opportunity for spatial data availability currently underserved by any existing application.

Archaeological data has begun to make its way onto the web through both existing media as well as new applications. Google Earth provides every user with the ability to create data additions in the form of .kml and .kmz files which can be added to the imagery within their program. Potential users only need to have the free program installed on their computers, and they can view these layers over the high resolution imagery. Projects such as the Egypt Exploration Society's Delta Survey (2012) or the Electronic Atlas of Ancient Maya Sites (Witschey & Brown, 2012) have presented compiled information for hundreds, if not

thousands, of sites and made them viewable within Google Earth. The EES Delta Survey also presents information about the site, its preservation status, and photos from the ground or of notable artifacts, while the Maya database gives rank dependent rendering to better understand site distribution and complexity.

There have been advancements working to bring archaeological information onto the web through mapping applications. An ongoing project called MAGIS, Mediterranean Archaeology GIS, presents a map based search option, but the resulting data are text based web pages which link to data about the individual projects within the database (Foss & Schindler, 2011). Middle Eastern Geodatabase for Antiquities (MEGA – Jordan) is a \$1 million project headed by the Getty Conservation Institute, and is a major leap forward in web-based dispersal of archaeological data. The system's primary focus is on the documentation of sites in a readily available format for risk assessment and monitoring purposes (Getty Conservation Institute, 2008). MEGA involved the digitization of antiquities records, and the building of the geodatabase in addition to the creation of a web viewer application capable of display and interactive selection of the more than 10,000 Jordanian archaeological sites (Kennedy, 2010; Getty Conservation Institute, 2011). Designed both for professionals as well as amateurs, sites are displayed over Google's high resolution satellite imagery as well as other Google basemaps, and the application allows a variety of search functions.

While it is easy to wax poetic over the wealth of information quickly available through MEGA, the system is only a searchable database. This leaves space for further development of web mapping for archaeology that PRAGIS is a test case to fill. Just like MEGA, there is a native geodatabase containing site information as well as several different search options, but it brings

in some of the functionality typically found only in a desktop GIS into a web-mapping environment.

1.3 Region of Study

The Puuc Region of the Yucatan, Mexico has been the subject of archaeological exploration for almost 2 centuries and professional archaeological investigation for about 90 years. This time depth has led to many sources with information regarding sites. Knowing how these works interrelate can often be challenging, and when dealing with sites that have been called by different names, or amalgamated with other sites, or assigned to geographic locations with widely varying degrees of accuracy, the opportunity for error increases greatly. Understanding the regional distribution of archaeological sites can be challenging at best, and has long relied on the accurate publication of all known locations within a single source. This presents an inevitable dilemma where information can quickly become obsolete, and any error made in the publication is likely to be reproduced before a revised edition can be released.

There have been several scholars who have published the known sites within the Puuc such as Garza and Kurjack (1980) and Dunning (1992), but these both exhibit the limitations of printed material mentioned above. Clifford T. Brown and Walter R. T. Witschey compiled a GIS for all Maya sites (Witschey and Brown <http://mayagis.smv.org/>) which they make partially available through a kmz file that can be used in Google Earth. They offer to run analysis, but all queries must be submitted with the results to be provided upon completion. Unless a person has a prior background working with GIS they may be unaware of the range of possible queries. Further, at least for the Puuc region, this data set has not been checked to verify site locations and eliminate numerous duplications. Though it is very useful, this data set and its presentation

could greatly limit the flexibility of researchers to investigate the data or pose questions of importance for many projects.

The Puuc is a region without well-defined boundaries (i.e., its boundaries vary considerably sources and the attributes being study, such as physiography or ancient architecture). In order to provide a definitive boundary for the GIS, four adjacent 1:50,000 topographic maps were used to delimit the study area. The maps are part of the 1 to 50,000 series available from INEGI which cover most of Mexico. Though the Puuc region extends both to the south and east, no sites were included in database beyond the joined map boundaries, and other data were clipped at this boundary.

2. Structure & Development

The data were compiled and tools were developed using ArcMap 10.1 with most information being stored within a single geodatabase. In an attempt to decrease server reaction times, data are fundamentally separated into two groups; active objects and viewable layers. Web services are published using ArcGIS Server 10.0 made available on the EGIS within the Department of Geography at the University of Cincinnati.

The web application is built using ESRI's ArcGIS Viewer for FLEX version 2.5. FLEX, or Adobe FLEX is an open source application framework useable for the creation of mobile as well as desktop applications. For the end user, it operates within the Adobe Flash Player version 10 or higher which has an estimated distribution of over 97% in emerging markets (China, South Korea, Russia, India, Taiwan), and over 98% in mature markets (U.S., Canada, U.K., France, Germany, Japan, Australia, New Zealand) (Adobe, 2012).

3. Data

Information available extends beyond just archaeological sites, and includes both feature data (Operational Layers) as well as basemaps. Important details of the data are provided, but for more information, including a full list of references for site coordinates, please visit <http://egis.artsci.uc.edu/PRAGIS/data/>.

3.1 Operational Layers

This group holds all interactive data within the system, and is divided into four groups based upon level of interaction and data-type: Layers, Viewable Layers, Soils and Elevation, and Land Use Land Cover Classifications.

3.1.1 Layers

Within this group are data capable of display and interaction for archaeological sites, caves, roads, railroads, residential area, urban area, municipal boundaries, states boundaries, and the Puuc study bounding area. Archaeological sites represented as point locations are conceptually divided into two layers based on the definition of “site”. The Urban Centers layer presents a site as being a nucleated settlement area so that an agglomeration of associated structural groups are represented by a single point location (ex. a single location for Yaxhom, or Sayil), and is intended to give a visual display of inter-site distribution (see Figure 1 left). All Sites shows point locations for all structural groups which have available coordinate locations, and are color coded based on associated Urban Centers (see Figure 1 right). This layer is intended to provide a visual approximation of intra-site distribution. Location data were initially obtained as a subset from those available within the MayaGIS (Witschey & Brown, 2012), which incorporated most previously published sources. Data were cleaned to remove site duplicates with coordinates checked against all published reference coordinates, and resulted in a reduction from 700 entries to 466 for All Sites (269 considered Urban Centers). Additional

locations from Stephan Merk as well as those published in his book were added to the database (Merk, 2011), along with others provided by Dunning's more recent field notes, and others will continue to be added when published or submitted from reliable sources.

Site data cleansing often involved reconciling older and newer sources. Older sources (e.g., Blom 1940; Pollock 1980) were based on surveys in the 19th and first half of the 20th centuries and the locations of many sites were only approximately known. Some sites have also been known by different names or different spellings over time. The Archaeological Atlas of Yucatan (Garza & Kurjack, 1980) was a big step forward, but many sites recorded via air photo interpretation or rapid road surveys are without names or descriptive information making verification of their locations difficult. Dunning's survey in the mid-1980s (Dunning 1992) was initially completed without aid of a GPS, though some sites were later revisited with a GPS and other locations have been verified or shifted slightly using satellite imagery. In short, while every effort has been made to verify site locations, eliminate duplications and other errors, some site information may still be erroneous. The advantage of the new GIS is that such errors can be quickly corrected when better data become available.

Roads, railroads, residential area, and urban area are provided to aid in the assessment of potential access and impacts to sites. These layers do not have unique attributes for query such as names, but roads can be buffered to search sites which may be impacted by a planned road expansion. A shapefile for roads was downloaded from Open Street Map which included a more thorough coverage of roads than was available in other data sets. Railroads, residential area, and urban area were part of the ESRI ArcGIS 9.3 media kit. Municipal and state boundaries are provided to allow for collection of sites based on their administrative control, though searching is limited to municipalities (searching by state was deemed unnecessary due

the small study area), and were also obtained from the ESRI media kit. The Puuc bounding area is based on the following maps: Muna F16C71, Ticul F16C72, Bolonchen F16C81, and Xul F16C82.

3.1.2 Viewable Layers

INEGI provides a WMS (Web Map Service) which offers a number of different display layers, of which only a small subset is offered within PRAGIS (INEGI, 2011). All layers have a display name in English (with the original layer name in Spanish) visible by further expansion. These data are only visible within the map, and cannot be searched or selected.

3.1.3 Soils and Elevation

Soils are given as a feature layer that was based on the Food and Agriculture Organization of the United Nations soil classification system provided by Witschey & Brown (2012). This layer is based on 1:250,000 maps, hence it provides only a crude distribution of regional soils. Elevation information is provided as two separate Digital Elevation Models (DEM), each with their own advantages and disadvantages. A DEM is a raster, a spatial grid of cell similar to a table, where the value for each cell is the mean elevation for that geographic area. The first DEM has a 30 meter resolution derived from stereo images taken with the ASTER sensor, and provided free of charge for most of the world (USGS, 2011). The second DEM is a 30 meter resolution generated from the digitization of contour lines on the 1 to 50,000 topographic map series for Mexico provided online until very recently by INEGI (2011; 2011)¹. While the ASTER data represent uniform collection of elevation at all points across the area, it preserves the artifacts within the image resulting from elevations obtained from stereo imagery. This is shown in the drop in forest canopy along the power line corridor running southwest to northeast through the image, which appear as a topographic drop throughout the

area. The INEGI 1:50,000 DEM also has artifacts along the borders of the topographic maps from which it was created. The chance of errors can be high due to generalization in the contour line creation from photogrammetric techniques or interpolation problems during DEM generation.

3.1.4 Land Use Land Cover Classifications

Land use land cover classifications are made available with the intention that they may be used to determine recent land use patterns that may have affected archaeological sites in ways not readily visible today. They may also be used to evaluate changing patterns of land use and how that may affect archaeological resources. Landsat 5 Thematic Mapper (TM) images were chosen for a multi-temporal group of land use, land cover (LULC) because of the TM sensor's comparative advantage in spatial and temporal resolution to the older Multi Spectral Scanner sensor. Data for the time period ranging from 1986 to 2011 were downloaded using the USGS Global Visualization Viewer and reviewed for cloud cover and seasonal distribution.² Three images were chosen based on relatively equal time intervals: October 23, 1986, July 31, 1999, and February 2, 2011.³ Only general land use classes were deemed beneficial given their intended use and were assigned to the following groups: Agriculture, Forest or Established Vegetation, Low Vegetation or Regrowth, and Urban Area of Manmade Materials.⁴

Images were processed initially in ENVI 4.4 by removing a subset of the study area for all bands excluding thermal. Data were converted to radiance images in BIL format, and then atmospherically corrected using ENVI's FLAASH module. To improve separation of classes, the following additional images were created for each original image: Normalized Difference Vegetation Index, Tasseled Cap transformation outputs Wetness-Greenness-Brightness, 3/4 and 3/5 band ratios, and either Low Pass Gaussian or Laplacian of Gaussian texture bands based on

a visual assessment of their respective ability to define features. Classification was done using these additional as well as the atmospherically corrected bands within Trimble's eCognition Developer 8.0 using a Segmentation Object Oriented method. Following segmentation, objects were edited to a minor extent in order to help isolate roads and their impacted area from surrounding vegetation.

Within each image, sample objects were selected for each class based on visual interpretation of natural color RGB and false color infrared band combinations with average band values recorded for each object in Microsoft Excel. Decision tree rules generated using See5 version 2.09, and classification done based on these rules as threshold values within eCognition's assign class function.⁵ An accuracy assessment was done for the 2011 image based on visual interpretation of the high resolution imagery within Google Earth using 35 randomly generated points within ArcMap for each class. The results are given in Table 1. Difficulty in separation between forest and low vegetation is believed to be the result of overall hydrologic stress within the ecosystem due to the season of image acquisition.

	Urban	Forest	Agriculture	Low Vegetation	Row Total
Urban	32	0	3	0	35
Forest	0	26	0	9	35
Agriculture	0	0	31	4	35
Low Vegetation	0	9	2	24	35
Colum Total	32	35	36	37	140

Producers Accuracy	100.00%	74.29%	86.11%	64.86%
User's Accuracy	91.43%	74.29%	88.57%	68.57%
Overall Accuracy	80.71%			

Table 1 Accuracy Assessment of 2011 LULC Classification

3.2 Basemaps

These layers can be displayed beneath any of the operational layers for better understanding of the physical and cultural environment, and are detailed below.

3.2.1 Site Plans

Scans were made of paper maps from different sources⁶, and georeferenced using available coordinate locations for site areas within the database or the single coordinate available and a second coordinate generated at a determined distance oriented in a map cardinal direction to establish orientation and scale if no additional points were known. Even with the most recently published maps within the system, there is significant warping of the image when multiple known locations are used for georeferencing. Plans should be considered simply “nailed” to the map, and are available to indicate intra-site layout, distribution, and overall relation to the surrounding terrain.

3.2.2 Topographic Map Mosaic

The four topographic maps which comprise the study area were scanned as single images using a drum scanner. Georeferencing was done individually for each scan within ArcMap based on the longitude and latitude tick marks present every 2.5’ throughout the maps. These georeferenced maps were then mosaicked together to form a single image layer.

3.2.3 Natural Color RGB and False Color RGB

Color composite images are available from the three Landsat images that were classified to allow users to make a visual interpretation of the classification accuracy for their individual areas of interest. A natural color RGB image utilizes the red, green, and blue portions of the electromagnetic (EM) spectrum and represents what is visible to the human eye. The false color RGB images are in fact false color Infrared images where the Near Infrared portion of the EM spectrum is given the visible color red, the red portion of the spectrum is displayed as green,

and the green portion of the spectrum as blue. Such false color images are useful for visualizing vegetation differences, and emphasizing urban area and bare earth image brightness.

3.2.4 Mexico Orthophotographs

Like the viewable layers, this imagery layer is provided by INEGI as a web map service. It is a continuous mosaic of 1 to 20,000 black and white aerial images managed by INEGI with new imagery added when available. Unfortunately, detailed metadata is not provided for this layer, so the acquisition date of individual images is unknown.

4. Functionality & Discussion

Searching of sites and other data is available through customization of the eSearch widget created by Scheitlin & Caradec (2012) which allows query of data based on text input, graphical selection, and spatial searching based on an existing search result. As emphasized, this system is intended to offer more than simple display and query of database information. A number of tools are currently available within the application including drawing graphic and text features onto the map, distance and area measurement, buffering, and interactive viewing. Printing and saving of the display as digital images is also available.

Analysis functionality available includes viewshed generation and determination of a least cost path. Viewshed calculation is offered both as a quick approximation, as well as an Intensive Viewshed Calculator created as a geoprocessing tool within ArcMap. A viewshed is defined as the area visible from a specific location. This rigorous tool allows the user to determine viewer and observed elevation above ground surface, maximum viewing distance, and to select the input surface from the two database DEMs (see Figure 4). The Least Cost Path tool determines the path of least resistance between a user specified beginning and ending location. For example, it may be easier for a person to walk around the base of a mountain or

around hills rather than over them. Despite the prevalence of settlement density studies in much of the archaeological literature involving GIS, it is believed that much of the current distribution is the direct result of differential survey intensity throughout the study area. Any generated density output would then only show regions of intensive or more recent survey as opposed to older, less intensively studied regions.

Concern over ease of access to specific site location information leading to damage from looting or additional traffic is valid. However, all data accessible are, or are intended to be published in a traditional format, and would be available to potential thieves regardless. Though an increase in traffic to unmonitored sites could result in damage, improved awareness of the regions archaeology could boost the tourist industry beyond the major sites currently visited. Such an increased focus could lead to better monitoring by the authorities. While extensive public interest can “love sites to death”, an argument in favor of deliberate obfuscation or concealment of sites for protection, and corresponding loss of knowledge dissemination, is hard to support.

5. Future Directions

To avoid the hated “link rot” which plagues web information, this web system is not presented as a permanent resource. It is guaranteed to be maintained and updated with additional data and tools for a minimum of two years from the date of this publication. Results of the user response will be provided to aid and encourage the development of future web-based GIS applications. The database itself will continue to be developed overtime, and I am hopeful to be able to expand its coverage. Functions currently in development include selective download of GIS data based on user selection. Expansion of tools and data within the web application will mostly be driven by user demand.

6. Conclusion

GIS has grown in archaeology to the extent that students are often told it is an essential tool for a successful career. Desktop GIS is not going to be replaced because of the sheer power and range of functionality it can bring to intensively analytical projects, but for many researchers repeated recreation of databases can be a waste of time and resources. As the amount of available data increases, and barriers to technological deployment decrease, systems such as PRAGIS represent the next logical step for archaeological mapping. Access to comprehensive databases along with many of the basic functions needed for project planning, impact and access assessment within a managed, updated application that is freely available, brings digital mapping and spatial analysis to all interested archaeologists.

¹The website was last successfully accessed January 2012, but has since become unavailable. For an English description of the data set go to the USGS: U.S. – Mexico Border Environmental Health Initiative (BEHI) website at <http://borderhealth.cr.usgs.gov/Redirect.html>.

² From approximately January until late April or May there is little rain which makes identification of vegetation differences difficult.

³There is a gap in data from Landsat 5 TM for most of the 21st Century, and Landsat ETM+ data is not useable beyond 2003 due to the failure of the Scan Line Corrector. The only images available for Landsat 5 were January 26, 2010 and February 14, 2011, and the most recent image was used to reduce time discrepancy between the source data and the imagery used for accuracy assessment.

⁴Images were initially classified into five categories which included bare earth to separate it from Urban Area. Bare earth was later included within the Agriculture class.

⁵1989=130 samples; 1999=150 samples; 2011=200 samples. Initially 100 sample objects were collected for each image with additional objects added for specific classes following unsatisfactory classification results using generated decision trees.

⁶Itzimte-Bolonchen (von Euw, 1977), Uxmal (Graham, 1992), Xkalumkin (Graham & von Euw, 1992), Xcoch(Foundations for Americas Research, 2010), Chunhuhub, Xcochkax-centro & Xculoc (Michelet et al, 2000)

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Figure 1 Left: Urban Centers Dolores (left), Chunhaymil I (top), and Rancho Chimai (right); Right: All Sites layer with locations color coded by Urban Center (Images from PRAGIS)

Figure 2 ASTER DEM version 2 subset showing Power line artifact

Figure 3 INEGI 1:50000 DEM subset showing topographic map boundary resulting in DEM artifacts

Figure 4 Viewshed output analyzing visibility from Uxmal, Xcoch, and Nohpat. Areas visible by only one location are blue, areas visible by two locations are red, and by three purple (Image from PRAGIS also showing Urban Centers)