The first systematic study of settlement patterns conducted in the Maya area was the Belize Valley Settlement Patterns Project, directed by Gordon Willey in early 1954 (Willey et al. 1965). However, many of the antecedents of that project had their roots in the northeastern Peten of Guatemala. Alfred M. Tozzer commented on various mounds that he observed on muleback during his early work at Nakum (Tozzer 1913), but the greatest advance in the collection of regional settlement data was accomplished by Sylvanus G. Morley. During his expeditions in 1920s and 1930s, sponsored by the Carnegie Institution of Washington, he created site maps and described the sites that he visited as part of his documentation of Maya hieroglyphic inscriptions (Morley 1937-1938). Another Carnegie investigator, Oliver Ricketson, investigated cruciform transects radiating from the center of Uaxactun as an early attempt to research settlement patterns (Ricketson and Ricketson 1937). The settlement data collected by Ricketson was analyzed by Robert Wauchope, who used excavations and ethnographic analogy to argue for the domestic function of mounds on the periphery of the center of Uaxactun (Wauchope 1934, 1938).

After Willey introduced the study of modern settlement patterns in the Maya area, its importance increased in project design, especially in the northeastern Peten. Investigations by William Bullard covered around 250 km of forest trails, and it is estimated that the reconnoitered area covered some 6.25 km² (Rice and Puleston 1981:130). Using his research data, Bullard (1960) proposed a hierarchy of three levels of Maya settlement, consisting of house ruins, minor ceremonial centers, and larger ceremonial centers organized in groups, zones, and districts.

The Tikal Project of the University of Pennsylvania made major contributions to settlement pattern studies in the northeastern Peten. The map of Tikal (Carr and Hazzard 1961) showed that the density of Maya settlements was greater than what had been thought previously, a finding of major significance to settlement patterns. However, it was Dennis Puleston's investigations in Tikal (Puleston 1983) and his study between Tikal and Uaxactun that most comprehensively analyzed the density of settlement (Puleston 1974, 1983). This research was part of the Tikal Sustaining Area Project, an extensive study of settlement patterns which was supplemented by excavations carried out by members of the Tikal Project (Fry 1969; Green 1970; Haviland et al. 1968). Puleston's plea for further intersite studies was responded to by Anabel Ford in her Yaxha-Tikal transect (Ford 1981).

In 1981 Wendy Ashmore's study of settlement patterns in the Maya lowlands was published following a School of American Research seminar (Ashmore 1981). In this volume, Rice and Puleston refer to three patterns of settlement in the Peten: "In sum, our needs are many, our region large, and there is much work to be done" (Rice and Puleston 1981:155). In reply to this statement, Richard E. W. Adams introduced a new remote sensing technique to study Maya settlement patterns with the use of radar for mapping (Adams et al. 1981). Adams used radar images to identify systems of canals in the large bajos around Maya sites in arguing for intensive agricultural practices that could sustain large populations (Adams 1980; Adams and Jones 1981; Adams et al. 1981). This complemented an already growing interest in Maya agriculture and subsistence, as part of the general patterns of settlement study (Harrison and Turner 1978).

In the northeastern Peten, Quintana and Wurster (2001) have published a catalog of sites and an urban analysis of sites in six river basins including the Ixcanrio. However, the Río Azul Archaeological Project directed by Adams was the only large-scale archaeological project northeast of Uaxactun that operated in the era of the Tikal Project and the San Bartolo Regional Archaeological Project (Adams 1984, 1986, 1987, 1989, 2000). The settlement research of the Río Azul project focused on the sites of Río Azul and El Pedernal (and later Kinal), as well as the Bajo Azúcar and associated cultivation fields and canals (Black 1987; Black and Suhler 1986; Ellis 1989; Orrego 1987; Ponciano 1989). The Río Azul...
project recorded 27 sites including the three previously mentioned, but these were not sufficiently sampled to be included in the settlement pattern study.

Coincidentally the San Bartolo Regional Archaeological Project has followed in the footsteps of the Río Azul project with its interest in remote sensing and settlement pattern studies. The analysis of settlement patterns in San Bartolo is conducted by William Saturno and Thomas Garrison with the cooperation of Thomas Sever and Daniel Irwin of the National Aeronautics and Space Administration (NASA). Just as Adams collaborated with NASA on his radar mapping, the San Bartolo project has used new technologies of satellite imaging and remote sensing to solve the problems associated with settlement pattern studies in a tropic rainforest environment.

Technology

NASA has developed various remote sensing technologies that have been used in archaeology for several decades (Sever and Irwin 2003). The following is a brief summary of the available technologies, their benefits and disadvantages.

**Landsat TM and ETM (Sever and Irwin 2003)**

Landsat satellites have been routinely collecting earth-surface data for decades. The Landsat Thematic Mapper, or Landsat TM, and the Enhanced Thematic Mapper, Landsat ETM, have provided data at a multispectral resolution of 30 m (visible bands and near-infrared). The ETM also produces panchromatic data at 15 m to enhance the spatial resolution. Landsat is not high resolution compared to other technologies but it offers some advantages. The repetitive and systematic nature of the Landsat data means that it is possible to access the data from different ground receiving stations, extending over many years from a diachronic perspective.

A good example of this is that Maya causeways are better detected when there is a difference in humidity between the vegetation of the causeway and the surrounding natural vegetation. Hence specific precipitation events can either facilitate or impede the ability to detect Maya causeways or other anthropogenic features in Landsat data. If there were not multiple records of the same area this could lead to errors in the analysis of the imagery.

Another advantage of Landsat is that a single Landsat TM/ETM image is 185 km per side, which is significantly larger than the footprints provided by higher-resolution technologies. Thus drainages and complete aguadas can be seen in a single Landsat TM/ETM image. In the case of the Maya area, improved techniques have been utilized with Landsat images in order to distinguish islands in bajos in the great seasonal swamps of the northern Peten. **IKONOS (Sever and Irwin 2003)**

The high-resolution IKONOS satellite, launched in September 1999, provides panchromatic images at a resolution of one meter, as well as four multispectral bands (visible and near-infrared) at a resolution of four meters. IKONOS covers a nadir swath of 11 km and has been used to collect 700 km² of data in selected areas of the Peten. The resolution of IKONOS over Landsat is shocking. In views of the Tikal national park, individual stelae can be seen in IKONOS satellite imagery. The San Bartolo project has conducted one of the first extensive field tests of IKONOS imagery with detailed maps of the San Bartolo-Xultun intersite zone, as well as reconnaissance and field testing of an island in the middle of the large bajo northeast of San Bartolo (Garrison 2003). Details of the results of these investigations will be discussed below.

One of the great advantages of IKONOS data is that it makes it possible to locate oneself at an exact point in the landscape using GPS. The ability to locate objects in relation to individual trees, trails, or stream crossings helps clarify the exact distribution of settlement on the terrain. IKONOS images are also useful in indentifying small drainages that do not appear in the lesser resolution of Landsat. This leads to a better understanding of the hydrography of a particular region. It can be supplemented by a detailed classification of vegetation derived from panchromatic and four-band multispectral data, as well as further techniques under study. The great disadvantage of IKONOS is its cost. On the basis of square kilometers, IKONOS data is approximately 1500 times more expensive than Landsat.

**STAR-3i (Sever and Irwin 2003)**

In the late 1970s and early years of the following decade, Adams and his colleagues collaborated with NASA on a radar map of the Maya area, using SEASAT radar providing images at a resolution of 1:250,000 (Adams et al. 1981). The San Bartolo project will be using NASA’s STAR-3i to carry out what was achieved in the 1980s, but at a higher resolution. The radar uses microwave energy in place of visible-light energy to produce an image of the surface of the earth. It can be used at any time of day and can penetrate clouds. STAR-3i is an interferometric synthetic aperture radar system operated by Intermap Technologies that was originally developed by NASA’s Jet Propulsion Laboratory and the Environmental Institute of Michigan. Around 2000 km² of data have been collected by STAR-3i over the eastern Peten. The data collected over Guatemala include an orthorectified image (ORI) at 2.5 m and a resolution of 10 m (3 m vertical) over a digital elevation model (DEM). The ORI is generated from a point that spreads the information which can be used for visual interpretation. The DEM can be utilized for various applications, such as
topographic mapping, analysis of bodies of water, and analysis from a visual point. DEM is particularly useful for the identification of islands in bajos that are ambiguous or cannot be identified in Landsat imagery. DEM can also be used to create three-dimensional models to aid in visualizing terrain.

Quickbird (Sever and Irwin 2003)

Quickbird is a commercial satellite with the highest resolution available to the general public. Quickbird has a panchromatic band of 61 cm and four multispectral bands at a resolution of 2.5 meters. The acquisition of data for the San Bartolo region was delayed by the wars in Iraq and Afghanistan. However, the data have now been collected and will be available for analysis in September 2003. Unfortunately there are no cost estimates for Quickbird at this time, but it safe to say that it will be significantly more expensive than IKONOS.

Geographic Information System (GIS)

Sever and Irwin (2003) have begun to integrate data using ERDAS Imaging GIS Virtual software. The San Bartolo project will integrate the data arrays into an ESRI ArcInfo 8.2 GIS. In order to create models, the data arrays combined with GIS will be useful for restructuring the investigation design to maximize efficiency cost in investigating settlement patterns. With the high resolution of IKONOS and Quickbird and data from STAR-3i, it will be possible to utilize GIS for more than site-projection models, as is common in archaeological applications of GIS, since the located sites are immediately visualized. The catalog of 63 sites recently published by Quintana and Wurster (2001) will also be integrated into GIS in order to create a more complete spatial analysis.

Preliminary Results

The San Bartolo Regional Archaeological Project has conducted significant tests of IKONOS imagery during the 2003 field season (Garrison 2003). The first was the mapping of a bajo and peninsula near the San Bartolo-Xultun transect by Garrison and Robert Griffin. The second was the reconnaissance of an island in a bajo northeast of San Bartolo by Saturno, Garrison, and Griffin.

Chaj K’ek’ Cue

Previous to the 2003 field season Saturno had easily identified San Bartolo and Xultun in an IKONOS image by matching a distinctive yellow signature to the available color images. The most important structures of San Bartolo could be identified. Based on preliminary analysis it was decided that a peninsula between the two sites would be mapped in order to test a probable settlement area identified by Saturno. Garrison, using false-color IKONOS imagery, refined the location, identifying Maya settlement by observing blue inclusions in the yellow areas, indicating the presence of mounds.

The settlements on the peninsula were modest, with 39 mounds and 16 chultuns recorded. Additionally, numerous areas of activity and limestone and flint quarries were mapped by the research team. The settlement as a whole was named Chaj K’ek’ Cue, which means “Island of Thirst” in Q’eqchi’, with reference to the preliminary reconnaissance of the peninsula (Figure 1). Three distinct architectural groups were mapped, each one corresponding perfectly with the blue and yellow settlement markers in the IKONOS image. These correspondences were made by anchoring the site map to the IKONOS image with the GPS points taken during the season, at a scale of 1:5000. The digital IKONOS data has not yet been obtained in order to extract higher resolution results. However, the results of the 1:5000 imagery is sufficient to confirm the usefulness of these images in the identification of Maya settlements.

Isla Oasis

Toward the end of the 2003 season a brief reconnaissance was made by Saturno, Garrison, and Griffin to investigate a settlement on an island in a large bajo seen in the IKONOS image northeast of San Bartolo. In the course of the investigation various settlements were located within the bajo on an extension of the peninsula on which Chaj K’ek’ Cue is situated, including the sites of Las Minas and La Prueba (Figure 1). Maps were not made but numerous GPS coordinates were taken for mound groups, indicated once again by the blue and yellow signatures of ancient sites. Unfortunately, even with the technology available the reconnaissance team was forced to confront the “green hell” of the northeastern Peten, and many of our intentions went unrealized due to sickness, confused guides, and the absence of resources. However, more sites were identified by means of images, and it is safe to say that the 2003 season was successful in field testing of IKONOS satellite imagery, although it will be necessary to undertake more work in following years.

Future Prospects and Conclusions

The San Bartolo project is integrating the use of new remote sensing technologies from NASA in its project design and objectives in the long term. At the regional level the imagery will eventually contribute to the identification of all the sites in the 500 km² in the flight path of the IKONOS and Quickbird satellites. This will facilitate the formation of a new map of the Ixcanrio Basin. Locally and in the short term, the investigation of settlements in San Bartolo will be used as a test of the IKONOS and Quickbird data, identifying the strengths and weaknesses of the technology through intensive investigation and extensive excavation.
The San Bartolo–Xultun intersite area will be used as a sampling universe for this testing. The investigation of an 18 km coverage area will be completed in the next field season, followed by an extensive sampling program to identify chronological sequences in the area covered. The research in San Bartolo will be the first major investigation of an intersite zone between a Classic site and Preclassic one. This is an excellent opportunity for examining social and political changes in the Preclassic to Classic transition. In the analysis, settlement data will be integrated with paleoenvironmental, geological, and hydrological data in a geographic information system in order to generate models of demographic change associated with the decline of San Bartolo and the flourishing of Xultun as a regional power. Later these models will be supplemented by iconographic and epigraphic studies, which will aid in the attainment of a more specific and localized interpretation. Ideally, general social processes detected archaeologically will be associated with specific individuals of the elite population of both sites.

The remote sensing technologies under discussion here are extremely expensive as research tools. The San Bartolo project has benefited from NASA’s aid and is fortunate in having been selected to test the IKONOS, STAR-3i, and Quickbird technologies. It is to be hoped that in the process of investigating settlement in San Bartolo and Xultun going forward, and in the larger project of mapping the Ixcanrio Basin, the cost of this high-resolution imagery will be reduced and made more accessible for wider use. In 1981, Adams, Brown, and Culbert recognized that all the problems related to the use of SEASAT remote sensing radar could be traced to its resolution. It seems that these obstacles have been overcome by the researchers at NASA, and it is now in the hands of archaeologists to reapply remote sensing to the study of Maya settlement patterns and once again to change the level of detail with which regional studies can be made. It has been a long tradition of Maya settlement studies beginning with the aerial reconnaissance of Alfred Kidder and Charles Lindbergh seventy years ago (Kidder 1930), the use of radar mapping by Adams and his colleagues fifty years later (Adams et al. 1981), and now the application of new remote sensing technologies in San Bartolo and other regions. The results are anxiously awaited.

Figure 1. Detail of IKONOS satellite image. Site locations are indicated by a blue-and-yellow signature. Image courtesy of NASA/MSFC. After Garrison et al. 2008:Fig. 2.
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