Mapping ancient chinampa landscapes in the Basin of Mexico: a remote sensing and GIS approach

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Abstract

This paper uses remote sensing data to document a raised field, chinampa system adjacent to the Postclassic kingdom of Xaltocan in the northern Basin of Mexico. Various forms of landscape information; historic records and maps as well as remote sensing; are considered to understand the chinampa system. The remote sensing data examined include 1950s aerial photographs, Landsat 7 data, and Quickbird VHR, multi-spectral imagery. This article evaluates the utility of each of these forms of data to identify buried chinampa features and integrates them in a GIS to produce a map of Xaltocan’s chinampa landscape. Canals of various sizes and hydrological positions comprised the chinampas and integrated the system together. Occupying at least 1500–2000 ha, Xaltocan’s chinampa system represents the largest pre-Aztec, chinampa system in the Basin of Mexico.

1. Introduction

Almost 40 years ago, Pedro Armillas (1971) published one of the first reports on chinampa agriculture in the Basin of Mexico that resulted from archaeological research. Theoretically, he attempted to introduce an explicit landscape perspective into Mesoamerican archaeology. Armillas envisioned an approach that was not simply settlement or environmental archaeology but one wedded to the materiality of the landscape itself—a palimpsest on which the imprints of human action “are continually being erased and rewritten, and quite often smudged” (Armillas, 1971:665).

Armillas used remote sensing data, aerial photos, to initiate his research on Aztec chinampas in the southern Basin of Mexico: “Methodologically, the archaeological investigation of a cultural landscape begins with the interpretation of aerial photographs” (Armillas, 1971:665). This approach influenced the methodologies of central Mexican surveys of the 1960s and 1970s (e.g., Sanders et al., 1979). Since then, archaeologists commonly use remote sensing data in investigations on early hydraulic systems in central Mexico (e.g., Frederick et al., 2005; Morehart, 2009; Nichols, 1988; Nichols et al., 1991).

Following Armillas, this paper uses remote sensing data to document a chinampa system adjacent to the Postclassic kingdom of Xaltocan in the northern Basin of Mexico. Xaltocan was a political center in the Basin of Mexico before the Aztec empire (Fig. 1). Like Tenochtitlan, the later Aztec capital, Xaltocan was an island kingdom. Brumfiel (2005) documented its initial settlement during the 10th century AD, a time archaeologists refer to as the Early Postclassic period. By the 14th century (Middle Postclassic period), Xaltocan was an influential city-state. Like many other political communities during the Middle Postclassic, Xaltocan was embroiled in conflict. By the end of the 14th century, an alliance of kingdoms conquered Xaltocan. The population fled. The town was re-settled after the Aztec empire incorporated the northern basin 40 years later.

Unlike the relict chinampas Armillas observed, Xaltocan’s chinampas are completely buried by a layer of eolian soil, with virtually no visible topographic relief with the exception of some locations where the largest canals created minor depressions (Frederick et al., 2005; Morehart, 2009). In such situations, remote sensing data are valuable tools for discovering past agricultural systems (Lasaponara and Masini, 2011). This article evaluates the usefulness of various forms of landscape imagery and integrates them into a GIS to produce a map of Xaltocan’s chinampa system. First, I discuss and define chinampa agriculture as a localized manifestation of the broader technology of raised field agriculture.
Second, I provide an overview of available historical data on chinampas and other hydraulic systems around Xaltocan. Much of this historical information elucidates the anthropogenic landscape of Xaltocan and provides a crucial starting point for subsequent remote sensing (and field) investigations. Next, I examine the utility of 1950s aerial photographs, Landsat data, and Quickbird VHR imagery. These data were used to create a map of the chinampa landscape, which provides an opportunity to consider the farming system’s size and structure. I conclude with a consideration of some of the broader social, political, and economic dimensions of this work as well as the strengths and weaknesses of the remote sensing data used.

2. Background

2.1. Chinampa agriculture

Chinampas are one of the most widely discussed yet least archaeologically studied forms of prehispanic agriculture. The number of archaeological projects that have examined chinampas has grown (Avila López, 1991, 2006; Parsons et al., 1982, 1985; Frederick et al., 2005; Morehart, 2009). However, most information continues to come from indirect means: historic texts, quasi-mythic narratives, ethnographic descriptions, and ecological research (e.g., Coe, 1964; Crossley, 1999; Gomez Pompa and Jiménez Osorno, 1989; Palerm, 1973; Rojas Rabiela, 1991; Sanders, 1957; Santamaría, 1912; West and Armillas, 1950).

The term chinampa derives from the Nahuatl word chinamitl, meaning an area enclosed by a hedge or canes (Molina, 1944:21). Despite the specificity of this definition, the term is used by both scholars and agriculturalists to designate agricultural land in a wetland environment in which plots are elevated above water levels and surrounded by canals. Chinampa fields are typically narrow, around 4 m wide, but may extend in length up to 400–900 m (Santamaría, 1912:13). Often willows or cypress trees are planted along the edges to protect the banks from erosion.

As a form of raised field agriculture chinampas share similarities with comparable systems in highland and lowland regions of the New World. Raised field have been documented elsewhere in highland Mexico as well as in the lowlands of the Mexican Gulf Coast, northern Belize, and Guatemala (e.g., Denevan, 1970, 1982; Doolittle, 1990; Farrington, 1985; Fisher, 2005; Pohl, 1990; Pohl et al., 1996; Puleston, 1978; Puleston and Siemens, 1972; Scarborough, 2003; Siemens, 1983; Turner and Harrison, 1983; Whitmore and Turner, 2001; Wilken, 1987). In South America, raised fields characterize landscapes in the Andean highlands and the Amazonian lowlands (e.g., Bandy, 2005; Darch, 1983; Denevan, 2001; Erickson, 1993, 1994, 2006; Janusek and Kolata, 2004; Kolata, 1991; Stanish, 1994, 2006; Walker, 2011; Zimmerer, 1991).

Although the physical characteristics of raised fields vary intra- and
inter-regionally, they share some similarities. Unlike other agricultural landscapes, too much rather than too little water is the major constraint for raised field systems, including chinampas (Jiménez-Osorno, 1999). Raised fields are known for high productivity and sustainability even under intensive and continuous cultivation. Soil from canals is used as fertilizer, and the local aquatic environments are rich in resources that are harvested in conjunction with farming.

Raided field systems occupy central positions in “top-down” and “bottom-up” debates on the political economy of agriculture (e.g., Erickson, 1993, 2006; Janusek and Kolata, 2004; Morehart and Eisenberg, 2010; Stanish, 1994; Walker, 2011). In fact, chinampas provide a key historical example of pre-Columbian state influence over agriculture. Prior to the formation of the Aztec empire in AD 1428, chinampas existed on a limited scale along the edges of lakes Xochimilco and Chalco in the southern Basin of Mexico (Parsons et al., 1982). After the empire formed, the Aztecs implemented systematic chinampa agriculture in this region. The highly standardized chinampa layout over approximately 12,000 ha suggests state administration in their planning and construction (Armillas, 1971:660). These chinampas supported up to one-half of the population Tenochtitlan, the Aztec capital (Armillas, 1971; Parsons, 1976).

2.2. Xaltocan’s chinampas in the historical record

Chinampa agriculture’s association to Early and Middle Postclassic period political entities, such as Xaltocan, has received less attention than later Aztec (Late Postclassic period) chinampas. However, the existence of ancient chinampas at Xaltocan has been known for several decades and even centuries. The early 17th century chronicler Tezozómoc (1975:38) wrote that the Mexica (who would become a powerful ethnic group in the Aztec Triple Alliance) witnessed chinampas in Xaltocan at the end of the 12th century A.D. during their mythic migration into central Mexico. During the Spanish invasion, Cortés and Bernal Díaz del Castillo described Xaltocan as a town with many channels and canals (Palerm, 1973:37–39).

Discussion of chinampas is sporadic following the Spanish conquest. The Descripción del Arzobispado de México, written in 1571, states that Xaltocan had farms adjacent to lagoons, which might refer to chinampas (Paso y Troncoso, 1905a:35). Another significant record is a document made by Luis Carrillo de Guzmán in 1599, who visited the area to assess the capacity of local people to pay tribute (Frederick Hicks, personal communication 2009). According to this document, these areas were characterized by “lands of chinampas and nitrate [salitrales] and other flat, plain land in which they sow their fields, which are fertile and are fed from a river that passes to the east of the town and from the sources of water that come from Ozumbilla” (AGN Tierras 1584/1 ff.4v-5r). Ozumbilla, near an area also referred to as Ojo de Agua, would have provided one of the few freshwater sources in the brackish lacustrine environment (Frederick et al., 2005).

Carrillo de Guzmán also described chinampas in other nearby locations, such as San Joan Atenango, San Pedro Miltengo (Mil- tenco), Santa María Tenamitlan (Toniñita), and Santa Ana Nestitalpa (Nestitlapan). The Suma de Visitas, written in the mid-16th century, records that Nestitlapan had two harvests a year for both wheat and maize (one on irrigated land and the other on dry) (Paso y Troncoso, 1905b:166). Due to regional disparities in land quality, “chinampas from this town [Xaltocan] are divided up because those that they have are flooded...and thus each town is given [land] according to the number of people” (AGN Tierras 1584/1 ff. 30–31). The reference to Colonial towns using Xaltocan lands for agriculture may reflect the role of Xaltocan, then municipal capital (cabecera), in administering land resources to local residents not technically residing in the town itself.

Unlike the chinampas, the Ozumbilla springs are less ambiguous. They appear in several historic maps (Fig. 2). The Relación Geográficas de Chiconautla states that “in this jurisdiction there are

![Fig. 2](Image 132x75 to 473x339)
five rich sources from which water flows” (Paso y Troncoso, 1905c:172). The source and canals that led from it are also described in detail by Carillo de Guzmán. He not only describes a canal that led to Xaltocan from the source but that another major canal branched off and headed south toward Tonanitla:

They say that...this arroyo of water comes from the slopes of a bare hill [Chiconautla] where there are some small trees...and that the source from which the arroyo emerges is called the sources of Ozumbilla, and that this hill is to the southeast...and before arriving in the said town [Xaltocan] a branch of the said arroyo splits off and goes to the town of Santa María [Tonanitla] (AGN Tierras 1584/1, f. 6v).

The source also figures in the history of the drainage of the Basin of Mexico’s lakes. Don Luis de Velasco, Viceroy of New Spain (AD 1550–1564), ordered the diversion of the springs at Ozumbilla to create an artery to bring supplies to Mexico City and to alleviate the bad odor of the drying lake (González Obregón et al., 1902:69). Velasco’s efforts never got off the ground, but they represent the initial planning efforts to drain the basin’s lakes: the Desagüe. The springs and associated drainages were functioning in the 19th century. Orozco y Berra (1864:169–170) discussed the source principally in terms of fishing, suggesting a shift in the local economy. The springs can also be seen in 1950s aerial photos (see below), though they no longer exist.

2.3. Rediscovering Xaltocan’s chinampas

Frederick conducted the first archaeological study of Xaltocan’s chinampa system in the late 1980s (Frederick et al., 2005). Using aerial photographs made by the Compañía Aerofoto Mexicana in 1956, Frederick was able to partially map and estimate the scale of the system. In the aerial photos, the chinampas are visible as canals of various sizes and orientations (Fig. 3). Given the extent of the chinampa system observable in the photos, he estimated the size of the system to be between 100 and 200 ha.

Frederick identified the major canal that brought water into the chinampa system from the Ozumbilla springs (Fig. 3). This feature is clearly visible in the aerial photos and was between 50 and 80 m wide. It was critical in changing the hydrological nature of the lake environment, creating a less saline environment (Frederick et al., 2005:107).

3. Remote sensing data

The historical data and Frederick’s pioneering work constitute key sources of data on Xaltocan’s ancient chinampa landscape. However, the spatial extent and the structure of the chinampa system were still not well known prior to this research. To do so, I examined several different kinds of remote sensing data: (1) the same aerial photos Frederick examined; (2) Landsat data; and (3) Quickbird VHR satellite data. The utility of these data were compared, and they were integrated into a Geographic Information System (ArcGIS) to create a map of Xaltocan’s chinampas.

3.1. Aerial photos

The 1950s aerial photographs of the northern Basin of Mexico were incorporated in ArcGIS to reassess the spatial extent of agricultural features (Fig. 3). The images were scanned at 3200 dpi using an Epson Photo Flatbed Scanner, which produced sufficiently high resolution images to re-examine the landscape (Fowler and Fowler, 2005). The images were georeferenced using GPS ground control points collected in the field at historically persistent places (i.e., ranches, haciendas, or churches). A 95% linear Gaussian enhancement was applied to the imagery to accentuate the contrast between pixels prior to incorporating them into ArcGIS.

Based on this work, Frederick’s estimate of the size of the chinampa zone was too conservative: the area seemed to be at least 400–500 ha. Given that the springs were at least about 2.5 km south of the chinampas he documented, it is likely that the chinampas occupied an even larger area (see Fig. 8, lower right inset). The system was composed of canals of various sizes: the principal canal Frederick identified (Fig. 3, white arrows), smaller canals leading off from it, and narrow canals probably separating individual fields. Another major canal splits off from the principal canal south of Xaltocan and heads south (Fig. 3, black arrows). This canal is most likely the same one Carillo de Guzmán described that branched off and connected Xaltocan to Tonanitla. Moreover, a long narrow canal can be seen heading south from Tonanitla, though it does not appear to be connected to any other branching canals (Fig. 8, lower left inset).

3.2. Landsat data

Landsat 7 ETM + data were acquired and incorporated into the GIS to assess the applicability of satellite imagery. This imagery is comprised of 7 bands from the visible to the mid-infrared parts of the spectrum. Each band has an Instantaneous Field Of View (IFOV) of 30 m, with the exception of band 6 (thermal infrared), which has an IFOV of 60 m. These data also include a panchromatic image with an IFOV of 15 m. Thus, particular band combinations can be pan-sharpened to produce multi-spectral images with a resolution of 15 m per pixel (Parcak, 2009). Pan-sharpened composites were produced using ArcGIS’s raster processing tools. Fig. 4 presents a False Color, pan-sharpened composite made by assigning bands 4, 3, and 2 to the red, green, and blue color channels of ArcGIS (4–3–2 RGB).

The Landsat data show the major branching canal described in historic sources, though the source canal from Ozumbilla is less obvious. Additional possible canal features were detected to the northwest of the chinampa zone. Regardless of the band combination employed, the resolution of the pan-sharpened data was not high enough to detect smaller linear features. Nevertheless, this endeavor demonstrated the potential of satellite data.
3.3. Quickbird data

Archaeologists interested in identifying archaeological features are increasingly employing very high resolution (VHR) commercial satellite data (e.g., De Laet et al., 2007; Due Trier et al., 2009; Garrison et al., 2008; Lasaponara and Masini, 2007, 2011; Parcack, 2009). To better document the chinampa system, Quickbird VHR satellite data was obtained from Digital Globe (acquired March 3, 2005, during the local dry season). The imagery is multi-spectral, combining bands from the visible blue (Band 1), visible green (Band 2), visible red (Band 3), and near infrared (Band 4) parts of the spectrum. Like Landsat 7, Quickbird data also come with a panchromatic band. The multi-spectral images each have an IFOV of 2.5 m, whereas the panchromatic image is 0.60 m. Specific band combinations can be pan-sharpened to produce composite images with a resolution of 60 cm. Digital Globe delivered the imagery with a standard georeference, which was checked using ground control points and found to be adequate given the flatness of the terrain and the relatively restricted spatial scale of the study area.

Fig. 5 displays all four multi-spectral images individually over a section of the coverage. Canal features are clearly visible. Different bands accentuate specific surface attributes to varying degrees. For example, the very light areas in the near infrared image, especially the rectangular parcels, indicate the presence of green vegetation (or organic-rich irrigation water) because vegetation reflects strongly in the near infrared part of the spectrum (Lillesand and Kiefer, 1994). This band can be a useful if subsurface features affect the vitality of vegetation (Lasaponara and Masini, 2007; Parcack, 2009:91). In examining each individual band, however, it appears that none captures chinampa features better than any other.

Fig. 6a and b shows a pan-sharpened false color composite and a pan-sharpened true color composite of an area in the image. Despite differences in how each composite accentuates surface characteristics, little difference can be seen. In fact, isolated chinampa features were almost entirely overwhelmed by strong reflectance in the near infrared in many areas, especially in irrigated farm parcels. A normalized difference vegetation index (NDVI) can be used to better assess how buried features affect vegetation vigor (Lasaponara and Masini, 2007). I calculated a NDVI with the multi-spectral data (visible red and near infrared bands) using ArcGIS’s raster calculator (Fig. 6d). This technique emphasized areas accentuated by the near infrared band but almost completely obscured canal features. The low utility of the NDVI and the NIR alone, suggests that the NIR band is not useful for highlighting buried chinampa features. Several band combinations were tried but none had a global impact on accentuating archaeological features. In fact, the panchromatic image alone can be usefully employed to study the extent of chinampa features (Fig. 6c).

3.4. Mapping chinampas

The primary objective was to create a map to understand the scale and structure of the farming system. Because Quickbird imagery has a high resolution, it is an ideal source for mapping the agricultural landscape. Given the high degree of “noise” and the lack of a distinctive spectral signature for buried agricultural elements, digital feature extraction and edge enhancement techniques were not very successful except at extremely restricted spatial scales. Even combining a low pass filter to reduce noise and a high pass filter to enhance feature edges (Lasaponara and Masini, 2011:196) was productive only in localized areas. In order to map the chinampa landscape, however, it was often necessary to undertake such highly localized techniques to accentuate features. Envi’s Region of Interest tool (ROI) was useful for such spatially restricted tasks. Nevertheless, positive results of these analyses were always re-incorporated into the ArcGIS map.

Potential features in the satellite images were compared to areas in the aerial photos to better assess their identification as ancient, providing a useful historical check. Some had to be excluded from the map. For example, Fig. 7 shows a situation where a road that led west from a ranch in the 1950s left a linear shadow after it was shortened to meet the local highway (left) as well as a 20th century field boundary that no longer exists but left a linear feature in the landscape (right). This method reveals the continued utility of historic aerial photos even in areas where VHR satellite images are available.

4. The map

The map was made in ArcGIS by digitally drawing polyline and polygon features over canals, using polygons for major canals and lines for small canals adjacent to fields. Where identified, parcels were mapped with polygon features. Fig. 8 shows a map of the chinampa system. Its extent is much larger than Frederick et al.’s (2005) or my estimate using aerial photos: 1500–1600 ha is an acceptable (and likely conservative) estimate. It may be larger and extend farther south into the farm land of Tonanitla. An estimate of 2000–2500 ha is probably more accurate. In fact, if the area is expanded beyond the system’s primary canal network to include the major canal that leads south from Tonanitla and the springs (rather than just the canal emanating from it), the system would approach 3500 ha in size. However, I maintain the more conservative estimate between 1500 and 1600 ha.

The system’s structure can be characterized in terms of the size, shape, and hydrological position of canals. There were three types of canals, which I label primary, secondary, and tertiary. Two primary canals existed. One led from the springs at the Ozumbilla source. The other, discussed above as the branch, departed this...
Fig. 5. Four, individual multi-spectral band images comprising the Quickbird multi-spectral imagery.

Fig. 6. Comparison between (a) true color composite (3, 2, 1-RGB); (b) a false color composite (4, 3, 2-RGB); (c) the 60 cm panchromatic image; and (d) the results of a normalized difference vegetation index. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
canal south of Xaltocan and connected with Tonanitla. The canal connected to the Ozumbilla springs was approximately 4 km long, whereas the canal between Xaltocan and Tonanitla was almost 3 km in length. These canals were between 40 and 60 m wide.

The major functions of primary canals were as central freshwater arteries. The primary canal leading from the Ozumbilla springs was more hydrologically significant, bringing fresh, spring water into the brackish environment (Frederick et al., 2005:93). Given the degree of land modification in this region, it is not possible to estimate the amount of water that flowed from these springs. The other primary canal, the “branch,” is classified as a primary canal due to its size and linear nature. Its hydrological role in the chinampa system was secondary to the Ozumbilla canal. It likely was a transportation artery between Xaltocan and Tonanitla to the south, one of Xaltocan’s possible tributaries during the Middle Postclassic. Lastly, the linear canal heading south from Tonanitla may be another transportation artery connecting this area to communities farther south, such as Ecatepec.

The principal role of secondary canals was to distribute water from the primary canals into the heart of the chinampa system. In the central area, where they branched off from the primary canals, they formed a complicated network, unlike the standardized chinampa system that the Aztec’s would later sponsor in the south. Farther to the east, however, secondary canals appear more organized, possibly reflecting a need for greater network simplicity given their distance from the primary canal. Although these canals likely constitute a hydrological network in a topological sense, it is problematic to undertake a quantitative analysis of network complexity and connectivity with incomplete data (Haggett and Chorley, 1969).

Tertiary canals were “feeder” canals that separated individual fields. These are the long, narrow canals that give chinampas their characteristic appearance. They operated at the most localized spatial scale, providing water and access to individual fields. Most tertiary canals led off from secondary canals, though some were connected to primary canals. It was possible to map 1017 tertiary canals of various sizes. In areas where they are visible in the remote sensing data, the canals were between 1.5 and 2 m wide and the adjacent field surfaces were about 4 m, which is supported by excavation data on the chinampas (Morehart, 2009). On average, the mapped canals were 49.05 m long, though they have a standard deviation of 25.54 m and a range of 127 m. In some instances, canals had short lengths because newer canals truncated them. However, mapping tertiary canals is highly affected by preservation and visibility. They are the narrowest and shallowest. In areas that have been plowed, they are not visible and cannot be mapped.

Xaltocan’s chinampa system appears to have been parcelled into groups of fields. Parcels occupied a level of land integration above individual fields. They are delineated either by the presence of secondary canals that divide one parcel from another or by an abrupt reorientation of tertiary canals. The upper right inset of Fig. 8 shows a unique case where one large parcel (1.25 ha) had groups of fields with clearly distinct orientations bundled by a distinct secondary canal. Fig. 9 shows the chinampa system highlighting the distribution of mapped parcelled lands. It was possible to document 422 parcels. The number of fields in each parcel visible varies, ranging from three to four to over twenty. The lengths of fields in each parcel differ also, but generally larger parcels had longer fields. Sometimes it was possible to map parcels but not internal fields, and in other instances tertiary canals but not parcels. Notwithstanding the unavoidable gaps, the high degree of variability in parcel size is notable. The average area of a parcel is 0.25 ha, but the standard deviation is large, 0.30, and the range is 2.63. Nevertheless, caution must be employed when interpreting these figures given limitations in data coverage.
5. Discussion and conclusions

This report is focused only on exploring the utility of remote sensing data to identify and map the chinampas of Xaltocan, Mexico. But it is part of a larger project on the sociopolitical dynamics of chinampa agriculture (Morehart, 2009, 2010). Multiple excavations in the chinampa zone yielded unequivocal evidence of buried agricultural features. Although historical records suggest the continued use of these features following the Spanish conquest, this claim is not certain. Virtually all chronological data (AMS dates and pottery) date to the Middle Postclassic (AD 1200–1400), when Xaltocan was an independent polity. The chinampa landscape seems to have been mostly abandoned after the kingdom’s conquest. Later drained fields probably existed but on a more limited scale. The major canals no doubt continued in use, however, which may explain the historical records.

The integrated system of fields and canals described above likely represents the largest pre-Aztec chinampa system in central Mexico. This study provides dramatically larger estimations of the size and integration of Xaltocan’s chinampa system than previous approximations, results with significant implications for understanding the sociopolitical implications of agriculture. The global structure of Xaltocan’s chinampas is as much an integrated, irrigation system as it is a lacustrine, raised field landscape (cf. Palerm, 1973). In a lake setting with abundant freshwater, water scarcity may not create organizational problems requiring a high degree of coordination (Erickson, 1993). Where freshwater is scarce or is confined to specific sources, such as at Xaltocan, farmers must coordinate their activities at greater levels of integration, which may involve the co-participation not only of individual households but of entire communities (Morehart, 2010:86). Together with integration, the size of the system also would call for some degree of supra-household administration (Hunt, 1988).

The combination of (1) large size and (2) a high degree of integration can make such socio-ecological systems susceptible to influence by pre-existing or emergent power-brokers not simply due to their physical characteristics but due to their social ones (Morehart, 2010:90–91). “Cooperative relationships are one way in

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Fig. 8. Map of Xaltocan’s chinampa system showing canal typology. The upper right inset is a close-up of Quickbird’s panchromatic image. The lower left inset shows the canal south of Tonanitla in the aerial photos. The lower right inset shows the springs in the aerial photos, which still existed in the 1950s. This inset, however, is not offset but is in its actual location in reference to the other mapped landscape features.
which local hierarchy is constructed and power exercised” (Cohen, 1999:7). The chronological correlation between Xaltocan's chinampas and its existence as an independent polity suggests a degree of dependence between the agricultural landscape and the political community. This aspect of Xaltocan's chinampas contrasts with the later Late Postclassic chinampas in the southern Basin of Mexico. These chinampas were not highly integrated but were influenced by the Aztec state (Sanders and Price, 1968:177), suggesting differences between these two cases in the mechanisms of integration of political institutions with the local institutions that govern farming landscapes.

The previous discussion of the chinampa landscape clearly displays a territorial bias, yet this was an aquatic agricultural system. Water was critical to the hydrological functioning and cycle of the system. The presence of canals allowed plants to be watered systematically via pot irrigation, using a pole with a bag attached (called a zoquimaitl in Nahuatl), or by splashing water onto plants with canoe paddles (Sanders, 1957:78–80; Santamaría, 1912:Fig. 3; West and Armillas, 1950:176; Wilken, 1987:170). Many scholars have argued that the proximity of field surfaces to canals allows the natural infiltration of water toward the center of the plots through the capillary fringe of upper soil layers, referred to as sub-irrigation (Rojas Rabiela, 1995:54; Sanders, 1957:76). Crossley (1999), however, observed that rather than facilitating sub-irrigation, water levels create warmer and more stable micro-climatic temperatures that protect crops from frosts that are common in this region during the dry season (see also Kolata and Ortloff, 1989).

Chinampa farming is closely integrated into local lacustrine environments. Lacustrine resources in central Mexico were important elements in both subsistence and market economies (Parsons, 2006; Sahagún, 1963). Up to the 20th century, residents collected fish and fish eggs, birds, insects, and other animals. Artifacts recovered from the chinampas, such as ceramic net weights for fishing or bird-hunting and ceramic pellets for hunting, suggest that past farmers undertook some of these activities (Morehart, 2010:268–273). The lakes were also sources for important non-domesticated flora. For example, between the 16th and 18th centuries, residents of Xaltocan and neighboring towns supplemented their incomes by making reed mats (Gibson, 1964:336). They likely integrated these activities with their agricultural strategies to obtain items for daily subsistence, for feasts or ritual events, or as goods to be traded in the market.

Different sources of remote sensing imagery were evaluated for this project. Landsat data are limited by their resolution. Aerial photographs and Quickbird multi-spectral and panchromatic images, however, are effective, especially given historical changes over the past 50 years. However, Quickbird data also had limitations. Grøn et al. (2011:2030) recently observed that “it is important to be aware...that spatial variations occurring within similar types of features due to ploughing, individual behavioral patterns in prehistory as well as variations due to the geological background noise can cause considerable variation in the way one type of archaeological feature will appear.” A mosaic of land-use practices surrounds Xaltocan. This diversity creates a considerable degree of “noise” that limits the global application of particular image analyses over the whole area. Mapping the system requires a technique that is flexible but is ultimately reliant on the knowledge of the individual analyst.

Specific band combinations were not very useful in distinguishing ancient agricultural features, including NDVI. This may be due to (1) the fact that the imagery was acquired in the dry season when most fields were bare and when non-agricultural vegetation was dormant, (2) the likelihood that buried features have little effect on vegetation, (3) the possibility that the signatures for the buried features have wavelengths located in parts of the spectrum not available in Quickbird data, or (4) that features have more “micro-level” spectral signatures that can only be discerned with hyperspectral data. Other archaeologists have had success in using specific band combinations and a NDVI to enhance past features (e.g., Lasaponara and Masini, 2007). Thus, imagery acquired in the rainy season may reveal associations between vegetation vigor and buried chinampas. However, many of these studies occurred (1) at more localized scales (2) on a small number of features (3) in a restricted area. Employing remotely sensed
topographic data is another option to map the landscape. High resolution LIDAR data, for example, represents a costly alternative that is not currently available for the study area. Micro-topographic field mapping may be useful too but likely only in small areas given the greater time investment compared to remote sensing. The application of both these methods is planned as a part of continuing work on the chinampas and the historical ecological region of the northern Basin of Mexico.

Despite some limitations, remote sensing imagery, particularly VHR satellite data, offered an effective strategy to identify Xaltocan's chinampa system, to map its extent, and to document its hydrological structure. This work provides a rare glimpse of an ancient farmscape that not only was an economic and ecological backbone of a broader political community. It was also a space where many past people spent much of their daily lives.

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