Describing Maize (*Zea mays* L.) Landrace Persistence in the Bajío of Mexico: A Survey of 1940s and 1950s Collection Locations[1]

K. J. Chambers[2,*], S. B. Brush[3], M. N. Grote[4], and P. Gepts[5]

[2] Geography Graduate Group, University of California, Davis, One Shields Ave, Davis, CA 95616.
[3] Human and Community Development, University of California, Davis, One Shields Ave, Davis, CA 95616.
[4] Department of Anthropology, University of California, Davis, One Shields Ave, Davis, CA 95616.
[5] Agronomy and Range Science, University of California, Davis, One Shields Ave, Davis, CA 95616.
[*] Corresponding author: Phone: 530-750-7820; e-mail: kimberlee_chambers@yahoo.ca.

Describing Maize (*Zea mays* L.) Landrace Persistence in the Bajío of Mexico: A Survey of 1940s and 1950s Collection Locations. Passport data for Mexico's Guanajuato State were used to locate the sites where maize was collected in the 1940s and 1950s in an effort to document and conserve diversity. A map presenting survey points illustrates that collections have occurred repeatedly in the same locations. Observations of these locations reveal that urbanization and industrialization, not high yielding varieties, are displacing traditional varieties. Non-linear principal components analysis was used to assess associations between variables in areas where maize persists. Landraces appear to be associated with mountains and mesas, mixed cropping, little or no access to irrigation and areas classified as having low agricultural capacity; conversely, landraces have more commonly been replaced in areas of high agricultural capacity. The areas of high agriculture capacity, located in the riparian areas and plains, also have been the easiest to develop for urban and industrial use. Increasingly high rates of urbanization and development in areas of high agriculture capacity will impede the conservation of crop diversity in these areas.

Key Words: Maize, crop diversity, in situ conservation, ex situ conservation, the Bajío, non-linear principal components analysis, Mexico, economic development, urbanization, industrialization, landraces, hybrid crops

Introduction

Many centers of crop domestication and diversity are experiencing rapid changes in agriculture practices resulting in the loss of crop varieties and the knowledge and customs that have sustained them (Brush 2004; Harlan 1975). Germplasm diversity is threatened by several factors including: replacement by high-yielding varieties, a shift to cash crop cultivation, change in land use, economic incentives to migrate or work off-farm, market integration, a dramatic reduction in the proportion of the population that farms, and infrastructure development (Aguirre et al. 2000; Bellon 2000; Serratos-Hernández 2002; Van Dusen 2000; Zimmerer 1991, 1996). Thus, more economically developed areas may have a greater probability of a loss of traditional landraces (Aguirre et al. 2000). In this paper, we examine sites of early maize (*Zea mays*) collection (undertaken in the 1940s and 1950s) to assess persistence of traditional varieties in an area of rapid agricultural and socioeconomic change.

Since the development of modern (high-yielding or commercial hybrid) crop varieties (MVs), there has been a concern that these are replacing the genetic diversity of important food crops (Harlan 1975; Plucknett et al. 1983). Many pro-

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ponents of the Green Revolution assumed that development in traditional agroecosystems would inevitably require the replacement of local crop varieties (landraces) with improved ones, and that the economic and technological integration of traditional farming systems into the global system would be a positive step enabling increased production, income, and well-being (Tripp 1996; Wilkes and Wilkes 1972). As Brush (2004: 175) notes, ". . . it has been assumed that modern crop varieties, which are broadly adapted, disease resistant and high yielding, have a natural and irresistible ability to replace traditional varieties that are locally adapted, disease prone, and lower yielding." Beginning in the 1940s, concerned observers cautioned that agricultural industrialization and the replacement of traditional varieties could have several negative impacts including: increased genetic uniformity, simplification of agroecosystems, and a trend toward monoculture (Wilkes and Wilkes 1972). In a letter to the Rockefeller Foundation in 1941, geographer Carl O. Sauer warned that "A good aggressive bunch of American agronomists and plant breeders could ruin native resources for good and all by pushing their American commercial stocks . . . The example of Iowa is about the most dangerous of all for Mexico" (cited in Wright 1984: 137). The introduction of modern varieties has resulted in monocropping and the virtual elimination of traditional varieties of maize in the American Corn Belt (Brush 2004). This common theory—that widespread adoption of high-yielding varieties has led to a reduction of biodiversity—is still prevalent. Supporting evidence is provided when looking at the agriculture of rice in the Philippines, India, and Bangladesh where high-yielding varieties have replaced more than 300 traditional varieties (Thrupp 2004).

Agricultural development institutions, such as the Rockefeller Foundation, responded to these potential problems in areas of agriculture origins and dispersals (Cotter 2003). In 1943, the Rockefeller Field Office opened in Mexico with the goal to "help Mexico help itself." One of the first projects concentrated on the collection and categorization of seeds from all over Mexico, North America, and South America. As a staff member of a Rockefeller Foundation-Mexico collaborative breeding program in the 1940s and 1950s, Edwin J. Wellhausen coordinated and took part in the systematic collection and preservation of native Mesoamerican maize germplasm against the day of its possible replacement or extinction. The result of Welhausen's work was the first thorough and uniform treatment of maize from throughout Latin America documented in a series of booklets describing the Latin American maize races (e.g., Wellhausen et al. 1952, 1957). For Mexico, Wellhausen et al. (1952) described and illustrated 25 races and three sub-races; moreover, there was mention of seven types poorly known at the time of the study.

After 60 years of concern, debate still exists about the impact of industrial agriculture and modern crop breeding on traditional varieties (Brush et al. 1992; Zimmerer 1996). Mexico is an important center for both agricultural diversity and development programs, yet it is still primarily planted in landraces of maize (Aquino et al. 2001). As Goodman (2004) notes, "Scientifically-improved corn has been around in Mexico since at least the mid or early 1930s. Yet this has had remarkably little effect on maize in Mexico."

There are arguments to support concerns that landraces are being replaced by high yielding varieties and that this is only occurring in a small percentage of agriculture areas. Brush (2004) notes that despite 30 years of crop collection and research, the replacement of traditional diversity by modern uniformity in crops remains more a presumption of what is likely to occur than a demonstrated fact. Furthermore, Brush (2004) draws attention to the fact that although genetic erosion has been a plausible "folk model" among crop scientists it has not been articulated thoroughly nor tested explicitly.

Aguirre et al. (2000) divided southeastern Guanajuato State into four environments based on growing degree days and with contrasting potential for agricultural productivity and infrastructure. Their findings indicate that landraces are dominant in all environments surveyed and that statistical differences in diversity arise when the development of infrastructure interacts with agroecological factors in an environment (Aguirre et al. 2000).

This paper presents data on the Bajío (Mexico) to understand the extent of the replacement of traditional maize varieties by high-yielding varieties and to identify common variables where landraces persist or have been replaced. As has been noted, if landraces are to be replaced by modern varieties, it is hypothesized that this will occur in areas of high agriculture capacity such as the Bajío. This study also addresses recent research drawing attention to concerns with ex situ collections (Berger et al. 2003; Hijmans et al. 2000; Jarvis et al. 2005). Early ex situ collection locations (dating from the 1940s and 1950s) were resurveyed to assess the comprehensiveness of early maize accessions from the Bajío region.

Biogeography and Agricultural History of the Study Site

The Bajío region is situated at the center of the modern Mexican Republic within the states of Guanajuato, Querétaro, Jalisco, and Michoacán. It is an extensive, fertile, and predominantly level area of approximately 26,000 square kilometers (km^2) without clearly defined boundaries. Although the word Bajío means "lowland," its elevation is mostly between 1,500 and 2,000 meters above sea level. The overall landscape is one of open plains interrupted by mountains. Besides its topography and varied environments, agriculture in the Bajío also has been shaped by the absence of intensive agriculture in Pre-Hispanic times, irrigation systems built during the Colonial period, evolving patterns of land ownership, and current economic pressures.

The Bajío is a complex, three-dimensional mosaic of soils and vegetation that partly masks the zonal effects of increasing aridity towards the north. Virtually all of the Bajío falls within the limits of the climatic region commonly known as the "tierra templada" since average daily temperatures do not vary much beyond 14° C in January to 22° C in May (Vivó Escoto 1964). About 80% of all rains fall in the summer months from June to September in the form of afternoon thunderstorms, with another 10% that falls in May and October. Considerable variations occur in both the intensity and incidence of these summer rains and the mountains accentuate rain-shadow effects. Portions of the Bajío nearly always suffer a period of water stress in the spring and failures of summer rains can occasionally bring severe droughts (Murphy 1986).

In contrast to most of Mesoamerica, the thriving agriculture systems of the Bajío were primarily the work of the Colonial period and not of Pre-Hispanic Mexican civilizations. During the Colonial period, the importance of the Bajío lay in its capacity to raise surplus food to supply the booming mining communities (Murphy 1986); a characteristic that gave it the description as "El granero de Mexico" (The granary of Mexico). The subsequent history of the Bajío was, in large measure, governed by the combination of a fertile soil and the absence of fixed settlement before the Spanish Conquest. It was the pattern of heavy, but highly variable summer rains preceded by a relatively hot, dry spring that determined the range of natural vegetation types and the limits of Colonial-period agriculture. Maize, which was planted by both landholders and share croppers, flourished in this climate and type of soil, whereas wheat required irrigation or proximity to running water if it were to survive the dry winter months (Murphy 1986).

The historical pattern of land tenure is reflected in the Bajío today, characterized by what Brading (1978) refers to as an unsuspected complexity in the pattern of land tenure. The land tenure pattern remains largely a mosaic of moderately sized *haciendas* and rented *ranchos*, but with occasional great estates and small independent farmers. In particular, the existence of a number of small landholders and tenant farmers, *rancheros,* is unique. Mexican agrarian reform (beginning in 1910) affected the highlands of Mexico where indigenous populations were already settled but did not have the same impact on farming systems of the Bajío. However, throughout Mexico, including the Bajío, agrarian reform granted primarily marginal, rain-fed lands to peasants (small-scale farmers), leaving developed and often-irrigated lands to large landholder farmers (Collier 1994).

Agriculture has retained its importance in the Bajío through the intensive cultivation of the limited expanse of good arable land. In some areas, irrigation has exploited water to the point of dangerously reducing the water table (Murphy 1986). The pattern that was established in the Colonial period—where owners farmed wheat on irrigated land and left the marginal areas for maize—continues today with cash crops (primarily for export to the United States) being farmed on irrigated land and peasant farmers growing maize for subsistence on non-irrigated land.

Today the Bajío is a center of industrialization and booming export agriculture. Broccoli is the major export crop, followed by cauliflower, cabbage, asparagus, garlic, onion, and strawberries. Tomatoes, green peppers, chilies, prickly pear cactus, green peas, snap beans, carrots, potatoes, eggplant, sorghum, and maize are produced for domestic consumption. The area is also important for fruit tree production, particularly avocado, guava, apples, and peaches. According to Mexico's *Instituto Nacional de Estadística Geografía e Informática* (INEGI), approximately 90% of the farming population in the Bajío are poor and depend on about 10% of the land despite the wealth of agricultural exports (INEGI 1980).

Recently, major urban centers such as Celaya, Irapuato, and Querétaro have become part of a new industrial corridor from Mexico City, across the Bajío, to León. This corridor symbolizes the contemporary Bajío, which is an area of rapid industrialization, booming export agriculture, and a population of over 4 million that is rapidly growing (Gobierno del Estado de Guanajuato 2006). The Bajío has received many migrants from Mexico City resulting in increasing population pressure while the state of Guanajuato has high labor migration to the United States, making it the second largest state in Mexico in terms of the number of migrants (Smith 2003).

Investigations in areas such as the Bajío can help provide a greater understanding of the interface between modern and traditional agriculture and whether landraces can persist in areas where it is theorized that only MVs and cash crops will come to dominate. Research has found that in the Bajío of Mexico—despite market integration, cash cropping, advanced infrastructure, a predominance of modern crop varieties, and a high percentage of labor out-migration—farmers continue to grow traditional varieties of maize (Aguirre et al. 2000).

Materials and Methods

For collections made in Guanajuato State in the 1940s and 1950s, passport information was obtained from CIMMYT (The International Maize and Wheat Improvement Center) and the United States Department of Agriculture. Data on collections are recorded by states, and not regions such as the Bajío; therefore, state data were used. Information on collections from the 1940s and 1950s was selected because these represent the earliest efforts to collect and document maize diversity in Mexico and were made during a time when MVs had minimal impact.

Topographic maps (1:50,000 scale) for the entire State of Guanajuato were obtained from Guanajuato's INEGI office. The latitude and longitude coordinates for each of the 1940s and 1950s collection locations were marked on the maps with coordinates referring to an area that is 1.5 kilometers (km) by 1.5 km. Given that farmers do not always grow the same crops in the same field each year and that farms often have more than one field, we determined that finding maize 55 to 65 years later within these dimensions would represent maize persistence in the area where original collections were made. Using a GPS unit (GPSMAP 76S, Garmin International Inc., Olathe, KS) and the marked topographic maps, we located the original collection sites. We then surveyed the entire 1.5 km by 1.5 km site for maize fields. Based on the terrain and vegetation cover, it was relatively easy to survey the entire quadrant and to determine the presence or absence of maize. In urban areas, we drove or walked a grid (transects north/south and east/west). If no maize fields were visible (particularly in urban areas), we asked numerous people (local residents, shopkeepers, workers in nurseries and seed stores, market vendors, etc.) about the possible existence of maize in the area (including kitchen or home gardens). We also asked if they remembered the last fields of maize in the area. If we were still unable to locate maize, using a GPS receiver, a data point was taken at the center of the 1.5 by 1.5 km plot and we recorded latitude, longitude, and elevation. We then assessed whether or not the site was rural or urban. We estimated topography based on the four descriptions included in Butzer and Butzer (1997) (riparian/riverine, level plains, rough uplands [mesas], and mountains). If more than one accession had been collected in the same latitude and longitude coordinates, we treated these combined points as one site because more than one collection of the same information would be redundant.

For locations with maize fields we collected data using a GPS receiver (latitude, longitude, and elevation); noted topography; and calibrated plot size, slope, and aspect. We then asked residents and farmers in the area for the person who farmed the survey field. We interviewed the person responsible for the maize field to determine agricultural practices and varieties in the field. We asked the owner/renter if the field was planted in landraces (*criollos*) or modern varieties (*híbridos*) and, if they used irrigation, what method. If the field was planted in landraces, we asked how many varieties, how long they had been growing those varieties, and what other crops were planted in the field. For all maize fields we asked if pesticides, herbicides, and fertilizers were used. All farmers agreed to be interviewed. We took a data collection point at each field site and the field was sketched, described, and photo points taken. If there was more than one previous collection point for the 1.5 km by 1.5 km site, we attempted to find as many individual maize fields as collections and treated each as an individual point. In other words, if, during the 1940s and 1950s, 11 collections had been made in the same quadrant, we searched for up to 11 fields of maize and recorded information for each as an individual point. When observations are taken repeatedly at the same relative geographical coordinates (in the 1940s and in 2004), it is expected that such observations share many more characteristics in the explanatory variables and the persistence of landraces than truly spatially independent observations would share. Maize fields were surveyed on both non-commercial and commercial farms.

For all sites we obtained further data using resources at the INEGI office in Guanajuato; in particular, *Síntesis Geográfica de Guanajuato* (INEGI 1980). Information recorded included: geology, soil type, soil structure, vegetation community, climate classification, average rainfall, average temperature, number of days with frost (or with temperatures below freezing), and agricultural capacity. Agricultural capacity is a widely used reference (INEGI 1980) and uses a combination of variables including: access to irrigation, climate, topography, and manual or mechanized labor. INEGI (1980) rates land according to four levels of agricultural capacity: high (mechanized, high-yield potential, high labor, high irrigation, semi-dry soil), medium (mechanized, medium-yield potential, moderate labor input, low irrigation, semi-dry soil), low (manual, low-yield potential, labor intensive, no irrigation, sub-humid soil), and no agriculture capacity. Climate classification uses the Köppen system and soil data are based on the FAO World Reference Base for Soil Resources (1998). Figure 1 presents the format followed and data collected for each of the 1940s and 1950s maize collection locations.

Analysis

Two approaches were used to analyze data collected: mapping and non-linear principal components analysis (nlPCA). A map (developed in ArcGIS 9.0, ESRI, Redlands, CA) provides visual representations of the site locations. Non-linear principal components analysis, described in detail by Gifi (1990), was used to capture structure in the explanatory variables, to display the structure in two dimensions, and to assess qualitatively the associations between the explanatory variables and the persistence or absence of landraces. We used the "homals" function, which is available as an add-on package for the statistical software R (R Development Core Team 2005), to perform nlPCA. We utilized the explanatory variables (Agric. capacity [agricultural capacity], Other crops [other crops grown in the field surveyed], Plot size [size of field surveyed in square meters], Fertilizer [use], Irrigation [use], and Landscape [the ecogeographic zones of the Bajío] to construct the principal components. We also used "object" plots (depicting individual observations in the two-dimensional component space), labeled by the persistence or absence of landraces, to investigate qualitative associations between the explanatory variables and landrace persistence. A lack of associations between the explanatory variables and the presence or absence of landraces indicates no structure in the plot of labeled objects. Conversely, observable structure in the object plot may be interpreted in light of the explanatory variables. Kroonenberg et al. (1997) successfully used nlPCA to find and describe associations between a mixed (nominal, ordinal, numeric) group of descriptive variables and accessions of the Australian groundnut (*Arachis hypogaea* L.). We use similar methods for a mixed group of explanatory variables and presence or absence of landraces.

In the original variables for which data were collected (Fig. 1), there is little or no variation between sites for elevation, slope, aspect, names of landraces, number of years growing landraces, geology, soil structure, climate classification, average rainfall, average temperature, and number of frost or freezing days. We chose not to include these in the analysis as they would not increase the understanding of the persistence or absence of landraces. Landscape and vegetation community presented similar information; thus, landscape was the only variable used. We found that pesticide, herbicide, and fertilizer use were highly correlated, so we chose to use just one variable—fertilizer—to represent all inputs. Table 1 presents the variables used to determine the two-dimensional principal component space. Both landscape and agriculture capacity had two categories with relatively low counts. "Mountain" and "upland" vegetation communities were combined

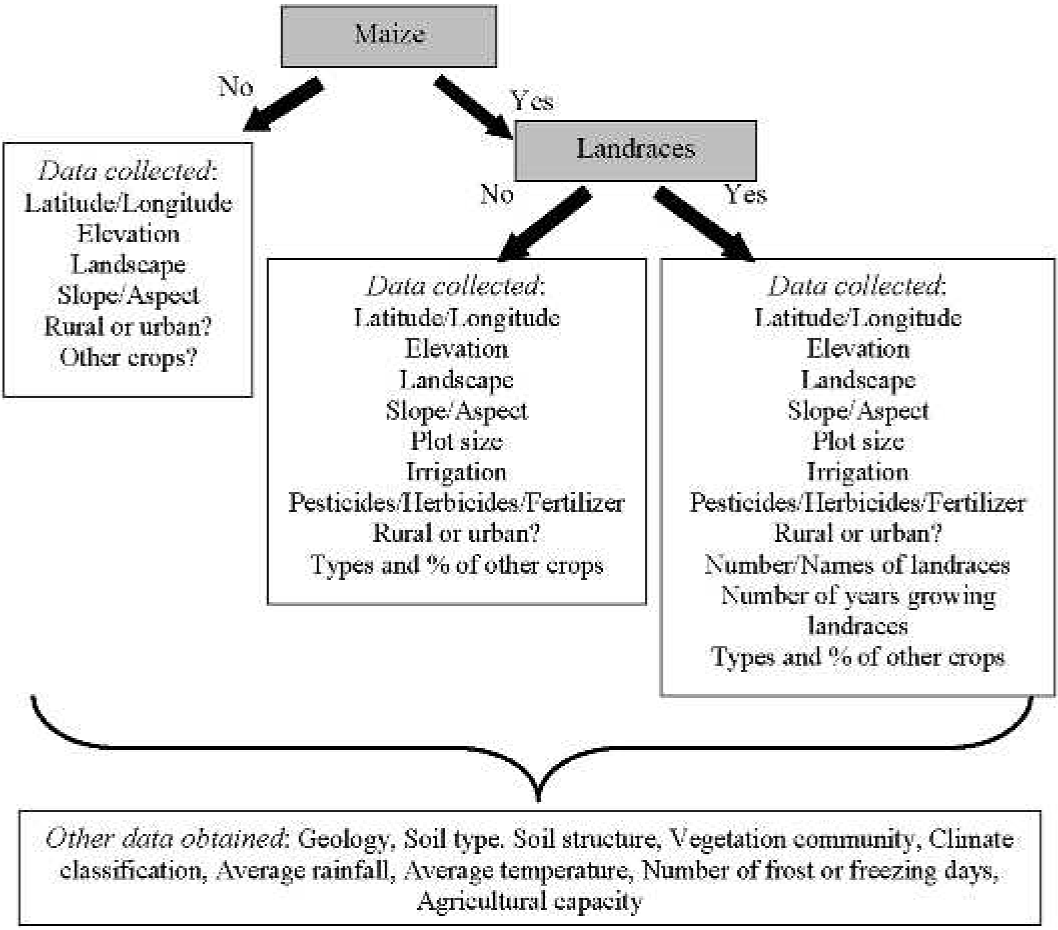

Fig. 1. A schematic of questions asked and data collected at each of the 1940s and 1950s collection sites surveyed.

to provide more numerically stable results. The same is true of "none" and "low" agriculture capacity. The variables used in the analysis represent key characteristics of maize locations in the Bajío.

Results

Of the 74 collections from Guanajuato made in the 1940s and 1950s, seven did not have location coordinates and four had incorrect latitude and longitude coordinates. We found that the remaining 63 points did not represent a diversity of locations throughout Guanajuato State, but were repeated in samples from 21 sites. The early sampling sites repeatedly visited over the 20-year period are primarily located in the southern portion of the state. Geographic limitation in the collections makes it difficult to truly assess change in terms of MVs (modern varieties) replacing landraces and could mean that the diversity of varieties grown in Guanajuato during the 1940s and 1950s was not fully surveyed. A total of 51 points (or fields or individual points for sites with no maize) were surveyed in the 21 sites with the number of accessions per site ranging from 1 to 11. Figure 2 illustrates the concentration of data collection points in 21 sites.

Errors with original data in early collections have been previously noted by Jarvis et al. (2005) who observed that, frequently, the locality data are missing or erroneous, especially for older collections. Furthermore, collecting localities often are distributed non-randomly in space, shaping distinct geographical biases (Marshall 1989; Hijmans et al. (2000).

Table 1. Variables Observed for Maize Fields in Guanajuato (Mexico) Based on Accession Locations from the 1940s and 1950s (46 Data Points)

Abbreviation	Description	Category definitions
Binary descriptors:		
Landrace	landraces of maize observed?	yes, no
Irrigation	irrigation used?	yes, no
Fertilizer	fertilizers used?	yes, no
Other crops	other crops in the field?	yes, no
Ordinal descriptors		
Agric. capacity*	agriculture capacity	none or low, medium, high
Unordered multicategory		
Landscape**	topography, vegetation, soils	riparian, plain, upland or mountain
Numerical		
Plot size	size of maize field	meters^2

* Secretaría de Programación y Resupuesto, Coordinación General de los Servicios Nacionales de Estadística, Geografía e Informática. 1980. Síntesis Geográfica de Guanajuato. Mexico, D.F.

** Butzer, K. W. and E. K. Butzer. 1997. The 'natural' vegetation of the Mexican Bajío: Archival documentation of a 16th-century savanna environment. Quaternary International 43(44):161–172.

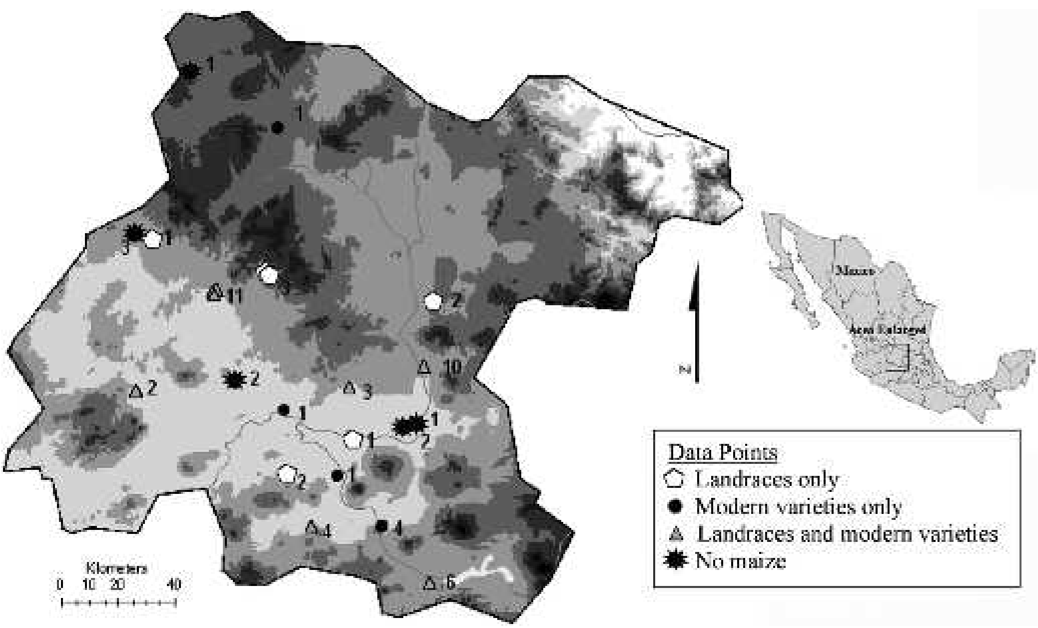

Fig. 2. Elevation map of Guanajuato State (Mexico) indicating the 20 sites (based on latitude and longitude coordinates) where accessions were collected in the 1940s and 1950s.*

*Twenty-one sites were sampled but two of the sites are too close in proximity to appear separately on the map. How many times a site was visited is indicated by the numbers beside the symbols. Elevation is not to scale but has been accentuated in order to emphasize contrasts.

Data Sources: Collection points surveyed summer 2004; Elevation data Hole-filled seamless SRTM data V1, 2004, International Centre for Tropical Agriculture (CIAT), avbailable from http://gisweb.ciat.cgiar.org/sig/90m_data_tr0pics.htm.

TABLE 2. LOADINGS FOR THE OPTIMALLY SCALED VARIABLES ON THE FIRST TWO DIMENSIONS*

	Correlation coefficients	
Variable name	Dimension 1	Dimension 2
Agric. capacity	0.35	−0.01
Other crops	0.27	0.04
Plot size	0.28	−0.12
Fertilizer	−0.27	0.16
Irrigation	−0.26	−0.24
Landscape (1st dimension)**	−0.28	
Landscape (2nd dimension)**		−0.24
Landrace	0.24	0.05

* Loadings are correlation coefficients between the optimally scaled variable and the two dimensions, respectively.

** Because Landscape was treated as an unordered multicategory descriptor, it received separate independent quantifications for each dimension and thus the correlations between Landscape and the two components pertain to these two independent quantifications (based on Kroonenberg et al. 1997).

There were 46 data collection points where maize was present and of these, 14 were MVs. We used nlPCA to describe characteristics common to points where landraces persist and, in contrast, where landraces have been replaced by MVs. A key aspect of nlPCA is the production of optimal scalings of the variables—mappings of the variable categories into a two-dimensional principal component space. Ordinal, numeric (real-valued), and binary variables have rank-one optimal scalings, meaning that the ordering of categories is the same in dimensions 1 and 2. The nominal variables have rank-two optimal scalings, meaning that the ordering of categories can be different in dimensions 1 and 2. Factor loadings are correlation coefficients between the optimally scaled explanatory variables and the two principal components. The loadings measure how well the principal components succeed in accounting for the variability of the optimally scaled explanatory variables (Kroonenberg et al. 1997). Factor loadings for the variables of Table 1 are given in Table 2. The loadings are small to moderate, indicating that the two components capture some (though limited) structure in these data. The relatively large, positive loading 0.35 for Agric. capacity on dimension 1 indicates a positive association between the first principal component and increasing agricultural capacity, whereas the small loading for Agric. capacity on dimension 2 indicates little discrimination of the levels of this variable by the second principal component.

These properties are illustrated by the notably horizontal orientation of Agric. capacity in the variable plot of Figure 3a. Variables with similar patterns (larger loadings on dimension 1 than on dimension 2) may be interpreted in an analogous way. The variables Landscape, Irrigation, and Fertilizer have loadings of similar magnitudes on both dimensions 1 and 2; therefore, both principal components are needed to describe structure in these variables. Landrace is treated here as a passive variable, and has not been used to determine the two principal components. Nonetheless, loadings for landrace can be calculated for the two dimensions determined by the other variables.

Continuing with the variable plots, Figure 3c shows that plot size is discriminated by the first principal component (with smaller plots in the negative part of dimension 1), and to a lesser extent by the second principal component. In Figures 3b, 3d, and 3e, principal component 1 is seen to discriminate mixed-crop fields lacking fertilizer and irrigation from fertilized and irrigated single-crop fields, and principle component 2 further discriminates the use of fertilizer and irrigation. Figure 3f shows that principal component 1 discriminates upland and mountain vegetation communities from plain and riparian communities, whereas principal component 2 discriminates plains communities from the others.

The plot of labeled object scores can now be interpreted using the two principal components. Each MV observation (labeled with "x") in the noticeable cluster in the upper right corner of the object plot shown in Figure 4 corresponds to irrigated fields in riparian areas. Because these observations have positive scores in dimension 1, they also tend to share characteristics of medium to high agriculture capacity, larger plot sizes, use of fertilizer, and monocropping. The three MV observations in the lower right corner of the object plot have unique characteristics; for example, one might be the farmer who is a butcher in the dry upland mesa growing MVs for livestock and another might be the farmer in the midst of urban development on the irrigated plain who continues to grow landraces.

Turning now to the fields in which landraces persist (objects labeled with open circles), we note that these observations are found throughout the object plot. A broad conclusion sup-

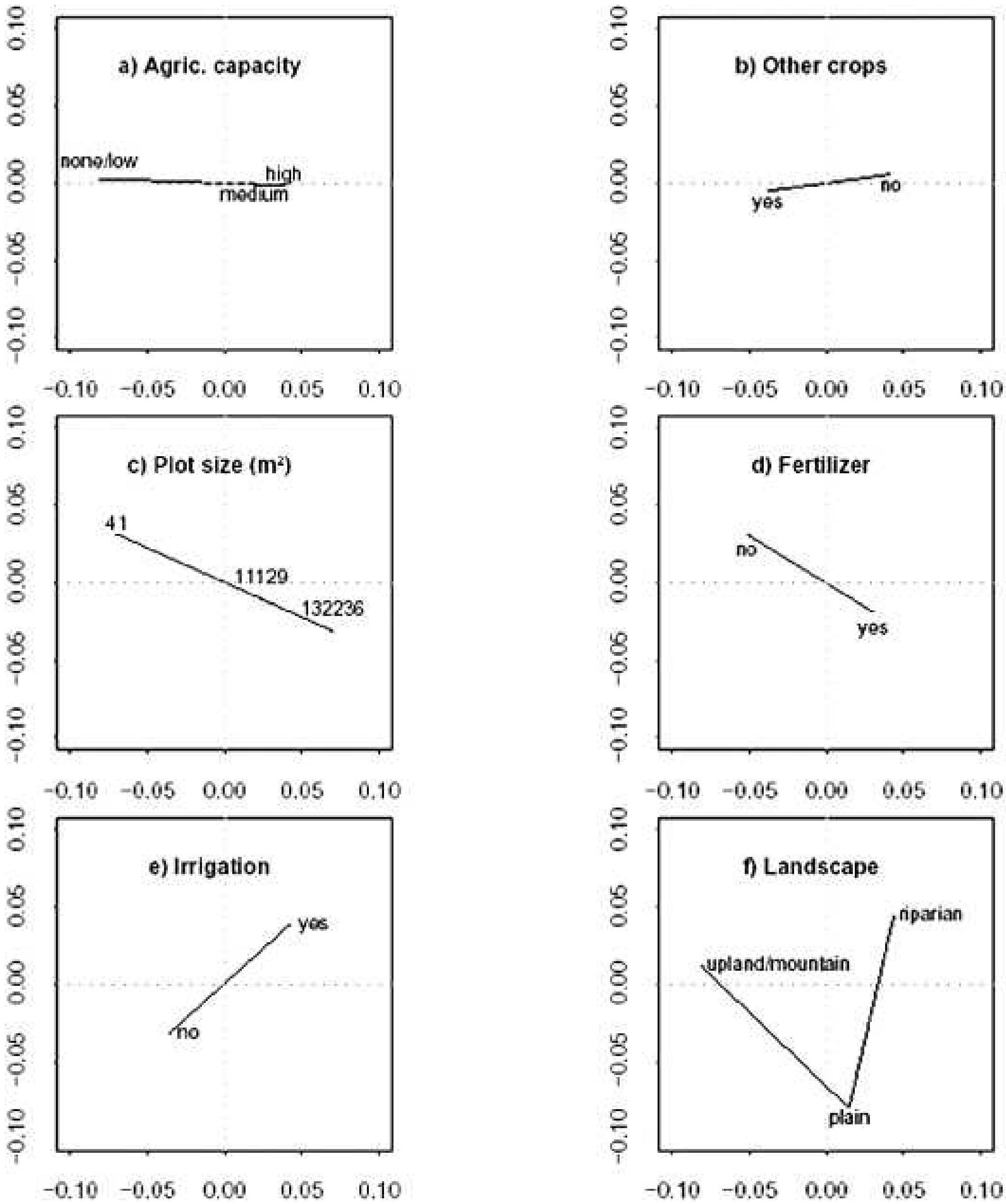

Fig. 3. Optimal scalings of six explanatory variables along the 1st and 2nd principal component vectors, based on the summer 2004 surveys of 1940s and 1950s collection sites.

ported here is that landraces persist under a wide range of circumstances from mountainous areas to irrigated valleys, large to small fields, and areas of high to low agriculture capacity. The noticeable cluster of landrace observations in the upper left quadrant of the object plot share the characteristics of none to low agriculture capacity, small plot sizes, upland or mountain vegetation communities, and lack of fertilizers. Because these objects have negative scores in dimension 1, they

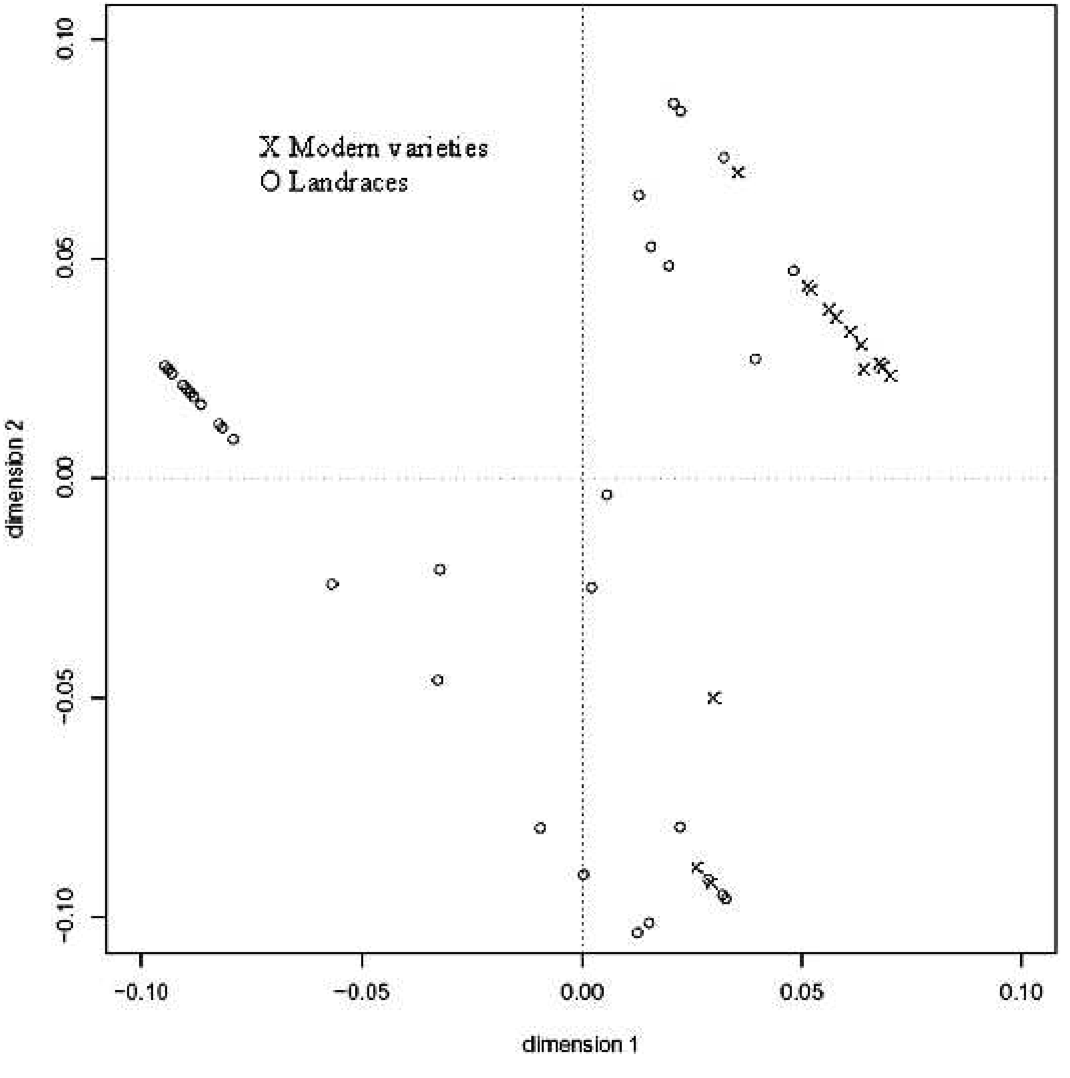

Fig. 4. Object scores in the two-dimensional principal component space, with objects labeled by presence (open circles) or absence ("x") of landraces.*

*The object score of an observation is the position of the observation in the two-dimensional space determined by the first two principal components. Objects located in specific regions of the two-dimensional space have similar values of the explanatory variables, and can be broadly characterized by the variable categories seen in Figure 3 to map to the same region. For example, observations located in the upper right corner of the object plot tend to be in riparian areas with irrigation.

also tend to lack irrigation and experience mixed cropping. Speaking with farm laborers harvesting fields of MVs on the edge of Salamanca (an irrigated area), one told us that they come down from the hills to work on the fields of MVs but in the mountains they grow *criollos*, or local landrace varieties. The use of the maize from these fields was also differentiated, with many farmers stating that the MVs were for animals or commercial seed, and the laborers adding that to find maize for food—tortilla maize—we would have to go the hills. The association of large plot sizes with MVs and smaller plots with landraces reflects the legacy of Colonial period landholdings in the Bajío, when large haciendas grew grains such as wheat and maize for commercial production and peasant farmers produced maize for subsistence on small plots of land in the more marginal agriculture production areas.

Discussion

Since the 1970s, there has been a concern that MVs of maize will replace traditional or landrace varieties (Harlan 1975). However, farmers continue to grow landraces to reduce production risks, manage pests and pathogens, avoid or minimize labor bottlenecks, fit different budget constraints, provide variety to diets, provide special consumption items, fulfill rituals, generate prestige, and forge social ties (Bellon 1996). Furthermore, MVs are not well adapted to the diversity of environments often found in farmers' fields or agriculture landscapes where irrigation is not available and soils may be poor. Another explanation why farmers are not adopting MVs is because they cannot afford the seed and required inputs such as fertilizers, pesticides, and herbicides. In Jaral and Acambaro, farmers told us that they were only growing MVs because they had been "given" the seed by Monsanto and Pioneer, respectively.

It appears that landraces are being replaced by industrialization and urbanization, not by modern and commercial maize varieties. The majority of the collection locations were clustered along major roadways and close to, or now within, urban areas. Of the 21 sites (representing clusters of the 51 survey points in 1.5 by 1.5 km areas) surveyed, five were found to no longer contain maize and three of these were in urban areas. The other two sites had recently switched to growing wheat and sorghum. Only four of 21 sites were found to have MVs and no landraces. For the individual data collection points, 46 of 51 had maize and 14 of these were MVs.

Like rare plants left in the remnants of landscapes and marginal habitats, some landraces of maize persisted in fragmented urban landscapes too steep for development. Urban development appears to influence whether or not maize is present, but does not necessarily inform on landrace persistence. Other maize fields persevere in enclaves surrounded by encroaching urbanization, particularly in the cities on the relatively flat plain, such as León and Silao. In Silao, housing developments spread around fields of maize on two sides with the main Guadalajara-Mexico City toll road a third side, and large factories, including Toyota, on the fourth. Farmers in these fields spoke of a constant pressure to sell their land and stated that yields suffer as a result of theft from the neighboring housing developments (basically shanty towns) that have grown up to the edges of their fields. In León, the one maize field we were able to find within the coordinates was adjacent to a large Coca-Cola factory. The farmer told us that he only rented the field and did not think that the owners would renew his lease next year; there was a large "for rent" sign on the edge of the field adjacent to a major road. In Cortázar, the expanding highway passed through the quadrant and the maize fields were located underneath a freeway overpass.

In Commonfort, Guanajuato, and Valle de Santiago, the terrain is varied and in places very steep. It is on these slopes and in home gardens where we found small maize fields. It has been long recognized that maize diversity is found in environmental niches where different varieties respond to factors such as rainfall, temperature, soils, and freezing days (Brush 2004). To this we can add the concept of maize occupying "niches" in developed areas where there is nowhere else for the crop to grow.

An increasing concern is that the greatest threat to diversity may be when farmers abandon farming (Taylor 2003). The exodus of rural farmers to cities is occurring at a rapid pace around the world, not just in Mexico. The loss of diversity when farmers leave their fields is now being compounded by losses as cities swell to accommodate an exploding population and encroach on the surrounding agricultural areas.

Aguirre et al. (2000) concluded that landraces are dominant in all environments and that statistical differences in diversity are apparent when the development of infrastructure interacts with agroecological factors in an environment. Our research finds that landraces are more commonly found in marginal agricultural production areas and MVs increase in the areas of high agricultural production. These differences could result from the fact that the research area Aguirre et al. (2000) used was southeastern Guanajuato State and our research was the entire state. We add to the work performed by Aguirre et al. (2000) the observation that urbanization and industrialization are impacting the presence or absence of landraces. Given industrial and urban demands for land and the added pressures for water, landraces of maize will likely continue to be marginalized into the areas of lower agricultural capacity and

MVs, if present at all, will be replaced by buildings. This pattern is not unique to the Bajío, or even Mexico, but is an acknowledged trend that is occurring in important agriculture areas around the world such as the Central Valley of California and the Fraser Valley in British Columbia.

Concerns over genetic erosion in maize refer to not only those varieties grown in areas of lower agriculture capacity but to the varieties that have done well in the lowlands and fertile plains of Mexico as well. These varieties may carry important traits for future adaptations and can provide alternatives to MVs in areas where the water table is dropping or the climate is shifting; varieties that require less water would be beneficial. The irrigation system of the Bajío is a legacy of Colonial Mexico that pre-dates the development of MVs (Murphy 1986). In general, the Bajío has very little water with only one perennial river. Many of the reservoirs are silting up, and there is an increased pressure from industrial development, resulting in additional loss of water quantity and quality. Landraces generally require less water than MVs and may provide a solution to the concern over reduced water in the future.

Both ex situ and in situ conservation are important for protecting crop diversity. Finding ways for in situ conservation to persist in these areas of high agriculture capacity with increasingly high urbanization and development may be the greatest challenge in the near future. Although small areas with traditional maize populations are likely to persist in an industrialized and urbanized landscape, further research is needed on the viability of these populations for the purpose of in situ conservation. Viability may be compromised by such things as inbreeding and lack of heterozygosity, the lack of knowledge of seed sources, or social networks to obtain seed. Our research suggests that the most likely area for the loss of traditional maize is in the region with high agricultural and urban/industrial capacity. While in situ conservation of maize within the core area of this region may not be practicable, it is possible that very similar maize populations will persist in the periphery of the high capacity region, and these would make ideal targets for in situ conservation.

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