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A Regional Analysis of Maize Biological Diversity in Southeastern Guanajuato, Mexico

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Contents

Abstract

Four environments with contrasting potential for agricultural productivity and infrastructure development were identified in Guanajuato State, Mexico, to test hypotheses about the relationship of maize biological diversity to the region's potential for agricultural productivity and infrastructure development. Samples of all types of maize grown by a random sample of farmers were collected from each environment. The maize samples were classified by race, racial mixture, or type of "creolized" or improved variety. Landraces were the dominant maize class in all four environments; the use of improved varieties was negligible. Several diversity indices were calculated, and no statisticallly significant differences were apparent between the enviroments with the most contrasting agroecological and infrastructural conditions. Statistical differences in diversity are apparent when the development of infrastructure interacts with agroecological factors in an environment. Qualitative data suggest that the richness of maize populations may be associated with maize yield potential in a geographical area, whereas the evenness of maize populations may be associated with the presence of infrastructure. These findings suggest further hypotheses about regional patterns of maize diversity.

Resumen

Análisis regional de la diversidad biológica del maíz en el sureste del estado de Guanajuato, México

Este estudio examina la relación entre la diversidad biológica del maíz presente en una región con su potencial de productividad agrícola y el grado de desarrollo de su infraestructura. Con el propósito de poner a prueba ciertas hipótesis acerca de esta relación, se identificaron cuatro ambientes con características de productividad potencial e infraestructura contrastantes en el suresete del estado de Guanajuato, México. En cada uno de estos ambientes, se colectaron muestras de maíz de todas las variedades sembradas por una muestra aleatoria de agricultores. Las muestras de maíz fueron clasificadas por la raza, mezcla racial, o el tipo de variedad mejorada o acriollada a la que pertenecían. Las variedades criollas fueron dominantes en los cuatro ambientes, y el uso de variedades mejoradas es muy limitado. Varios índices de diversidad fueron calculados con los datos recabados. No se encontraron diferencias estadísticamente significativas entre los ambientes más contrastantes en ninguno de los índices de diversidad. Sin embargo, si se encontraron para un ambiente, donde el desarrollo de la infrastructura y el potencial productivo parecen interactuar. El patrón en los datos cualitativos sugiere que la riqueza de las poblaciones de maíz puede estar asociada con el potencial productivo de un área, mientras que la equidad en la distribución de las muestras parece estarlo con la presencia de infraestructura. Los resultados de este estudio sugieren algunas hipótesis sobre los patrones regionales de la diversidad biológica del maíz.

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Introduction

Mexico lies within the world's primary region of maize diversity. Mexican farmers are not only heirs to this diversity, but many of them continue to maintain it, together with the extensive knowledge and management practices that have shaped it for generations. Social and biological scientists are concerned about the potential loss of maize diversity as Mexican agriculture modernizes. With modernization, farmers experience new commercial opportunities and economic incentives to migrate or work off-farm (Barkin 1987; Brush, Bellon, and Schmidt 1988; Hernández 1985; Ortega-Pazcka 1973).

Concern for diversity loss has led to research aimed at describing and understanding the factors that influence the diversity of Mexican farmers' maize populations. Previous research has included detailed farmer- and village-level studies of the diversity of maize varieties and their management (Bellon and Brush 1994; Louette, Charrier, and Berthaud 1997), as well as national comparisons of the use of improved varieties versus landraces based on secondary data (Yúnez, Taylor, and Barceinas 1994). Hernández (1971) and Ortega-Paczka (1973) have analyzed state-wide collections of landraces over time to assess changes in their composition and in the relative occurrence of certain populations. The study described here is unique because it provides a regional context for comparing the roles of socioeconomic and agroecological factors in determining maize biological diversity. The study region of southeastern Guanajuato State, Mexico, is of particular interest because it borders one of the most commercialized, productive maize growing areas in Mexico, the Bajío.

The first two sections of this paper explain the conceptual basis of the study. The next section describes the site selection process and methods used for the study. Findings are summarized and discussed in the fourth section. The final section presents the implications for genetic resource conservation.

Maize Biological Diversity

In the study described in this paper, maize biological diversity was defined and measured on the basis of ear samples collected from the maize populations grown by a sample of farm households drawn from several communities in a specified environment of the study region. Farmers recognize and name maize populations as units, such as varieties or types. A variety is composed of all of the lots of seed that different farmers use and recognize as forming distinct units and that share the same common name (Louette, Charrier, and Berthaud 1997).

Maize taxonomists and geneticists classify maize populations by the race or combination of races to which they belong. A maize race is defined as "a group of related maize plants with enough characteristics in common to permit their recognition as a group…. From the standpoint of genetics a race is a group of individuals with a significant number of genes in common, major races having a smaller number in common than do sub-races" (Anderson and Cutler 1942:71). The racial taxonomic classification system employed here, originally developed by Wellhausen et al. (1952), is based almost exclusively on observable characteristics of the ear. The system also reflects folk taxonomies historically and currently used by Mexican farmers. Despite the development of more powerful taxonomic tools, race remains an important concept for understanding maize in Mexico (Bretting and Goodman 1989; Doebley, Goodman, and Stuber 1985; Sanchez and Goodman 1992). More than 30 races are found in Mexico (Bretting and Goodman 1989). Isozyme analysis and analysis of morphological characteristics reveal significant variation between races (Doebley, Goodman, and Stuber 1985; Sanchez and Goodman 1992).

Maize populations can also be classified by their breeding history. A modern variety has been selected for certain characteristics (such as high yield, short stature, or good response to fertilizer) using scientific methods. Landraces are crop populations that have become adapted to farmers' conditions through natural and artificial selection. In open-pollinated crops such as maize, "creolized" varieties are defined as improved varieties that have mixed with landraces in farmers' fields for at least several years, either through deliberate farmer practice or through natural outcrossing.

By combining these classifications, we can categorize any sample of ears collected from a variety grown by a farmer as follows:

1. *A pure race*, which is a maize population whose individuals show characteristics of only one race. The individuals in a race have a significant number of alleles in common, and their characteristics are sufficiently similar for them to be recognized as a homogeneous group.
2. *A racial mixture*, which is a maize population whose individuals show characteristics of two or more races.
3. *An improved variety*, which is a maize population that is the product of formal plant breeding.
4. *A creolized or rusticated variety*, which is a maize population that originally was improved but has been under farmer management for several seasons and has mixed with local maize populations.

Different numbers of samples (a sample consists of a group of ears identified as belonging to a variety by the farmer donating the sample) collected from a community or region may fall into one of these classes. Each group of classified samples can contain more than one race, racial mixture, improved variety, or creolized variety.

Although the idea of diversity is intuitive and has received great attention because of the global environmental movement (e.g., the Convention of Biological Diversity), it is far from simple to develop an operational definition and means of measuring diversity. Here we use several of the numerous diversity indices employed by ecologists (Magurran 1988) (Table1). All have been adapted from the literature on species diversity. Magurran (1988) defines species diversity as consisting of not one but two components—the number of species (also known as "richness") and the relative abundance of species (also known as "evenness") (Ludwig and Reynolds 1988). Because diversity indices generally attempt to express both of these components in a single indicator, these indices share the obvious disadvantage of confounding the effects of more than one variable by treating them as one (Ludwig and Reynolds 1988). The construction and comparison of several indices rather than one may therefore provide us with a more realistic characterization of the diversity present in a geographical region at any time.

A species count, or species richness, is clearly a function of sample size, and the Margalef index adjusts for sampling effect by weighting the number of species counted by the natural logarithm of the sample size. Another problem with a simple species count is that each species is given equal weight regardless of the frequency with which it occurs. Measures of evenness capture the relative abundance of the individuals within each species, across the species counted in the sample.

Two widely used diversity indices, the Simpson and the Shannon, incorporate richness and evenness into a single measure. The Simpson index is a function of the probability that two individuals sampled at random will belong to the same species. The lower this probability, the higher the diversity. The Simpson index weights the concept of relative abundance more heavily than richness (Magurran 1988). According to Harper and Hawksworth (1995:10), the Simpson index "suffers for some purposes because it is possible for a species-rich but inequitable community to have a lower index than one that is less species-rich but highly equitable."

The Shannon index is derived from information theory and is based on the rationale that diversity in a natural system can be measured in a similar way to the information contained in a code or message (Magurran 1988). This index is a measure of the average degree of "uncertainty" in predicting the species to which an individual chosen at random from a

Table 1. Definition and description of the diversity indices used in this study

Index	What does it measure?	Definition
Margalef	Richness	$(S-1)/\ln N$
Berger-Parker	Evenness	$1/(N_{max}/N)$
Shannon Evenness	Evenness	$H'/\ln S$
Shannon	Combination of richness and evenness	$H'=-\sum p_i \ln p_i$
Simpson	Combination of richness and evenness	$1-(\sum p_i^2)$

Note: S= number of classes (pure races + racial mixtures + improved varieties + creolized varieties); N= total number of samples summed over all classes (pure races + racial mixtures + improved varieties + creolized varieties); N_{max}= number of samples in the most abundant class; and $p_i = n_i/N$ is the number of samples in class i as a proportion of the total number of samples.

collection of *S* species (maize classes) and *N* individuals (maize samples) will belong (Ludwig and Reynolds 1988). The greater the uncertainty, the higher the diversity.

Any index of evenness should reach a maximum when all species in a sample are equally abundant and should decrease towards zero as the relative abundance of species diverges (Ludwig and Reynolds 1988). Both the commonly used Shannon Evenness (also known as *J'*) and Berger-Parker indices meet these criteria. The Shannon Evenness index is the ratio of the observed to the maximum diversity based on the Shannon index. The Shannon index is maximized when the total number of individuals in a sample is evenly distributed among the species represented in a sample. This maximum is given by the natural logarithm of the number of species. The Berger-Parker index is the inverse of the proportion of the sample occupied by the most abundant species.

In applying the concepts derived from ecological analysis of inter-species diversity to the study of within-species diversity, two important questions have to be answered: What is the equivalent of species, and what is the equivalent of an individual belonging to a species? For this study, we used the number of classes into which maize samples can be classified as the analog of the number of species. We defined maize richness as the number of distinct classes (pure races, racial mixtures, improved and creolized varieties) among the ear samples as analyzed by a maize taxonomist. Maize evenness was defined as the distribution of maize samples among these classes. For example, suppose that a maize taxonomist obtains ten samples of maize ears and identifies them as two pure races (pure race I, pure race II) and one racial mixture (racial mixture I), representing three classes. He or she then classifies four of the samples as belonging to pure race I, three as belonging to pure race II, and three as belonging to racial mixture I. As with other operational measures of diversity, this measure is imperfect. By counting as separate items a single race and a mixture that includes the same race, we overstate the presence of the race.

Regional Determinants of Maize Biological Diversity

Farmers' decisions to maintain or discard crop varieties as well as their decisions about the number and types of varieties to cultivate have been well documented in the anthropological and applied economics literature. There is also a good theoretical understanding of many of the factors that affect these decisions (Bellon 1996; Brush, Taylor, and Bellon 1992; Meng, Taylor, and Brush 1998; Smale, Just, and Leathers 1994). By contrast, little is known about the effects of these household-level decisions on crop diversity outcomes when the region is the scale of the analysis. Regional factors such as the agroecology of a crop production zone or the development of its infrastructure affect the range of choices made by each of the farmers who resides in the region. The converse is not true, however; these factors are not affected in a significant way by the specific conditions of any one farm or by the deliberate actions of any one farmer.

The central hypothesis of this study is that the agroecological and the socioeconomic conditions in a region are associated with its crop diversity, although the direction of the effect is difficult to specify *a priori*. Agroecological conditions are the climate and soils that determine the yield potential for a crop in an area; socioeconomic conditions are the presence of infrastructure such as roads, stores, clinics, and schools. These conditions define the potential of households and their members to participate in markets as consumers and producers as well as to acquire new ideas and information. Among other factors, the presence of infrastructure may contribute to cultural change in a region.

We can investigate the relationship between these factors and crop diversity in a region by comparing areas with contrasting productivity potential (good versus marginal) and infrastructure availability (low versus high). These comparisons are illustrated in Figure 1. Each quadrant represents contrasting levels of each of the two factors. We can imagine a third axis depicting the crop diversity present in the regions as an outcome of these two factors. Given that diversity has several components, measurement on this axis entails the use of more than a single index. Comparisons among areas allow us to analyze the association between any one of these factors and the individual diversity indices while keeping the other factor constant. We can also observe the relationship of the interactions between the two factors and crop diversity.

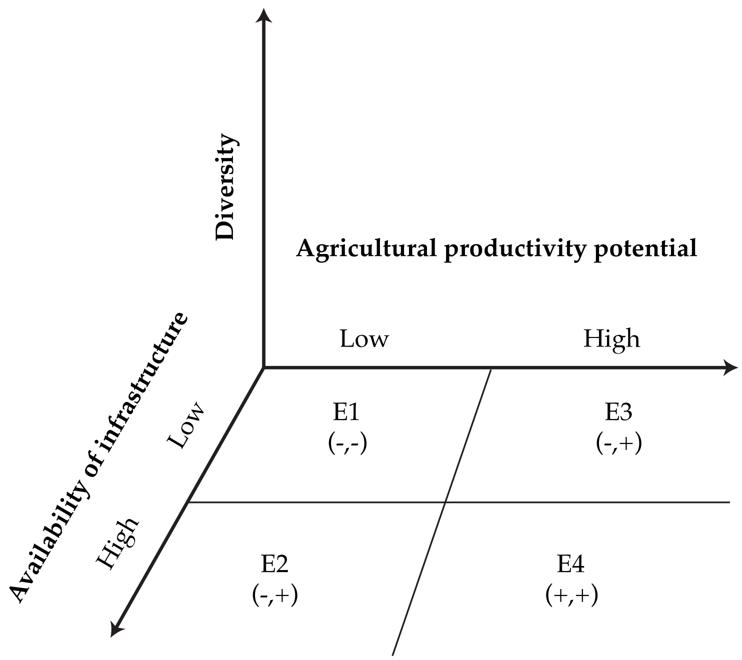

Figure 1. Conceptual model of comparisons: agroecological versus socioeconomic conditions.
Note: E = environment.

Study Environments and Methods

The study was conducted in Rural Development District 004 in the southeastern part of Guanajuato State. The region has great agroecological variation, with annual rainfall ranging from 550 mm to more than 850 mm and altitudes of 1,500–2,700 masl. Most agricultural soils are Vertisols and Phaeosen. Most farmers cultivate their crops under rainfed conditions, although a few have access to irrigation. The average landholding for this region is 8 ha, compared to an average of 6 ha for the state and 4.8 ha for the country[1] (INEGI 1991).

1 These numbers refer only to area planted to any crop and do not include other land uses.

Areas with contrasting yield potential within this region were identified based on research by the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) in Guanajuato (García 1989; Tapia and García 1991), in which the concept of growing period (GP) was used to classify areas by maize yield potential. Growing period is defined as the number of days during a year when moisture and temperature are favorable for the development of a crop (FAO 1981; Villalpando 1983). This parameter also accounts for soil depth as a factor in determining the moisture available to the crop. Areas with a long GP are considered to have a higher productivity potential than areas with a short GP. Since rainfall is variable, areas are classified according to different probabilities. Figure 2 shows five geographical areas in southeastern Guanajuato. Each area has a probability that a GP of at least the lower bound of a specified range will occur in seven out of ten years (a 70% probability) (García 1989). In southeastern Guanajuato, the most contrasting conditions for the 70% probability level are the isolines for GPs of less than 80 days and of 140 or more days. The municipalities of Apaseo el Grande and Jerécuaro are each located within one of these isolines. Apaseo el Grande represents the area with the lowest potential for agricultural productivity and Jerécuaro represents the area with the highest potential in the study region.

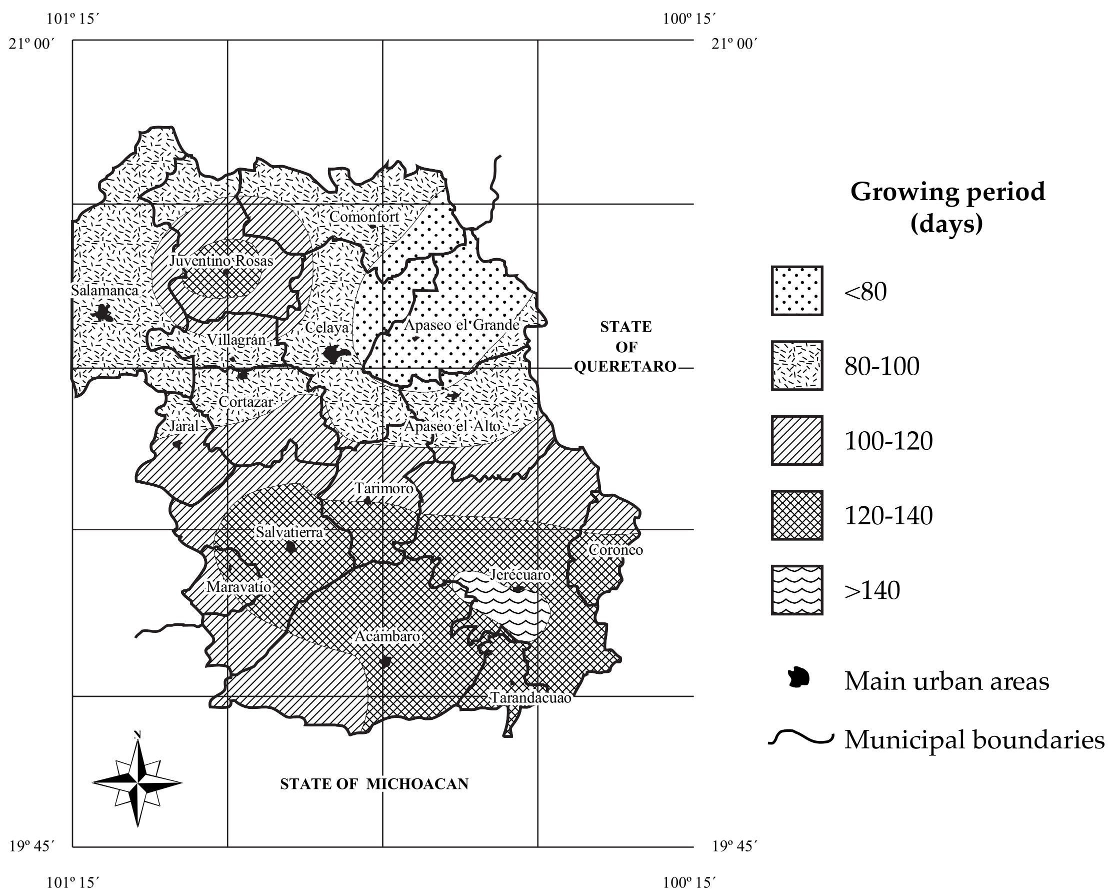

Figure 2. Isolines of growing periods (70% probability that growing period will occur), southeastern Guanajuato, Mexico.

Source: García (1989).

To identify communities with contrasting infrastructure within the two municipalities, we used secondary data from diagnostic studies (INCA RURAL 1987; FMDR 1987). These studies described the availability of infrastructure, including roads, schools, electricity, health centers, and business establishments for all communities within the municipalities. Based on the data we selected isolated (integrated) communities in each municipality with low (high) availability of infrastructure.

Combining the agroecological and the socioeconomic data, we defined four environments: E1, with low agricultural productivity potential and availability of infrastructure; E2, with low agricultural productivity potential and high availability of infrastructure; E3, with low availability of infrastructure and high agricultural productivity potential; and E4, with high agricultural productivity potential and availability of infrastructure.

From a complete census of households engaged in maize farming in the communities identified in the four environments, lists of 400 households were enumerated in each community (a quadrant in Figure 1, representing a stratum). From each list of 400 households, a systematic random sample of 10% of households was selected, for a total sample of 160 households located in 21 communities in four environments. The sample is self-weighting, since the probability of selection is equal across strata. There was no apparent periodicity in the list used to draw the sample.

Fieldwork was conducted from August 1995 to January 1996. In each selected household, the person in charge of agricultural production was identified and interviewed. The interview was based on a questionnaire that elicited information on socioeconomic characteristics of households, maize plot and variety characteristics, as well as seed selection and management (detailed in Aguirre 1998).

After harvest, samples of all maize varieties planted in each household were collected from all households that had not already shelled their maize. Each sample consisted of six ears per variety selected by the farmer as representative of the variety. While this number of ears is not enough to capture the genetic variation present in a population, it is adequate to identify the races and racial mixtures present and classify the samples accordingly. In this study, analysis of diversity is confined to variation among classes and does not address variation within populations or classes.

In total, 257 maize samples were collected. Juan Manuel Hernández Casillas, a specialist in maize genetic resources at the INIFAP genebank, identified the specific races and racial mixtures found in the samples and classified them into the four categories described previously. Whenever possible, he identified the type of improved variety and the race involved in the samples of creolized varieties. Information provided by the farmers donating the samples was also used in the classification. As classified by Hernández, the six-ear sample per variety, per farmer, was the basis for the diversity indices and analysis described later.

One important operational problem in analyzing diversity indices is that because all data collected are used to develop the indices, it is impossible to generate a standard error and to test hypotheses about their differences. Ecologists solve this problem by using techniques such as the "jackknife" to generate variances for the indices (Magurran 1988; Zahl 1977). This technique yields approximately normally distributed jackknife estimates and also provides estimated standard deviations, making it possible to test hypotheses and produce estimates of confidence intervals (Zahl 1977). The technique consists of the sequential exclusion of each sample in the data and repeated calculation of the standard estimate V for each index. Each calculation produces a jackknife estimate, VJ_i. For each sample a pseudovalue (or VP) is then calculated:

(1) $VP_i=(nV)-[(n-1)(VJ_i)]$.

The best estimate of V is the mean of the pseudovalues VP. We can derive the standard error from the mean (VP) in the usual way (Magurran 1988). A confidence interval is then derived for the diversity index of interest using the mean and standard error. We used the jackknife method to generate 95% confidence intervals for each diversity index.

Maize Biological Diversity by Environment

The classification of maize samples revealed that landraces dominated in all four environments (Table 2); 92% of all samples were either pure races or racial mixtures. Improved varieties accounted for only 3.9% of the samples and creolized materials for 3.5%. The largest number of samples was collected in E1 and E3 (mostly landraces), followed by E4 and E2. Improved varieties were collected primarily in E4. Creolized varieties were more likely to be found in E3. It is important to point out that improved maize varieties have been available for more than 20 years in the neighboring region of the Bajío, but their adoption even in the integrated areas of the study region has been minimal. The dominance of landraces and racial mixtures is an indicator of their agronomic and economic competitiveness. These results are consistent with the findings of Perales (1998), who found minimal adoption of improved varieties in the highly commercial maize area of Chalco in the State of Mexico. Perales also concluded that landraces were competitive with improved varieties in terms of yield and net profits.

Table 2. Frequency of maize samples by class and environment (E), southeastern Guanajuato, Mexico

	E1		E2		E3		E4		Total	
Class	**No.**	%	**No.**	%	**No.**	%	**No.**	%	**No.**	%
Race	55	61.1	10	40.0	55	64.7	32	56.1	152	59.1
Racial mixture	34	37.8	11	44.0	25	29.4	16	28.1	86	33.5
Creolized variety	0	0.0	2	8.0	5	5.9	2	3.5	9	3.5
Improved variety	1	1.1	2	8.0	0	0.0	7	12.3	10	3.9
Total	90	35.0	25	9.7	85	33.1	57	22.2	257	100.0

The samples were also classified by grain color (Table 3). Most samples were white, followed by black, red, yellow, and pinto. In all environments white-grained materials predominated, although the importance of colored maize varied by environment. In the integrated environments (E2 and E4), the frequency of colored maize was much lower than in the isolated ones (20% in E2 and 15.8% in E4, compared to 42.2% in E1 and 34.1% in E3).

Yellow and pinto maize were found only in the two isolated environments. These results suggest that market integration may play a role in the diversity of grain color, with isolated environments having more diversity of grain color than integrated ones.

Table 3. Frequency of maize samples by grain color and environment (E), southeastern Guanajuato, Mexico

	E1		E2		E3		E4		Total	
Color	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
White	52	57.8	20	80.0	56	65.9	48	84.2	176	68.5
Black	21	23.3	2	8.0	19	22.4	4	7.0	46	17.9
Red	13	14.4	3	12.0	8	9.4	5	8.8	29	11.3
Yellow	4	4.4	0	0.0	0	0.0	0	0.0	4	1.6
Pinto	0	0.0	0	0.0	2	2.4	0	0.0	2	0.8
Total	90	100.0	25	100.0	85	100.0	57	100.0	257	100.0

Table 4 lists the specific races and racial mixtures to which the samples belong as well as their frequency by environment. Most of the races encountered have already been found and collected in the central part of Mexico (Wellhausen et al. 1952; LAMP 1991), although some unexpected races and landrace mixtures were also identified. As Table 4 shows, the samples represent a great number of races and racial mixtures. Three races (Elotes Cónicos, Celaya, and Conico Norteño) dominated in all environments, accounting for 54.9% of all samples. Mixtures of these three races as well as mixtures of Bolita with local materials were also common in all environments. A few races and mixtures were specific to certain environments, such as Amarillo Dulce and Tablilla de 8 in E1, Mushito in E3, and Tabloncillo in E4. Considerable variation was found within the race Elotes Cónicos in E1 and E3, including three different grain colors (black, red, and pinto). Maize belonging to the race Elotes Cónicos seems to play an important role in household consumption, because in addition to being used in *tortillas,* it is used to prepare specialty foods, including *tamales, elotes, esquites, pozole, pinole,* and *pontedure* (maize candy).

Table 5 presents basic data on diversity by environment and by combination of environments, including diversity indices and the number of unique races and racial mixtures. The number of unique races and racial mixtures is an indicator of rarity among maize populations.

The number of classes and unique pure races and racial mixtures was highest in E1, followed by E3—the two environments with comparatively poor infrastructure. The largest number of samples per sampling effort (40 farmers) was collected in these environments. E2 and E4 had a similar number of classes and unique pure races, although more unique racial mixtures were found in E2. In E2, the total number of maize classes, unique pure races, and racial mixtures was derived from the smallest number of samples. Only 26 of the 40 farmers sampled in E2 grew maize in the survey year.

Diversity indices vary across environments, and the ranking of each environment by diversity changes according to the index used. For the Margalef index the rank by environment is E1> E2> E3> E4. The indices are similar for all environments with the

Table 4. Frequency of races, racial mixtures, and creolized and improved varieties by environment (E), southeastern Guanajuato, Mexico

	E1		E2		E3		E4		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Pure races										
Bolita	–	–	1	–	–	–	–	–	1	0.4
Tablilla de 8	1	1.1	–	–	–	–	–	–	1	0.4
Tabloncillo	–	–	–	–	–	–	1	1.8	1	0.4
Amarillo Dulce	3	3.3	–	–	–	–	–	–	3	1.2
Mushito	–	–	–	–	3	3.5	–	–	3	1.2
Conico Norteño Tipo Pepitilla	1	1.1	–	–	2	2.4	2	3.5	5	1.9
Versión 1000 Granos	4	4.4	1	4.0	–	–	–	–	5	1.9
Conico Norteño	15	16.7	1	4.0	11	12.9	8	14.0	35	13.6
Celaya	11	12.2	4	16.0	15	17.6	15	26.3	45	17.5
Elotes Cónicos	25	27.8	4	16.0	26	30.6	6	10.5	61	23.7
Bolita * Olotillo	–	–	1	4.0	–	–	–	–	1	0.4
Racial mixtures										
Celaya * Elotes Cónicos	1	1.1	–	–	–	–	–	–	1	0.4
Celaya * Mushito	–	–	–	–	1	1.2	–	–	1	0.4
Celaya * Olotillo	1	1.1	–	–	–	–	–	–	1	0.4
Celaya * Tablilla de 8	1	1.1	–	–	–	–	–	–	1	0.4
Celaya * Tabloncillo Perla	1	1.1	–	–	–	–	–	–	1	0.4
Celaya * Tuxpeño	–	–	1	4.0	–	–	–	–	1	0.4
Cónico Norteño * Pepitilla	–	–	–	–	1	1.2	–	–	1	0.4
Elotes Cónicos * Pepitilla	–	–	–	–	–	–	1	1.8	1	0.4
Elotes Cónicos * Celaya	–	–	1	4.0	–	–			1	0.4
Mushito * Cónico Norteño	–	–	–	–	1	1.2	–	–	1	0.4
Mushito * Celaya	–	–	–	–	1	1.2	–	–	1	0.4
Tablilla de 8 * Cónico Norteño	1	1.1	–	–	–	–	–	–	1	0.4
Bolita * Celaya	1	1.1	1	4.0	–	–	–	–	2	0.8
Celaya * Bolita	–	–	2	8.0	–	–	–	–	2	0.8
Celaya * Tabloncillo	1	1.1	–	–	1	1.2	–	–	2	0.8
Cónico Norteño * Tablilla de 8	2	2.2	–	–	–	–	–	–	2	0.8
Tablilla de 8 * Celaya	2	2.2	–	–	–	–	–	–	2	0.8
Bolita * Cónico Norteño	–	–	–	–	2	2.4	1	1.8	3	1.2
Celaya * Pepitilla	–	–	1	4.0	1	1.2	1	1.8	3	1.2
Cónico Norteño * Bolita	1	1.1	–	–	1	1.2	1	1.8	3	1.2
Pepitilla * Celaya	1	1.1	1	4.0	1	1.2	1	1.8	4	1.6
Pepitilla * Cónico Norteño	–	–	–	–	1	1.2	3	5.3	4	1.6
Elotes Cónicos * Cónico Norteño	5	5.6	–	–	–	–	–	–	5	1.9
Elotes Cónicos * Celaya	3	3.3	–	–	3	3.5	–	–	6	2.3
Celaya * Cónico Norteño	5	5.6	1	4.0	1	1.2	4	7.0	11	4.3
Cónico Norteño * Celaya	3	3.3	1	4.0	8	9.4	4	7.0	16	6.2
"Creolized" varieties										
Cónico Norteño * AGIV[a]	–	–	–	–	–	–	1	1.8	1	0.4
AGIV[a]	–	–	–	–	–	–	1	1.8	1	0.4
Bolita * AGIV[a]	–	–	–	–	2	2.4	–	–	2	0.8
AGIV[a]	–	–	2	8.0	–	–	–	–	2	0.8
Celaya * AGIV[a]	–	–	–	–	3	3.5	–	–	3	1.2
Improved varieties										
Híbrido (Pioneer)	1	1.1	–	–	–	–	–	–	1	0.4
Híbridos (A791, An-447)	–	–	2	8.0	–	–	7	12.3	9	3.5
Total number of samples	90	100.0	25	100.0	85	100.0	57	100.0	257	100.0
Total number of classes	23	–	16	–	20	–	16	–	44	–

a AGIV= advanced generations of improved varieties.

Table 5. Indices of biological diversity by environment (E), southeastern Guanajuato, Mexico

	E1	E2	E3	E4
Number of types	23	16	20	16
Number of samples	90	25	85	57
Number of unique races	2	1	1	1
Number of unique racial mixtures	5	4	4	1
Margalef	4.8891	4.660	4.2767	3.710
Berger-Parker	3.597	6.25	3.267	4.237
Shannon Evenness	0.791	0.9409	0.7667	0.8419
Simpson	0.8662	0.912	0.8429	0.8686
Shannon	2.4802	2.6089	2.2969	2.3343

exception of E4, which has the lowest diversity ranking. The richness in E2 relative to E4 reflects the fact that the same number of maize classes was derived from a smaller number of maize samples in E2.

The two evenness indices (Berger-Parker and Shannon Evenness) give similar rankings for the environments (E2> E4> E1> E3), which suggests that environments with good infrastructure have a higher evenness than those with poor infrastructure. Given similar levels of infrastructure, environments with a GP of 80 days seem to be more even in the distribution of their maize populations than those with a GP of 140 days.

The Simpson and Shannon diversity indices, which express both richness and evenness in a single indicator, rank environments as follows: E2>E1>E4>E3. Compared to the rankings based on the Margalef index, the rankings based on Simpson and Shannon are different for GP. Although the environments with a GP of 80 days have more diversity than those with a GP of 140 days, within each GP the environments with good infrastructure (and higher evenness) rank more highly for diversity than environments with poor infrastructure (and lower evenness).

The fact that different indices rank environments differently illustrates the many dimensions of diversity, which are not necessarily positively correlated. Although the findings shown in Table 4 are qualitative, the patterns suggest that the potential for agricultural productivity may influence the richness of the crop populations grown in an area, while market integration may affect the evenness with which crop populations are distributed. The interaction of both factors (productivity potential and market integration) translates into different levels of diversity.

In many cases the ranking of environments by diversity index is based on small quantitative differences. The jackknife method described earlier provides a statistical basis for comparison. Figure 3 presents the 95% confidence intervals for each of the indices.

There are no statistical differences among the four environments for the Margalef index of richness, although environments with a GP of 80 days have a higher mean than those with a GP of 140 days. Based on the Shannon Evenness index, E2 is statistically different from all other environments, with a higher mean. Although there are no other statistical differences among the remaining three environments, E4 has a higher mean evenness than the

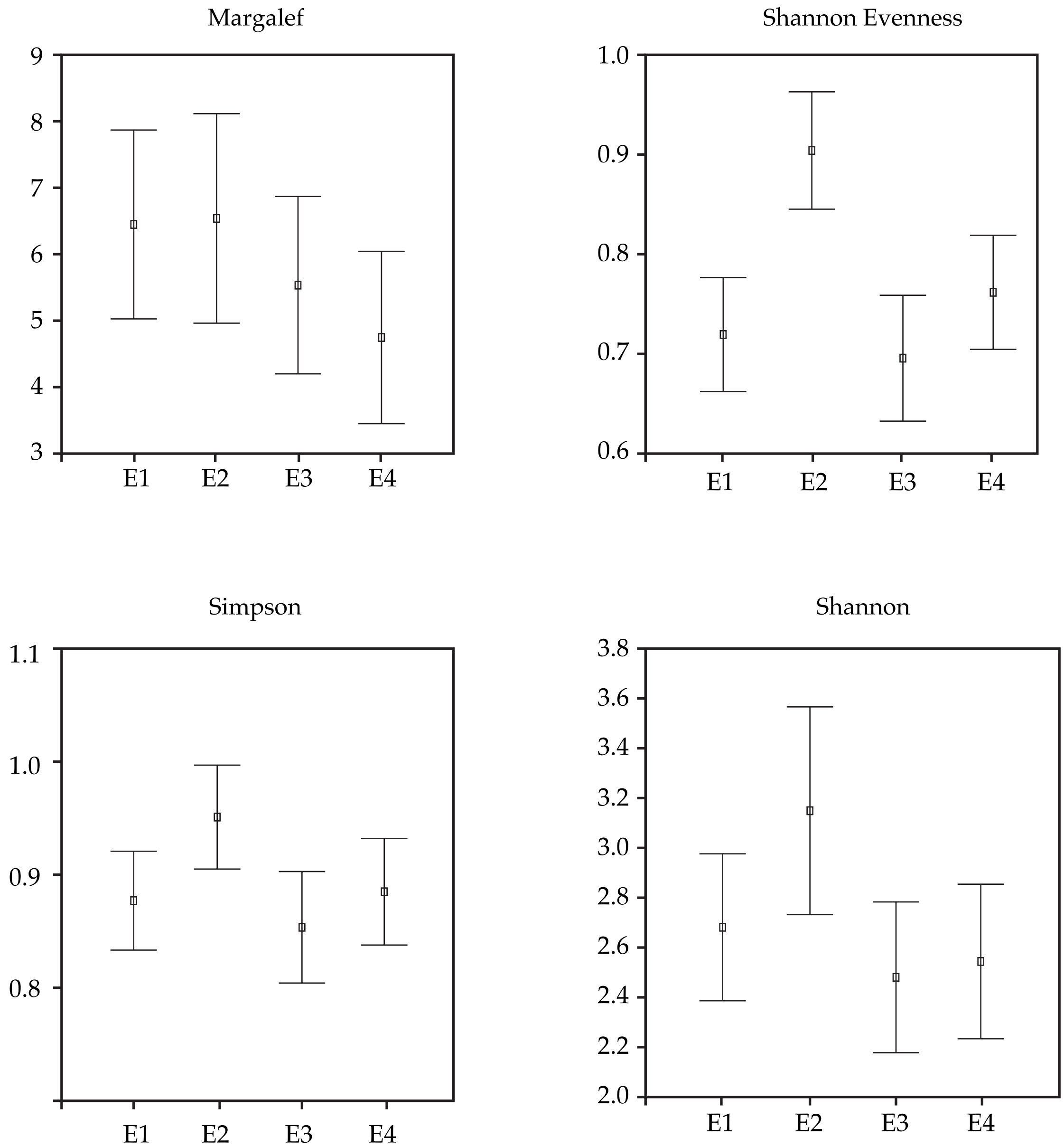

Figure 3. Ninety-five percent confidence intervals for the mean of diversity indices by environment, southeastern Guanajuato, Mexico.

remaining two. The mean of the Simpson index for E2 is also statistically significantly different from that of E3. This finding is consistent with the qualitative rankings for this index, in which E2 is the highest and E3 the lowest. The Shannon index shows no statistical differences by environment, although the mean is highest in E2. At a 90% rather than 95% level of confidence, the mean of E2 is statistically different from that of E3 (not shown).

The major result that emerges from this comparison is that environments with the most contrasting agroecological and socioeconomic traits (E1 and E4) are not statistically different from each other in terms of any of the diversity indices employed in this study. The analysis does not support the hypotheses that either the potential for agricultural productivity or the development of infrastructure is associated with maize diversity. This result holds despite the fact that distinct classes of maize are grown in each environment. This finding suggests that some indices may overstate the concern for loss of genetic resources in such areas. As shown by other studies, there may be reasons why farmers continue to grow a range of maize populations despite economic change (in other words, there may be reasons for *de facto* maize conservation) (Brush 1995; Brush and Meng 1998; Perales 1998). It is important to remember, however, that the study region is primarily rainfed and the maize populations grown in all environments are predominantly local. The range of variation among the environments in the study region does not include areas with widespread use of irrigation and extensive adoption of improved varieties. Over a wider range of opportunity costs for farm labor or consumer preferences, would these results hold? How many farmers are needed to effectively conserve a set of maize populations *in situ*? These questions cannot be answered in the context of this study.

E2 emerges as statistically different from the other environments, showing higher levels of diversity according to several of the indices. The few farmers who grow maize in E2 maintain a rich set of maize populations, and these populations are distributed more evenly than in other environments, leading to differences in both the Simpson and Shannon indices. Given the lack of difference among other environments, the superior diversity found in E2 suggests that there may be an association between diversity and the interaction of productivity potential and availability of infrastructure. This result suggests hypotheses for future work on regional patterns of maize diversity. For example, GP may influence the richness of the maize classes grown, while the availability of infrastructure may affect their relative abundance.

Although E2 is the environment with the greatest maize diversity, it is also an environment in which many farmers have abandoned maize production. While only 26 of 40 farmers sampled in that environment grew maize in the survey year, all or almost all farmers sampled in the other environments grew maize. One possible interpretation of this finding can be offered. In any area with increasing market development, the opportunity cost for farmers' labor will rise until it reaches a threshold above which farmers will no longer allocate any resources to maize production. Since the value of labor in the production system of a farm household is defined by the assets and other conditions specific to each household—including the value household members attach to special maize foods—not all farmers in a zone will reach this threshold value at the same time. Those who have not reached the threshold will continue to grow maize, maintaining roughly the same total number of classes as in other environments because there is a minimum set that satisfies their household requirements for special foods, fodder, and other maize needs. Cash income from other sources may effectively subsidize maize production in environments that are more marginal for growing maize, enabling households to continue producing the crop they value for non-commercial reasons. In a related study with this same data set, the most significant factors affecting the shares of area that farmers allocated to their maize varieties were related to the taste of *tortillas* or special foods (Smale, Bellon, and Aguirre 1998). Such characteristics are not usually traded on local markets in rural areas. Comparatively speaking, farmers in E2 grow more classes per sampling effort, and the relative abundance among the classes is greater. The uniqueness of an environment like E2 merits further research.

Implications and Conclusions

The richness, evenness, and rarity of maize landraces in an area are attributes of interest for planning and implementing any effort to conserve maize genetic resources. Given that E2 had the highest diversity and was statistically significantly different from the other environments, one might think that similar areas should receive high priority for collecting materials for *ex situ* conservation or serving as sites for *in situ* conservation. The fact that many farmers in E2 have abandoned maize production and that the number of samples per maize class was the smallest in this environment suggests, however, that this type of environment may not be the best candidate for genetic resource conservation. The diversity present may be high but fragile. Patterns in the qualitative data, although not statistically significant, show that E1 had a high level of richness, including rare maize types, and had many samples per class (i.e., it had redundancy). Therefore, it may be better to give higher priority to environments such as E1 for *ex situ* and *in situ* conservation. In any case, our results suggest that GP—as an indicator of potential for agricultural productivity—could be helpful in defining and prioritizing sites for genetic resource conservation.

Landraces were the dominant class of maize in all four environments studied. Different diversity indices ranked environments differently, highlighting the many dimensions of diversity, which are not necessarily positively correlated. No statistically significant differences were apparent between the environments with the most contrasting agroecological and infrastructural conditions. However, significant differences were found between environments when there was an interaction between the two types of factors. The data indicate that productivity potential may influence the richness of the maize populations in an area while the availability of infrastructure may affect their evenness. These findings suggest hypotheses for future work on the regional patterns of maize diversity. Information on these two factors can be helpful in designing *ex situ* as well as *in situ* conservation efforts.

References

Aguirre, J. A. 1998. Análisis regional de la diversidad del maíz en el Sureste de Guanajuato. Ph.D. thesis, Universidad Nacional Autónoma de México, México, D.F.

Anderson, E., and H. Cutler. 1942. Races of *Zea mays*: I. Their recognition and classification. *Annals of the Missouri Botanical Garden* 21:69-88.

Barkin, D. 1987. SAM and seeds. In J.E. Austin and G. Esteva (eds.), *Food Policy in Mexico: The Search for Self-Sufficiency*. Ithaca, New York: Cornell University Press. Pp. 111-132.

Bellon, M.R. 1996. The dynamics of crop infraspecific diversity: A conceptual framework at the farmer level. *Economic Botany* 50: 26-39.

Bellon, M.R., and S.B. Brush. 1994. Keepers of maize in Chiapas, Mexico. *Economic Botany* 48: 196-209.

Bretting, P.K., and M.M. Goodman. 1989. Karyotipic variation in Mesoamerican races of maize and its systematic significance. *Economic Botany* 43:107-124.

Brush, S.B. 1995. *In situ* conservation of landraces in centers of crop diversity. *Crop Science* 35: 346-354.

Brush, S.B., M. Bellon-Corrales, and E. Schmidt. 1988. Agricultural development and maize diversity in Mexico. *Human Ecology* 16: 307-328.

Brush, S.B., and E. Meng. 1998. Farmers' valuation and conservation of crop genetic resources. *Genetic Resources and Crop Evolution* 45: 139-150.

Brush, S.B., J.E. Taylor, and M.R. Bellon. 1992. Biological diversity and technology adoption in Andean potato agriculture. *Journal of Development Economics* 39:365-387.

Doebley, J.F., M.M. Goodman, and C.W. Stuber. 1985. Isozyme variation in the races of maize from Mexico. *American Journal of Botany* 72: 629-639.

FAO (Food and Agriculture Organization). 1981. *Informe del proyecto de zonas agroecológicas .* Vol. 3. *Metodología y Resultados para América del Sur y Central.* Informe sobre Recursos Mundiales de Suelo 48/3. Rome, Italy: FAO.

FMDR (Fundación Mexicana para el Desarrollo Rural). 1987. Diagnóstico municipal de Apaseo el Grande, Guanajuato, México. Internal document of the Presidencia Municipal de Apaseo el Grande, Guanajuato, México.

García, N.H. 1989. Potencial agroclimático de cultivos en el estado de Guanajuato. In J. Valero (ed.), *Primer Taller de Diagnóstico de Sistemas de Producción Agrícola*. Celaya, Guanajuato: INIFAPCIF AP-GTO.

Harper, J.L., and D.L. Hawksworth. 1995. Preface. In D.L. Hawksworth (ed.), *Biodiversity: Measurement and Estimation.* London, UK: The Royal Society and Chapman and Hall. Pp. 5-12.

Hernández, E. 1971. Exploración etnobotánica y su metodología. In *Obras de Efraím Hernández Xolocotzi*. Chapingo, Mexico: Universidad Autónoma de Chapingo. Pp. 163-188.

Hernández, E. 1985. Maize and the greater Southwest. *Economic Botany* 39: 416-430.

INCA RURAL (Instituto Nacional de Capacitación Agrícola). 1987. *Diagnóstico de las microregiones de Apaseo el Grande Guanajuato.* Guanajuato, Mexico: INCA-RURAL.

INEGI (Instituto Nacional de Estadística, Geografía e Informática). 1991. *VII Censo Agrícola*. Mexico. D.F.: INEGI.

LAMP (Latin America Maize Program). 1991. México. In *Catálogo del Germoplasma de Maíz*, Volume 2. Lima, Peru: CIPIA. Pp. 395-703.

Louette, D., A. Charrier, and J. Berthaud. 1997. *In situ* conservation of maize in Mexico: Genetic diversity and maize seed management in a traditional community. *Economic Botany* 51:20-38.

Ludwig, J.A., and J.F. Reynolds. 1988. *Statistical Ecology: A Primer on Methods and Computing.* New York, New York: John Wiley.

Magurran, A.E. 1988. *Ecological Diversity and its Measurement*. Princeton, New Jersey: Princeton University Press.

Meng, E.C.H., J.E. Taylor, and S.B. Brush. 1998. Implications for the conservation of wheat landraces in Turkey from a household model of varietal choice. In M. Smale (ed.), *Farmers, Gene Banks, and Crop Breeding: Economic Analyses of Diversity in Wheat, Maize, and Rice.* Norwell, Massachusetts: Kluwer Academic Press. Pp. 127-142.

Ortega-Paczka, R. 1973. Variación en maíz y cambios socioeconómicos en Chiapas, México 1946-1971. M.S. thesis, Colegio de Postgraduados, ENA, Chapingo, Mexico.

Perales-Rivera, H.R. 1998. Conservation and evolution of maize in Amecameca and Cuautla Valleys of Mexico. Ph.D. thesis, University of California, Davis. University Microfilms International, Ann Arbor.

Sanchez, J.J., and M.M. Goodman. 1992. Relationships among Mexican races of maize. *Economic Botany* 46:72-85.

Smale, M., R.E. Just, and H.D. Leathers. 1994. Land allocation in HYV adoption models: An investigation of alternative explanations. *American Journal of Agricultural Economics* 76: 534-546.

Smale, M., M. Bellon, and A. Aguirre. 1998. Variety characteristics and the land allocation decisions of farmers in a center of maize diversity. Selected paper, Annual Meetings of the American Agricultural Economics Association, 2-5 August, Salt Lake City, Utah.

Tapia, N.A., and N.H. García. 1991. Marco de referencia y catálogo de tecnologías agropecuarias para el Distrito de Desarrollo Rural 004 CELAYA. SARH-INIFAP-CEBAJ. PROCATI, Celaya, Guanajuato, Mexico. Internal document.

Villalpando, J.F. 1983. Metodología de investigación en Agroclimatología. Cuernavaca, Morelos. Internal document, SARH-INIA, Mexico.

Wellhausen, E., J. Roberts, L.M. Roberts, and E. Hernández X. 1952. *Races of Maize in Mexico: Their Origin, Characteristics, and Distribution*. Cambridge, Massachusetts: The Bussey Institution, Harvard University.

Yúnez, N.A., J.E. Taylor, and F. Barceinas.1994. Reflexiones sobre la biodiversidad genética de las semillas; Problemas de análisis y el caso del maíz en México. In A. Yúnez Naude (ed.), *Medio Ambiente Problemas y Soluciones*. Mexico, D.F.: El Colegio de México. Pp. 63-98.

Zahl, S. 1977. Jackknifing an index of diversity. *Ecology* 58: 907-913.

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