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Socio-ecological considerations on the persistence of Mexican heirloom maize

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Abstract

The vulnerability of 59 Mexican landraces of maize was assessed in relation to five socio-ecological factors, namely, social and economic marginalization, association with indigenous peoples, high biodiversity regions, environmental suitability for cultivation, and climate change effects. The most marginalized states had the highest number of landraces, 80% of which were found in predominantly or substantially indigenous municipalities. While only one third of 152 regions of high biodiversity had collection records, 47 landraces had at least one collection record in these regions. Eleven races can be cultivated in at least 10% of the Mexican territory, while 13 can occupy less than 1% under current environmental conditions. Given a projected temperature increase of 0.5 ºC and a 5% reduction in annual precipitation, 66% of the landraces could disappear during the current decade. A normalized Vulnerability Index was constructed (can have values from 0.00 for non-threatened landraces to 1.00 for the most vulnerable) that averaged 0.76 ± 0.02 for the 59 landraces. The most vulnerable third of the landraces were threatened by being from a region of low marginalization combined with a limited potential distribution both under current conditions and under the climate change scenario considered.

Keywords: climate change, food security, orphan crops, risk assessment, rural

Introduction

Maize is the most widely cultivated cereal in the world, being a staple crop for essentially all the countries in the Americas and for many in Africa (Food and Agriculture Organization, 2013). The role of this cereal is particularly special in Mexico, stemming from its domestication here some 10,000 years ago (Miranda Colín, 2005; Benz, 2006). Indeed, not only 40 kg of tortillas –a flatbread baked from a maize dough- are consumed annually per capita in this country, but maize also has a remarkable historical and cultural importance for more than 60 indigenous peoples of Mexico (Boege, 2008; Instituto Nacional de Estadística y Geografía, 2013). Indeed, indigenous peoples are considered to be the guardians of the country's maize genetic diversity; while their ancestors domesticated this plant and developed numerous varieties, they currently maintain a vigorous utilization and barter of maize throughout the country (Boege, 2008; Dyer and López-Feldman, 2013). Illustrating the cultural importance of maize is Mayan mythology, according to which humans were crafted out of maize after several failed trials with other materials (Anonymous, 1550). Also, various pre-Columbian codices depict mythical scenes about maize domestication that usually involve the technology transfer from a deity (Carrasco and Sessions, 2007). Currently, a synchronization of the agricultural and religious (usually Roman Catholic) calendars is prevalent in many rural communities. For instance, sowing should be performed by 15 May, day of S. Isidore the Laborer, patron saint for agricultural workers, and 24 June, a mere three days after the start of Summer, is often considered to be the «official» onset of the rainy season, in veneration of St John the Baptist, a main character of Christian mythology who used water in the process of conversion of early adepts.

Mexico had historically been a net exporter of maize, a situation that has changed notoriously after the first two decades of the North American Free Trade Agreement that favors the production of high-value horticultural commodities in Mexico, including a substantial proportion being allocated to export. As a result, an increasing proportion of maize –mainly the varieties utilized for forage and industrial uses– is imported from the USA at such low prices that effectively discourage local production, at least at the smaller scales (Fox and Haight, 2010; Sistema de Información Agroalimentaria y Pesquera, 2015). This situation, in combination with a reduction of the country's rural population driven both by migration to cities or to the United States and by mere demographic change, has resulted in a high proportion of poor rural dwellers who increasingly resort to small-scale subsistence agriculture that predominantly relies on the native maize germplasm (Appendini et al, 2003; Instituto Nacional de Estadística y Geografía, 2006; Dyer and López-Feldman, 2013).

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The regions of crop domestication and diversification tend to overlap with regions of high biological diversity around the world (Diamond, 1997; Zeder, 2005). This is true for the case of Mexico, where conservation scientists and environmental authorities have long recognized that a human component is an integral part of biodiversity (Bazzaz et al, 1998; Perales and Aguirre, 2008). In this country an intricate topography, a diverse climate, and the meeting of holarctic and neotropical biological elements have given origin to one of the world's more diverse biotas (de la Barrera and Andrade, 2005). In turn, crops like amaranth, avocado, beans, cacao, chía, papaya, hot pepper, prickly pear and other cacti, various squashes, tomato, among others, were domesticated here in addition to maize (Khoury et al, 2016). At present, agriculture in homegardens is recognized as a most effective means of preserving phytogenetic diversity and for the ongoing domestication of species (Casas et al, 2007).

Over half of the Mexican territory is semi-arid or arid and ample regions are considered to be marginal for agriculture, at best. However, domestication and development of traditional agricultural practices have allowed for the rainfed cultivation of landraces of maize in essentially all the territory (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2009). In this respect, climate change models project a substantial alteration of temperature and, especially, precipitation that could lead to a substantial reduction of maize productivity during the present century (Conde et al, 1997; Comisión Intersecretarial de Cambio Climático, 2009; Sáenz-Romero et al, 2010; Ureta et al, 2012).

In order to assess the importance of multiple socio-ecological factors with influence on the persistence of Mexican landraces of maize, a normalized-indicator approach was utilized to construct a synthetic Vulnerability Index describing the risk facing each heirloom maize.

Materials and Methods

Landraces of maize

Information on the distribution of maize landraces within Mexico was obtained from the Mexican Information System for Genetically Modified Organisms (Comision Nacional para el Conocimiento y Uso de la Biodiversidad, 2009). This database reports race and geographical information for 7015 accessions of maize collected throughout the country. Only the 5292 records that actually indicated the race were utilized in the present study.

Socio-ecological factors of vulnerability

Given the disparate nature of the factors considered here, including their different units and various degrees of subjectivity regarding their contributions to maize vulnerability, they were normalized so that they could be compared. In particular, individual dimensionless indices were created for each factor that ranged in value from 0 for no vulnerability to 1 for the most vulnerable condition.

Marginalization

The marginalization index is a metric utilized by the Mexican government for quantifying poverty and for targeting and evaluating poverty-alleviating public policies and programs (Anzaldo and Prado, 2005). This index considers access to various services and public infrastructure such as floors of family dwellings that are covered with cement versus dirt, the completion of primary education, perception of low income, and residence in small settlements. Calculated at the state level, the Marginalization Index ranges from –1.505 for the Federal District (DF), a megalopolis of 25 million that houses the Federal Government, to 2.412 for the State of Guerrero, where 20% of the population of 15 years or more is illiterate, 35% have incomplete primary education, and 33% lack drainage, among other parameters (Consejo Nacional de Población, 2006). Considering that poverty, especially in a rural setting, drives the use of heirloom varieties that are the predominant input for subsistence agriculture, the vulnerability of native maizes was considered to be lower in more marginalized states than in less marginalized states (Appendini et al, 2003; Boege, 2008). The normalized vulnerability of maize due to marginalization was calculated for each accession considering its state of provenance as Vulnerability = (Maximum Marginalization Index – State Marginalization Index) / (Maximum Marginalization Index – Minimum Marginalization Index) = (Marginalization Index of Guerrrero – State Marginalization Index) / (Marginalization Index of Guerrero – Marginalization Index of the Federal District) = (2.412 – State Marginalization Index) / 3.917. Thus, it ranged from 0 for accessions collected in Guerrero to 1 for those from DF.

Indigenous peoples

The presence and number of speakers of indigenous languages at the municipal level were considered as indicators of the preservation of traditional agricultural practices (Boege, 2008; Turrent Fernández et al, 2012; Ureta et al, 2013). Data were obtained from the 2005 Inter-Census poll (Instituto Nacional de Estadística y Geografía, 2006) for each one of 2,440 municipalities of Mexico. A municipality was considered to be «predominantly» indigenous and was assigned a low vulnerability of 0.5 when the number of speakers of an indigenous language amounted to or exceeded 40% of its population (Instituto Nacional de Estadística y Geografía, 2004). In addition, the municipalities that had at least 5,000 speakers of an indigenous language, but that did not reach 40% of the total population, were assigned a higher vulnerability of 0.75 and were considered to have a "substantial" presence of indigenous people (Comisión Nacional para el Desarrollo de los Pueblos Indígenas, 2006). Finally, municipalities with a «low» indigenous population had less than 5,000 inhabitants and 40% of the total population and were assigned the highest vulnerability of 1.0. For this factor, the minimum vulnerability was defined at 0.5, not at 0.0, considering that the cultivation of landraces of maize is just one of various possible economic activities and that an accelerated loss of original cultures is underway (Boege, 2004; López-Feldman et al, 2014).

Biodiversity

Mexican conservation scientists as well as the environmental authority have long recognized that humans are an integral part of the environment (Bazzaz et al, 1998; Boege, 2008; Perales and Aguirre, 2008). In this respect, because Mexico is one of so called megadiverse countries because it contains over 10% of the world's biological species, high biodiversity regions often coincide with the presence of communities that practice traditional diversified agriculture. The environmental authority has identified 152 terrestrial regions whose conservation is prioritary given their biodiversity and ecosystemic integrity (Arriaga et al, 2000). For the present study it was assumed

Table 1 - Distribution of Mexican landraces of maize per state, total number of accessions per race and ethnolinguistic distribution. State abbreviations are from Appendix I. For the ethnolinguistic distribution «I» indicates that the landrace was found at least in one predominantly indigenous municipality (at least 40% of population speaks an original language), and «i» indicates that at least one record was found in a substantially indigenous municipality (more than 5,000 speakers but less than 40%).

Race	Distribution	Number of accessions	Ethnolinguistic distribution
Amarillo	SR, VZ	2	I, i
Ancho	GR, MC, MS	100	I, i
Apachito	CH	13	I, i
Arrocillo	HG, PL	14	I, i
Arrocillo Amarillo	HG, MC, PL, VZ	76	I, i
Arrocillo Azul	PL	1	I
Arrocillo Blanco	PL	1	I
Azul	CH, JC, MC	22	I, i
Blandito	DG	1	I, i
Blando de Sonora	DG, SL, SR	16	I, i
Bofo	NT, DG, SL, ZS	25	I, i
Bolita	CH, DG, GR, HG, JC, MS, OC, PL, VZ, ZS	243	I, i
Cacahuacintle	HG, MC, MN, PL, TL,VZ	36	I, i
Carmen	TS	1	I, i
Celaya	AS, CH, CL, CM, DG, GT, HG, JC, MC, MN, NT, NL, OC, QT, SP, VZ, ZS	272	I, i
Chalqueño	AS, CH, DF, DG, GT, HG, JC, MC, MN, OC, PL, QT, SP, TL, VZ, ZS	357	I, i
Chapalote	SL	2	I, i
Clavillo	CC, CS	6	I, i
Comiteco	CS, MS	54	I, i
Complejo Chihuahua Blanco	CH	5	I, i
Complejo Serrano Jalisco	JC	2	I, i
Conejo	GR, MN, OC	6	I, i
Conico	AS, CS, CH, CL, DG, GT, GR, HG, JC, MC, MN, MS, OC, PL, QT, SP, TL, VZ, ZS	1042	I, i
Conico Norteño	AS, CH, CL, DG, GT, GR, HG, JC, MC, MN, NL, OC, PL, QT, SP, VZ, ZS	483	I, i
Coscomatepec	VZ	1	I, i
Cristalino Chihuahua	CH, DG	80	I, i
Dulcillo Norteño	CH, DG, SL, SR, ZS	29	I, i
Dzit-Bacal	CC, CS, GR, MN, MS, QR, SP, TS, VZ, YN	54	I, i
Elotes Conicos	DG, GT, GR, HG, JC, MC, MN, MS, OC, PL, QT, SP, TL, VZ	122	I, i
Elotes Occidentales	CS, CM, DG, GT, JC, MN, NT, PL, QT, SP, VZ, ZS	41	I, i
Fasciado	QT	1	I, i
Gordo	CH, DG	15	I, i
Harinoso de Ocho	CH, JC, NT, SL, SR	12	I, i
Jala	CM, JC, NT	19	I, i
Lady Finger	CH, SL, SR	3	I, i
Maiz Dulce	CH, DG, GT, JC, MN, NT, SL, ZS	22	I, i
Maizon	CH, MS	4	I, i
Mushito	GR, HG, MN, OC, PL, VZ	76	I, i
Nal-Tel	CC, CS, GR, MS, OC, QR, SR, VZ, YN	106	I, i
Olotillo	CS, GR, MN, MS, NT, OC, PL, QR, SP, TC, VZ, YN	124	I, i
Oloton	CS, OC, VZ	68	I, i
Ovaneño	QT, SR	31	I, i
Palomero	CH, GR, MC, MN, PL, TL, VZ	32	I, i
Pepitilla	DG, GR, JC, MC, MN, MS, PL, VZ	124	I, i
Reventador	CH, CM, DG, GT, GR, JC, MN, NT, SL, SR	62	I, i
San Juan	CH, DG, JC, SL, SR, ZS	17	I, i
Tablilla	CH, DG, NT, ZS	9	I, i
Tabloncillo	AS, CH, CM, DG, GR, JC, MN, MS, NT, SP, SL, SR, ZS	236	I, i
Tabloncillo Perla	BS, CH, CM, DG, JC, NT, SL, SR	128	I, i
Tehua	CS, CL	8	I, i
Tepencintle	CS, GR, MS, OC, QR, VZ, YN	64	I, i
Tunicata	DG	1	I
Tuxpeño	CC, CS, CH, CL, CM, DG, GR, HG, JC, MN, MS, NT, NL, OC, PL, QT, QR, SP, SL, SR, TC, TS, VZ, YN	769	I, i
Tuxpeño Norteño	CH, CL, MS	21	I, i
Vandeño	CS, CM, GR, JC, MN, MS, NT, OC, TC	91	I, i
Xmenhal	YN	1	I
Zamorano Amarillo	JC, MN	17	I, i
Zapalote Chico	CS, MS, OC, YN	109	I, i
Zapalote Grande	CS, MS, OC	15	I, i

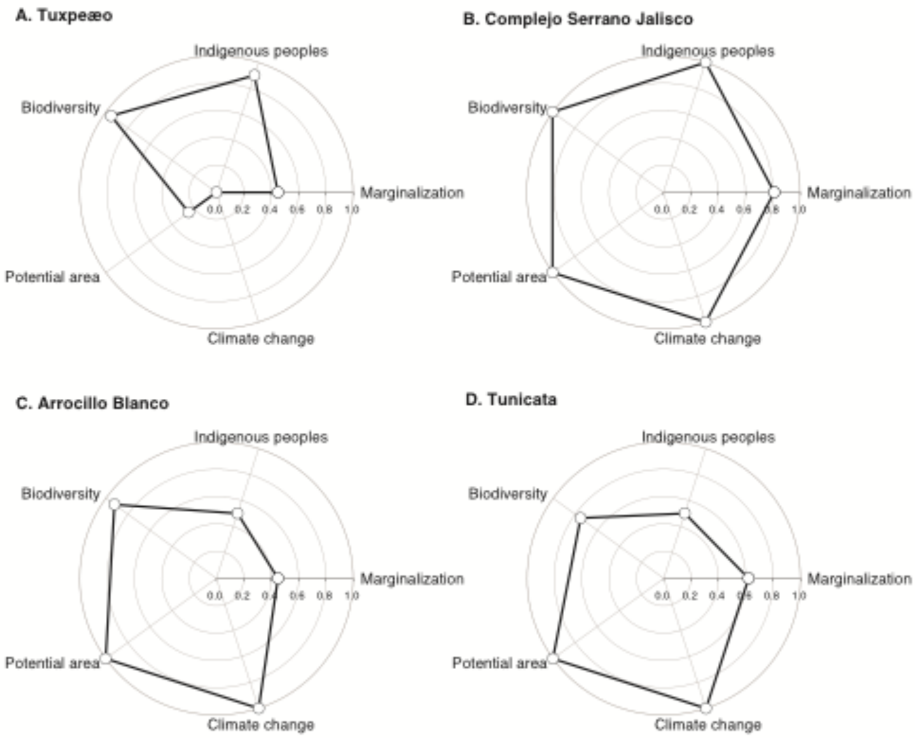

Figure 1 - Components of the Vulnerability Index for the (A) least vulnerable (Tuxpeño;vulnerability of 0.51 ±0.18) and (B) most vulnerable (Complejo Serrano Jalisco;0.97 ± 0.04) landraces, as well as two (C,D) that shared the median vulnerability (Arrocillo Blanco,0.774 ± 0.12; Tunicata, 0.774 ± 0.10) owing to the varying contributions of different socio-ecological factors.

that landraces that are found within these high biodiverstiy areas are less vulnerable than those found outside, considering that low impact traditional agriculture is one of very few productive activities permitted in these sites. A relatively high vulnerability value of 0.75 was assigned to accessions contained in a high biodiversity region because the recognition of priority does not automatically grant actual protection to natural protected area and various designations of protected area allow for different types of use. In turn, accessions that were found outside of the priority regions for conservation were assigned a vulnerability of 1.0.

Potential area for cultivation

The potential area for cultivation of each landrace was modeled based on the geographical distribution of its collection records and projected on the Mexican territory with the BIOCLIM niche envelope model that considers the environmental conditions of each collection site (Hijmans et al, 2001; Elith et al, 2006). The country was divided in an array of 152,526 cells (2.5' × 2.5' each) and the vulnerability was scored as 0.25 for landraces that could occupied at least 10% of the country's surface, 0.5 for those with 5-10%, 0.75 for 1-5%, and 1.00 for less than 1%.

Climate change responses

Considering anthropocentric climate change, the potential area of distribution for each landrace was also modeled with BIOCLIM for the year 2020 based on a temperature increase of 0.5 ºC and a reduction of annual precipitation of 5%, an average scenario for Mexico (Comisión Intersecretarial de Cambio Climático, 2009). In this case, vulnerability was proportional to the change of potential distribution in the year 2020 relative to the current distribution (see Potential area of cultivation, above), ranging from 0.00 for those that could occupy the same surface area or whose distribution could increase to 1.00 for those that had a decrease of 100%.

Vulnerability Index

A so-called Vulnerability Index was calculated for each landrace as the average of the normalized individual indices for each socio-ecological factor as an indicator of the integrated integrated vulnerability facing each landrace. Considering that a single number for each landrace does not fully describe the contributions of the individual factors, a principal components analysis was also performed to group the landraces that shared similar types of vulnerability.

Table 2 - State marginalization index and vulnerability for accessions collected in each state.

State	Marginalization index	Marginalization degree	Landraces	Vulnerability
Aguascalientes	–0.954	Low	5	0.859
Baja California	–1.253	Very low	0	0.936
Baja California Sur	–0.719	Low	1	0.799
Campeche	0.559	High	4	0.473
Chiapas	2.326	Very high	14	0.022
Chihuahua	–0.684	Low	23	0.790
Coahuila	–1.137	Very low	6	0.906
Colima	–0.738	Low	8	0.804
Distrito Federal	–1.505	Very low	1	1.000
Durango	–0.019	Intermediate	22	0.621
Guanajuato	0.092	Intermediate	7	0.592
Guerrero	2.412	Very high	17	0.000
Hidalgo	0.751	High	11	0.424
Jalisco	–0.769	Low	20	0.812
México	–0.622	Low	11	0.775
Michoacán	0.457	High	19	0.499
Morelos	–0.443	Low	17	0.729
Nayarit	0.191	Intermediate	13	0.567
Nuevo León	–1.326	Very low	3	0.954
Oaxaca	2.129	Very high	16	0.072
Puebla	0.635	High	16	0.454
Querétaro	–0.142	Intermediate	9	0.652
Quintana Roo	–0.316	Low	5	0.696
San Luis Potosí	0.656	High	10	0.448
Sinaloa	–0.148	Intermediate	12	0.654
Sonora	–0.750	Low	12	0.807
Tabasco	0.462	High	3	0.498
Tamaulipas	–0.683	Low	3	0.790
Tlaxcala	–0.129	Intermediate	3	0.649
Veracruz	1.077	High	20	0.341
Yucatán	0.431	High	7	0.506
Zacatecas	0.160	Intermediate	12	0.575

Results

Landraces

A total of 59 landraces are recorded in the database (Table 1). The number of races for each state increased with the number of accessions per state, reaching an asymptote of 17 races per state ($p < 0.05$, $r^2 = 0.709$). The state of Puebla (Appendix I) had 627 accessions, the highest number for a state, corresponding to 16 different races. In turn, the 23 landraces of Chihuahua, stemming from a mere 383 records, constituted the highest landrace richness at the state level. The opposite situation occurred for the Federal District that had a single record, and Baja California that had none. Records for Cónico, the most abundant landrace, amounted to 19.7% of the database and to 55% of the records from Puebla (Table 1). In turn, Tuxpeño, with 14.6% of the accessions, was the most widely distributed race, being found in 24 states. Contrasting was the case for 12 races that were found in only one state (Table 1).

Marginalization

The assumption that marginalization can help preserve maize diversity was supported by a substantially higher number of races found for very marginalized states than for those with lower marginalization (Table 2). Vulnerability from marginalization was 0.54 ± 0.03 for the 59 landraces (Table 3). The lowest vulnerability of 0.03 was found for Comiteco and the highest of 0.82 was found for Tuxpeño norteño.

Indigenous peoples

A total of 641 municipalities (25% of total), covering 19% of the national territory, were found to have either predominant or substantial indigenous populations (Table 4). Oaxaca was the state with the largest indigenous population, whose 982,286 speakers were predominant in 260 out of 571 municipalities, followed by Chiapas, where 919,956 speakers were predominant in 44 out of 118 municipalities. In contrast, the municipalities from the states of Aguascalientes, Coahuila, Guanajuato, Morelos, and Tamaulipas had low indigenous populations, averaging 12,776 ± 4,208 speakers per state. Only 58% of the indigenous municipalities contained collection records, but 80% of records were found either in predominantly or substantially indigenous municipalities (Table 1). For instance, Tuxpeño was found in 52 indigenous municipalities from 16 states and Cónico was found in 42 indigenous municipalities from 11 states. Association with indigenous peoples led to a vulnerability of Mexican maize landraces of 0.89 ± 0.02 (Table 3). Four races, Arrocillo Azul, Arrocillo Blanco, Tunicata, and Xmenhal had the lowest vulnerability of 0.5 because they were exclusively found in predominantly indigenous municipalities (Tables 1 and 3). In turn, the highest vulnerability of 1.00 was found for 13 races (Table 3). Of particular interest was Tuxpeño, whose vulnerability of 0.90 resulted from the fact that less than 27% of its accessions occurred in indigenous municipalities, despite having more records within indigenous municipalities than the rest of the landraces. Similarly, Cónico had a vulnerability of 0.95 because a mere 13.8% of its accessions were from indigenous municipalities.

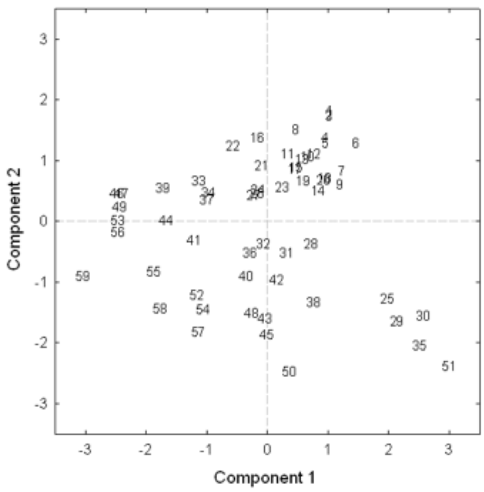

Figure 2 - Principal components analysis for the influences of five socio-ecological factors on the vulnerability of 59 Mexican landraces of maize. Numbers are the ranking for individual landraces according to the Vulnerability Index from Table 3 plotted along the two main Principal Components from Table 5.

Table 3 - Vulnerability from five normalized socio-ecological factors and the synthetic Vulnerability Index, calculated as the average of 5 factors ± S.E., for 59 Mexican landraces of maize.

Race	Marginalization	Indigenous peoples	Biodiversity	Potential area for cultivation	Climate change	Vulnerability Index	Ranking
Amarillo	0.57	0.88	1.00	1.00	1.00	0.89 ± 0.08	9
Ancho	0.61	0.98	0.96	0.75	1.00	0.86 ± 0.07	16
Apachito	0.79	0.88	0.87	0.75	1.00	0.86 ± 0.04	18
Arrocillo	0.43	0.82	0.96	0.75	1.00	0.79 ± 0.10	28
Arrocillo Amarillo	0.42	0.85	0.75	0.75	0.60	0.67 ± 0.08	42
Arrocillo Azul	0.45	0.50	0.75	1.00	1.00	0.74 ± 0.12	35
Arrocillo Blanco	0.45	0.50	0.92	1.00	1.00	0.77 ± 0.12	30
Azul	0.79	0.98	0.85	0.75	1.00	0.87 ± 0.05	12
Blandito	0.62	1.00	1.00	1.00	1.00	0.92 ± 0.08	5
Blando de Sonora	0.70	0.98	0.92	0.75	1.00	0.87 ± 0.06	13
Bofo	0.60	0.77	0.00	0.75	1.00	0.62 ± 0.17	52
Bolita	0.15	0.89	0.97	0.25	0.60	0.57 ± 0.16	58
Cacahuacintle	0.60	0.94	0.99	0.50	1.00	0.81 ± 0.11	24
Carmen	0.79	1.00	1.00	1.00	1.00	0.96 ± 0.04	2
Celaya	0.71	0.99	0.98	0.25	0.30	0.65 ± 0.16	46
Chalqueño	0.60	0.96	0.98	0.25	0.30	0.62 ± 0.16	53
Chapalote	0.65	0.88	1.00	1.00	1.00	0.91 ± 0.07	7
Clavillo	0.17	0.79	0.92	0.75	1.00	0.73 ± 0.15	38
Comiteco	0.03	0.78	0.97	0.50	1.00	0.66 ± 0.18	45
Complejo Chihuahua Blanco	0.79	1.00	0.80	1.00	1.00	0.92 ± 0.05	6
Complejo Serrano Jalisco	0.81	1.00	1.00	1.00	1.00	0.96 ± 0.04	1
Conejo	0.81	0.88	1.00	0.75	1.00	0.89 ± 0.05	10
Conico	0.55	0.95	0.98	0.25	0.30	0.61 ± 0.16	55
Conico Norteño	0.67	0.97	0.97	0.25	0.30	0.63 ± 0.16	49
Coscomatepec	0.34	1.00	1.00	1.00	1.00	0.87 ± 0.13	14
Cristalino Chihuahua	0.78	0.89	0.89	0.50	1.00	0.81 ± 0.09	23
Dulcillo Norteño	0.73	0.96	0.97	0.50	1.00	0.83 ± 0.10	21
Dzit-Bacal	0.54	0.61	0.92	0.50	0.60	0.63 ± 0.07	48
Elotes Conicos	0.53	0.97	0.98	0.50	1.00	0.80 ± 0.11	27
Elotes Occidentales	0.59	0.95	0.95	0.25	0.60	0.67 ± 0.13	43
Fasciado	0.65	1.00	1.00	1.00	1.00	0.93 ± 0.07	4
Gordo	0.22	0.97	0.95	0.50	1.00	0.73 ± 0.16	37
Harinoso de Ocho	0.75	1.00	1.00	0.75	0.60	0.82 ± 0.08	22
Jala	0.64	0.95	0.99	0.75	1.00	0.87 ± 0.07	15
Lady Finger	0.75	0.92	0.83	0.75	1.00	0.85 ± 0.05	19
Maiz Dulce	0.68	0.97	0.99	0.50	0.60	0.75 ± 0.10	33
Maizon	0.78	1.00	1.00	1.00	1.00	0.96 ± 0.04	3
Mushito	0.40	0.88	0.97	0.50	1.00	0.75 ± 0.13	32
Nal-Tel	0.41	0.64	0.98	0.25	0.60	0.58 ± 0.12	57
Olotillo	0.15	0.89	0.98	0.50	0.60	0.62 ± 0.15	51
Oloton	0.05	0.66	0.92	0.50	1.00	0.63 ± 0.17	50
Ovaneño	0.80	1.00	0.97	0.75	1.00	0.90 ± 0.05	8
Palomero	0.65	0.94	0.95	0.50	0.60	0.73 ± 0.10	36
Pepitilla	0.56	0.97	0.96	0.50	1.00	0.80 ± 0.11	26
Reventador	0.35	0.98	0.95	0.50	0.60	0.68 ± 0.12	41
San Juan	0.72	0.90	0.99	0.50	0.60	0.74 ± 0.10	34
Tablilla	0.62	0.94	0.94	0.75	0.60	0.85 ± 0.07	20
Tabloncillo	0.71	0.98	0.97	0.25	1.00	0.70 ± 0.13	39
Tabloncillo Perla	0.73	1.00	0.94	0.25	0.60	0.64 ± 0.16	47
Tehua	0.13	1.00	0.91	0.75	0.30	0.76 ± 0.16	31
Tepencintle	0.13	0.86	0.96	0.50	0.60	0.61 ± 0.15	54
Tunicata	0.62	0.50	0.75	1.00	1.00	0.77 ± 0.10	29
Tuxpeño	0.45	0.90	0.95	0.25	0.00	0.51 ± 0.18	59
Tuxpeño Norteño	0.82	1.00	0.98	0.50	1.00	0.86 ± 0.10	17
Vandeño	0.25	0.97	0.96	0.25	0.60	0.61 ± 0.16	56
Xmenhal	0.51	0.50	1.00	1.00	1.00	0.80 ± 0.12	25
Zamorano Amarillo	0.63	1.00	1.00	0.75	1.00	0.88 ± 0.08	11
Zapalote Chico	0.07	0.83	0.94	0.50	1.00	0.67 ± 0.17	44
Zapalote Grande	0.08	0.97	0.95	0.50	1.00	0.70 ± 0.18	40

Biodiversity

Only 52 of the 152 priority regions for conservation had collection records in the database, which were distributed in 28 states and covered 10.5% of the national territory. While a mere 13.5% of total accessions from the database occurred in a priority region for conservation, they represented 80% of the races. The highest richness of 12 races was collected for the region of Cuetzalan, Puebla, followed by the 10 races found for Babícora, Chihuahua. Vulnerability from association with high biodiversity regions was 0.93 ± 0.02 for 59 races of maize considered in the present study (Table 3). The lowest value of 0.75 was found for Arrocillo Azul, Arrocillo Blanco, and Tunicata for which all records were found within a priority region for conservation. In contrast, the highest vulnerability of 1.00 was calculated for 12 races for which their entire records occurred outside of these regions.

Potential area for cultivation

The potentially suitable area for cultivation increased asymptotically with the number of accession for each race ($p < 0.0001$, $r^2 = 0.754$). Vulnerability from a limited potential distribution area averaged 0.63 ± 0.03 for 59 Mexican landraces of maize (Table 3). The 13 landraces that could cover less than 0.1% of the country's area had the highest vulnerability of 1.0. In contrast, the landrace with the amplest potential distribution, Tuxpeño, could be cultivated in 87% of the country's area and had a vulnerability of 0.25.

Climate change

Under the climate change scenario considered in the present study, the vulnerability from a decreased potential distribution area was 0.83 ± 0.03 for 59 landraces of maize, 32% greater than under current environmental conditions (Table 3). The suitable area for 66% of the landraces could become nill by 2020, thus a corresponding vulnerability was 1.00 (Table 3). Contrasting was the case for Tuxpeño, the only race whose vulnerability could increase by 2020, thus its vulnerability was 0.00.

Vulnerability Index

The Vulnerability Index for 59 Mexican landraces of maize averaged 0.76 ± 0.2 (Table 3; Figure 1). It ranged from 0.51 for Tuxpeño (Figure 1A) to 0.96 for Complejo Serrano Jalisco (Figure 1B). Because a single value does not reflect the contributions of the individual factors, as was the case for Arrocillo Blanco (Figure 1C) and Tunicata (Figure 1D) both with the median Vulnerability Index of 0.774, a principal components analysis was able to group the landraces (Figure 2). In particular, the first two components explained 54% of the variation of maize vulnerability from the five factors that were considered here (Table 5). The ca twenty most vulnerable landraces (Vulnerability Indices ranging from 0.812 ± 0.085 to 0.962 ± 0.038) had positive values along both axes (Table 3; Figure 2). In contrast, those races with the lower vulnerabilities tended to have negative values along the second principal component and were spread all along the first component. Of particular interest were Arrocillo Azul, Arrocillo Blanco, Olotillo, Tunicata, and Xmnenhal that scored very positive along the first component and very negative along the second component. In contrast, maizes Celaya, Chalqueño, Tabloncillo, and Vandeño scored very negative along the first component but had slightly positive values along the second component.

Discussion

The existence of 59 distinct Mexican landraces of maize underscores the importance of the crop in this country and reflects its long history of selection and its ample use. The various factors considered here posed different sources and levels of risk for the different landraces. Mexico remains one of the countries with high richness of landraces, only rivaled by Peru (Grobman et al, 1961; Ortiz et al, 2008). New varieties are constantly being developed and newly discovered landraces are still being described (Mijangos-

Table 4 - Number of indigenous municipalities per state and number of indigenous language speakers per state.

State	Number of indigenous municipalities: Predominantly indigenous	Number of indigenous municipalities: Substantially indigenous	Indigenous population: From predominantly indigenous municipalities	Indigenous population: From substantially indigenous municipalities
Baja California	0	2	0	28129
Baja California Sur	0	1	0	5397
Campeche	3	3	52713	26656
Chiapas	39	5	799672	120284
Chihuahua	5	3	47620	26662
Colima	0	1	0	7806
Distrito Federal	0	7	0	129118
Durango	1	0	19766	0
Guerrero	17	9	231187	139927
Hidalgo	14	6	215645	61913
Jalisco	4	3	23113	20840
México	0	20	0	235384
Michoacán	3	5	28998	47268
Nayarit	1	1	21867	5988
Nuevo León	0	1	0	10063
Oaxaca	249	11	879200	103086
Puebla	52	8	357976	120754
Querétaro	0	2	0	16996
Quintana Roo	2	6	58638	116917
San Luis Potosí	13	1	196627	11284
Sinaloa	0	1	0	5840
Sonora	1	6	2131	88415
Tabasco	0	4	0	42926
Tlaxcala	0	2	0	60429
Veracruz	39	13	395664	159295
Yucatán	69	6	378325	124183
Zacatecas	0	2	0	58742

Table 5 - Principal components analysis for the contributions of 5 socio-ecological factors affecting the Vulnerability Index of 59 Mexican landraces of maize.

	Principal component				
	1	2	3	4	5
Marginalization	0.133	0.761	–0.508	0.353	0.141
Indigenous peoples	–0.412	0.736	0.023	–0.527	–0.103
Biodiversity	–0.412	0.381	0.752	0.344	0.029
Potential distribution	0.886	0.258	0.132	0.105	–0.348
Climate change	0.846	0.154	0.319	–0.254	0.306
Eigenvalue	1.858	1.356	0.943	0.597	0.246
Percent of variation explained	37.2	27.1	18.9	11.9	4.9
Degrees of freedom	9.631	7.456	4.809	2.16	—
P	< 0.0001	< 0.0001	0.0002	0.0066	—

Cortés et al, 2007; Dyer and López-Feldman, 2013).

An important association between maize diversity and marginalization was found in the present work. Despite holding one of the world's largest economies and having several members of the Forbe's fortune charts, Mexico is an extremely unequal country, with half of the population enduring some level of poverty (Instituto Nacional de Estadística y Geografía, 2006; Esquivel, 2011). In this respect, people in poverty often resort to cultivating maize and other associated crops at very small scales for subsistence. Because of cost, these peasants often lack access to improved seeds, agrochemicals, and machinery, so that their low input agricultural production relies on heirloom maizes, whose seeds are saved from one growing season to another and are vigorously traded among producers (Appendini et al, 2003; Boege, 2008). In turn, most urban poor have access to subsidized tortillas -usually through income supplement programs- that are industrially produced from a few produced improved hybrids.

Since the domestication of maize, indigenous peoples throughout the continent have bred specific varieties for numerous uses that are suited for particular environmental conditions, including extreme climates (Boege, 2008; Turrent Fernández et al, 2013). Indeed, indigenous peoples are regarded as the historical safe-keepers of phytogenetic resources, which definitely seems to be the case for extant maize. However, as a result of migration to the cities and development policies that favor other economic activities, a loss of genetic diversity has been found in landrace producing areas (Dyer et al, 2014)

An association of high crop genetic diversity with regions of high biodiversity has been well documented in Mexico, where rural homegardens have been regarded as sites for species and phytogenetic resource conservation (Casas et al, 2007). Indeed, it was most interesting that 80% of the races recorded in the database were found in priority regions for conservation. In turn, the fact that two thirds of the high biodiversity regions have not been surveyed yet, speaks of a potentially greater diversity of the crop. At least for the case of the Mexican maizes, high biodiversity seems to have favored the development of more races. After all, the environmental constraints, such as available water and particular temperature regimes resulting from Mexico's intricate topography and latitudinal spread, would impose similar selective pressures to cultivated plants as those for wild species, the former would be subjected to additional artificial selection for desirable traits such as yield, color, or flavor. Indeed, sites of domestication tend to be associated with high biodiversity regions (Diamond, 1997; Zeder, 2005).

Maize is cultivated throughout Mexico, with most production units being small-scale for subsistence (Appendini et al, 2003). Given a great variety of maizes and a substantial specificity of uses, it is likely that some maizes will be more utilized than others, despite a very vigorous seed exchange by peasants. As observed here, 22% of the landraces from the database had very limited potential distributions. This could be an effect of the sampling method utilized for constructing the database or the actual result of a very specific and localized use. Either way, these maizes should be considered highly threatened and prioritized in conservation efforts. Moreover, only 13 out of the 59 landraces may have a similar or greater potential distribution by 2020 than under current environmental conditions. This poses a risk for most landraces, especially for the eleven whose area for potential distribution could disappear during the current decade. In this respect, a consideration should be made that the climate change scenario considered in this work was relatively optimistic (Comisión Intersecretarial de Cambio Climático, 2009). These results are in agreement with other studies of maize responses to climate change considering other methods for climate change scenarios and distribution modeling (Conde et al, 1998; Sáenz-Romero et al, 2010; Ureta et al, 2012).

The socio-ecological factors considered in this work appeared to be adequate descriptors for maize persistence/vulnerability, especially those of socioeconomic nature. Environmental factors such as climate change also pose a threat for the survival of the heirloom races of maize in Mexico, but irrigation and other cultural practices can ameliorate this risk. However, because a high maize diversity appears to be associated with poverty and exclusion from development, a ethical dilemma is posed by the results of the present work if maize conservation is to be achieved. On the one hand, a State should strive to improve the life quality of its citizens. On the other hand, at least for the case of maize of Mexico, the State should also consider preserving maize genetic diversity. In addition to preserving germplasm, this must involve documenting the traditional cultural practices if maize is to retain its central cultural role (Pollan, 2002; Boege, 2008). Other factors that might pose a risk for maize, whose importance should be considered in future research, are ageing of producers, migration, homogenization of germplasm resulting from demands of reliable and high-yield varieties by an ever-increasing urban demand, and the use of transgenic crops. In the end, vulnerability of Mexican landraces of maize ranged from very low for those that are widely utilized, to those with a potential niche market that may guarantee their survival even if at very specific locations, to those that are at a high risk. Considering the international importance of maize and that heirloom varieties constitutes the «natural capital» that will eventually be used for developing climate-change resistant varieties, including for massive industrialized agriculture, their conservation in Mexico is an investment in global food security.

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