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TRADITIONAL AGROECOSYSTEMS AND GLOBAL CHANGE IMPLICATIONS IN MEXICO

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Abstract

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Global warming is producing negative effects on agriculture, changing the distribution and production of vulnerable crops. This phenomenon could also modify the production and distribution of plant species. Agroecosystems are highly diverse systems which could potentially reduce the impact of climate change. The following research work is founded due to this situation. The main objective of this study is to assess the impact of climate change on an unconventional agricultural system. Agroecosystems in the State of Puebla (Mexico) were analyzed under the horizons of the present, 2020, 2050 and 2080 under different socioeconomic scenarios (A1B, A2A, B1 and B2), to identify which areas could present changes in the distribution of at least 3 species in the State of Puebla. Three races of maize: Conico, Elotes conicos y Tuxpeño (*Zea mays* ssp. mays) were selected, and the most important crops from the state of Puebla: bean (*Phaseolus vulgaris*), amaranth (*Amaranthus hypochondracus*), courgette (*Cucurbita pepo*), coffee (*Coffea arabica*), chili (*Capsicum frutescens*), sugar cane (*Saccharum officinarum*), potato (*Solanum tuberosum*), avocado (*Persea americana*), apple (*Malus domestica*), peach (*Prunus persica*), orange (*Citrus sinensis*), Mexican hawthorn (*Crataegus pubescens*), and wheat (*Triticum spp*). We built niche models for some species and determinated the overlap areas (agroecosystems) with special emphasis on maize races. Our results showed an important persistence of different agroecosystems (73% of the territory in Puebla). These systems are likely to increase their surface area under scenario A1B and B1, while in the A2A and B2 scenarios the impact of climate change is greater in agroecosystems. In the first case, agroecosystems lose in average up to 13% of surface area, and 12% for the second scenario. Finally the growth margin is 8% compared to the A1B and B1 models. We determinate vulnerability areas to global change in the southwestern of Puebla (maize origin center) and the north (rainforest protect area).

Key words: Agroecosystem, biodiversity, climate change, ecological niche, Puebla

Introduction

The Global Climate Change is attributed directly or indirectly to anthropogenic activities which alter the atmospheric composition persisting over extended periods of time, associated with extreme climatic changes, such as floods, forest fires and heat waves (IPCC, 2007a). It has brought other serious consequences such as depletion of water resources, loss of natural ecosystems, loss of biodiversity, increases in soil erosion and loss of life and goods.

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Scientists are concerned that this phenomenon could change the production and distribution of plant species, because they underscore that the primary sector at highest risk is agriculture (Rosenzweig et. al., 2008). In addition, weather conditions directly affect crop quality and quantity (Betanzos et. al., 2009, Terrazas et. al., 2010), and other physiological and phenological changes of any plant species. Whereas the possibilities of increasing competition for water resources and decreasing production of crop growth will be severely affected, compromising food security (Lin, 2007; Lin, 2010).

Especially for the subsistence of many farmers' seasonal agriculture (Haile, 2005 and Verdin et. al., 2005) which will force to make future fundamental decisions (IPCC, 2007b; Brown 2004; Lang et al., 2004). In general, increases in temperature and humidity, depending on the area where they are located, suggesting that the impact of climate change was increasing the severity of diseases caused by pathogens, it has been causing changes in the geographical distribution of species of agricultural interest, that were not expected (Altieri and Nicholls, 2009; Rosenzweig and Hillel, 2008).

In 1957, Hutchinson defined the fundamental ecological niche as a multi-dimensional range of environmental conditions within which a species can survive and grow (Pearson and Dawson, 2003). And the geographical region that presents favorable conditions of this type is called "potential niche" or the "existing fundamental niche" (Peterson et. al., 2012; Soberón and Nakamura, 2009).

The factors that determine the most important areas of distribution are the tolerance limits and the needs of each species for certain biotic and abiotic conditions, interaction with other species habitat, colonization and the potential of dispersion within a certain period of time (Barve et al., 2011; Soberon and Peterson, 2011). And the ecological and evolutionary history of each species is the complex expression of the distribution area (Brown et. al., 1996), as that species respond in different ways to their environment already is physical and biotic (climate, topography and sunlight). Their ecological niche may evolve or continue being preserved, however in the latter case displacement may result in geographic isolation and eventual speciation (Peterson, 2003a; Wiens and Graham, 2005).

Since these processes affect the geographical distributions, numerous studies have been made focusing on the development of quantitative models of "niches" and the relationships of the species and the environment, in order to predict the distribution of the species (Store and Jokimaki, 2003; Zhao et al., 2006), to approach the niche made as a statistical model between the occurrence and environmental variables observed in places of occurrence (Elith and Leathwick, 2009; Guisan et. al., 2006b; Austin, 2002). Because climate change has been poorly evaluated for a set of species, the main objective of the present study is to assess the vulnerability of climate change in agroecosystems that are traditional in Mexico, by quantifying the degree of vulnerability of certain specific areas with strategies that could be determined and benefited from Global Climate Change.

The use of the ecological niche models in recent years has been focused in the assessment of the climate change impact on the distribution of the different species. These models used data of presence from natural history databases, and therefore implicitly incorporated biotic interactions that depend on the abiotic variables (Araujo et al., 2006; Kearney et al., 2004, Kearney, 2006; Soberon and Peterson, 2011; Zhao et al., 2006). However, this type of work has been done in protected species (Raxworthy et al., 2003); and has rarely been developed in managed species (Guisan et al., 2006a). It is therefore important to analyze the vulnerability of ecosystems to this irreversible effect, to determine strategies of adaptation, that is, comparing the current conditions and those that would potentially be present under different scenarios of Climate Change, allowing the identification and quantification of the vulnerability degree of the places where it would have adverse effects: for example, the reduction in the diversity of plant species or the reduction in agricultural yields (Conde, 2006).

In addition to ecological niche modeling, it provides information on a variety of issues related to the conservation, geographical distribution (Peterson, 2003), and distribution of future species (Raxworthy et al., 2003). Also, today new evidence indicates that ecosystems designated by means of agroecological principles not only provide possible directions for the transition to an ecologically sustainable agriculture that is very productive through efficient systems in food production but also provide benefits for the global climate; (Benites et al., 1999; Nowak and Crane, 2002). Moreover, the food crisis has given a new credibility and urgency in the solutions for organic agriculture, locally and ecologically (Pretty, 2008), where it's important for the agroecosystem management to maintain the sustainability of the agricultural landscape (Altieri and Nicholls, 2009).

Biodiversity refers to all existing plants species, animals and microorganisms that interact within an ecosystem (Altieri, 2000) and provides the basis for all agricultural plants and animals (Gliessman, 1998). Different world cultures are derived from wild species that have been modified through selective breeding, domestication, and hybridization (Altieri 1999, Altieri and Nicholls, 2000). Most diversity hot-spots contain population (variable and adaptable) varieties, as well as wild relatives and weeds, which provide valuable genetic

resources for the improvement of crops (Vandermeer and Perfecto, 1995; Altieri, 1999). That's the most important in the biodiversity of plants and animals present in ecosystems, since the level of internal function regulation of these agricultural systems depends largely on the level of biodiversity (Altieri and Nicholls, 2000).

Although the interactions between agriculture, environment and society are complex and multifaceted, it is necessary to recognize that in agroecosystems, biodiversity performs a variety of ecological or environmental services (Dale and Polasky, 2007), apart from food production, including: nutrient recycling , regulation of microclimate and local hydrological processes, elimination of undesirable organisms and detoxification of harmful chemicals. These ecosystem services provided by the agriculture receive increasing attention with regards to sustainability and economic prosperity in the intrinsic value of biodiversity (Power, 2010), aside from the fact that human needs and interests are paramount.

Ecosystems have played a very important role in the enrichment of our agricultural biodiversity (Zhang et al., 2007), for example the maize-bean-pumpkin association is found in cultures of almost all ecological zones, although varieties, populations, and types change, even the species of these plants, according to the environmental characteristics as well as the influences and customs of each human group.

Increases in the biodiversity include in some cases more species or more varieties of the same species (Aguilar et al., 2003) and symbiotic or "cooperative" interactions between plants (some are for troop support, soil moisture storage, shade and weeds control, others serve as hosts for beneficial insects, repellent, etc), the optimum use of space, both horizontally and vertically (encouraging greater efficiency in the use of light and humidity, etc). In addition "agrobiodiversity" remains the main raw material of agroecosystems to deal with climate change, since it can provide features of plant breeders, when farmers select resistant seeds; these generate natural crops for germplasm (Ortiz, 2011).

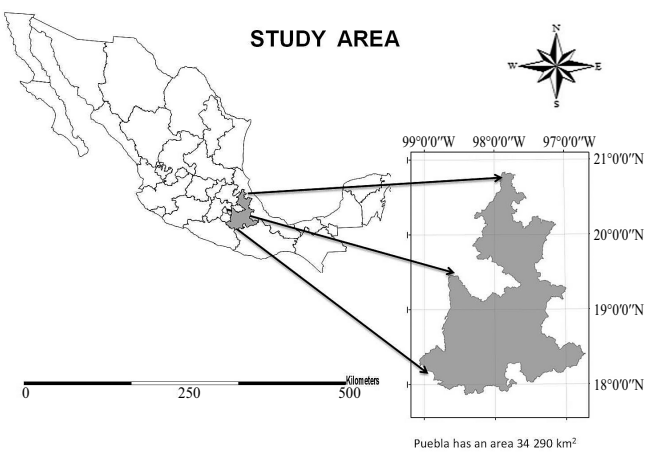

Fig. 1. Study area: Puebla State: Puebla is located in central Mexico. It is the fourth most important State in the country

Materials and Methods

Study Area

Puebla State is located in the central part of Mexico (Figure 1). Its geographic coordinates are: 19°03′00″N and 98°12′00″W (Gobierno del Estado, 2011). It borders on the North with the States of Hidalgo and Veracruz, on the East with Veracruz and Oaxaca, on the South with Oaxaca and Guerrero on the West with this State, Morelos, Mexico, Tlaxcala and Hidalgo (Tamayo, 1996).

Puebla has an area of 34 290 km^2, which represents 8% of the total land of the country, its borders contain areas that correspond to the four physiographic provinces of Mexico: Sierra Madre Oriental, Llanura Costera del Golfo Norte, Eje Neovolcanico and Sierra Madre del Sur (INEGI, 2008).

For the noticeable changes of altitude in its relief, Puebla possesses a great variety of climates, the most common in the territory are: temperate climate, followed by the warm climate and semi-warm**;** the least common correspond to medium-dry**,** dry, temperate, cold and semi-warm. The agricultural areas are in the regions with a subhumid and temperate climate, where the main crop is corn, but also pepper, potatoes, wheat and beans, etc. are produced. The fruits of major importance are: apple, peach, avocado, coffee, beans and orange. The annual average temperature of the State is 17.5°C, the mean monthly precipitation is 1270 mm annually, rainfalls are present only in summer, during the months of June and October (INEGI, 2008).

Database building

For this study, the agricultural species of greatest importance for Puebla were considered, according to the production reported by the Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA) which provides performance data through the Servicio de Información Agroalimentaria y Pesquera (SIAP). First of all, in this study three of the most produced types of maize were taken into account : Conico, Elotes Conicos y Tuxpeño (Zea mays ssp. mays), and also the species of agricultural interest with the most economic potential: *Phaseolus vulgaris* (beans), *Amaranthus hypochondriacus* (Amaranth), *Cucurbita pepo* (Courgette), *Coffea arabica* (Coffee), *Capsicum frutescens* (Chili), *Saccharum officinarum* (Sugar cane),

Solanum tuberosum (Potato), *Persea americana* (Avocado), *Malus domestica* (Apple), *Prunus pérsica* (Peach), *Citrus sinensis* (Orange), *Crataegus pubescens* (Mexican hawthorn), *Triticum spp* (Wheat). From all these species, the occurrences were recorded. These references were taken from the database of the Comisión Nacional para el Conocimiento y uso de la Biodiversidad (http://wwwconabio.gob.mx) the Global Biodiversity Information Facility (http://www.gbif.org/), and the SIAP (http://www.siap.gob.mx), for those species that do not have a reference in terms of location (latitude-longitude), the software ArcInfo (ESRI, 1999), was used.

Bioclimatic Data

The CGCM2 SRES climate change model was used, which was created by the Canadian Centre for Climate Modelling and Analysis (Flato et al., 2000). It is a spectral model with triangular truncation at the wave number 32 (that gives a resolution of the grid surface 3.7º x3.7º) and 10 vertical levels. In the first term location, the scenarios A1B and A2A were used. The first one assumes a very fast global economic growth, a maxim of global population by mid-century but that later decreases, a quickly introduction about new efficient technologies and a balance between the different sources. On the other hand, the A2A scenario establishes a strong population growth and slow economic development based on the preservation of local identities (IPCC 2007b). Others scenarios employed in the present work were the scenarios B1 and B2; the first one represents a convergent world, with the same global population as A1, but with a faster evolution from the economic structures to an economy of services and information. It describes reductions in consumption and the introduction of clean and efficient technologies (Jarvis, 2008). There is an emphasis on global solutions to sustainability, including improved equity, but without additional considerable climate initiatives. However, B2 presents a world that takes resources to care for the environment, which emphasizes local solutions focused on the social, economic and environmental sustainability. It is a world with a growing population, but at slower rates than in the other scenarios with intermediate levels of economic development and slow technological change but varied. Society is oriented toward environmental protection and social equity, and prioritizes local and regional levels. All scenarios are within an approximate spatial resolution of 1 Km² (30 arc-seconds), with different time points: present and future scenarios (2020, 2050 and 2080). Each one, with 19 bioclimatic raster variables generated from the monthly values of temperature and precipitation. All of them were obtained from Worldclim (Hijmans et al., 2005), and they were used to model the climate component of ecological niches for each species (Figure 2).

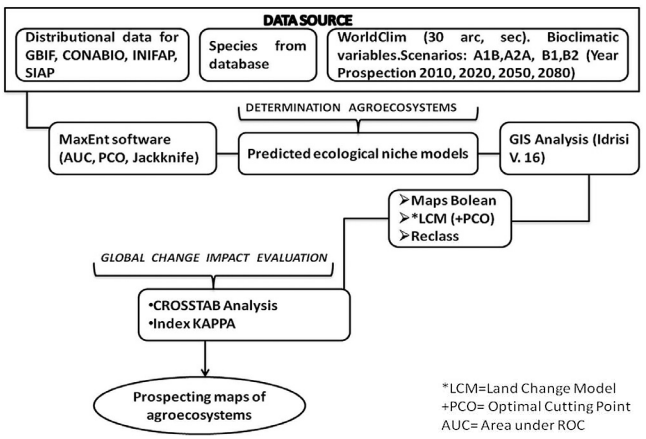

Fig. 2. Schematic representation of the involved methodology steps to generate the distribution of biodiversity in agricultural species.

Ecological Niche Modeling

The scenarios were used as independent variables in a maximum entropy algorithm, MaxEnt version. 3.3.1 (Phillips, 2004), to model the potential distribution across the survey years (present, 2020, 2050 to 2080) and with diversity of the agroecosystems and important species for Puebla State (Figure 2), making a model for each species of agricultural interest (n = 13) and the three corn types (n = 3). The result of the model expresses the value of habitat suitability for the species as a function of the variables. A high value of distribution function in a cell indicates that it presents favorable conditions for the presence of the species.

The values for the maximum number of interactions (500), the convergence threshold (0.00001), the execution type replicated (10 crossed with the default 90% training and 10% validation test matches), the selection of feature classes (auto feature) the points fund (10 000) and regularization values (1) as the default settings, to reject duplicate data of occurrences in the cells of the environmental grid variable were selected. The program provides the response curves for the species to the different variables, and considers the importance of each one in the species range (Leathwick et. al., 2006; Phillips et. al., 2004, 2006). Niche models were evaluated using ROC (Hernandez et al, 2006; Phillips and Dudík, 2008), which is considered a valid measure of relative performance of the model (Hernández et al., 2006; Phillips and Dudík, 2008). Therefore, projected distributions higher than 0.90 ROC values are considered accurate values.

The optimal cutoff point (PCO) was determined based on the most stringent threshold of MaxEnt (10 percentiles).

The importance of individual environmental factors on the development of models with built Jackknife technique was evaluated. During the process, the global environmental layers were projected in the geographic region of Puebla State (Mexico). This is due to the strict conditions required for ecological niche models, and finally, the distribution of each modeling agroecosystem was interpreted (Guisan and Thuiller, 2005).

Agroecosystems construction and GIS analysis

Agroecosystems are characterized by different components (sustainability, resilience and a great biodiversity). The space and time of the biodiversity associated with crops and livestock is regulated by the farmer. This biodiversity includes, flora and fauna (herbivores, carnivores, decomposers, etc.), which colonize the ecosystems and the surrounding environments that are developed according to its management and structure (Vandermeer and Perfecto, 1995; Altieri, 1999).

Biodiversity is one of the basic principles of agroecosystems, which means that they have many species of agricultural interest for the farmer to access at different times for food resources, and not be dependent on external products (Altieri, 1994). By these, the Niche Models were generated for each of the agroecosystem of the State of Puebla (Table 1, Figure 2).

For each of the thirteen species of agricultural interest in Table 2, and for the three types of maize that are sown in Puebla (Conico, Elotes Conico and Tuxpeño), niche models were built. Once the areas with the highest probability of presence (PCO= Optimal Cutoff Point), Boolean maps were generated, where 0 represents areas without environmental characteristics for the establishment of the species and 1 is the geographic area with more probability that the agricultural species of interest is present. It was considered that one pixel is an agroecosystem if it has more than three species in it. In Mexico traditional agroecosystems are composed by courgette, beans and some of the maize types (Hernández G, 1998). For this, the agroecosystem models have more than three species of agricultural interest and each one of the maize types (Table 2 and Figure 3). The whole cartographic model was made with the GIS Idrisi V.16 (Clark Labs, Clark University).

Global change impact evaluation

To determine the degree of potential impact in climate change on agroecosystems, a CROSSTAB analysis was performed to obtain the KAPPA index (Abraira, 2001; Fielding and Bel, 1997; Heikkinen, et. al., 2007), and to determine the changes that occurred under different climate change scenarios from the periods; present-2020 2020-2050 and 2050-2080 (Figure 2).

The KAPPA statistics (Congalton, 1991; Cohen, 1960), as cited in Lipsitz et. al. (2001) and Hord (1976) was also employed in this study to assess the differences between two maps from different periods. KAPPA statistics is a threshold-dependent measure and it was used to test the agreement between t_0 and t_1. According to Congalton 1991, "KAPPA is a powerful technique because of its ability to provide information about a single matrix as well as to statistically compare

Table 1

Surfaces and crop yields in Puebla. This State has an important surface of crops, niche models for present have more surface than planting surfaces. Niche models for maize are some results from this work

Crops	Niche Model (km^2)	Sown surface (km^2)	Cultivated surface (km^2)	Production (ton)	Yield (ton/ha)	PMR ($/t)	Production Value (Thousands of pesos)
Avocado	14107.13	1343.2212	1234.0369	1107135.16	8.97	12794.97	14165758.09
Amaranth	21477.05	22.36	22.29	2488.52	1.12	2546.44	6336.87
Coffee	5028.014	7810.1599	7414.1069	1332263.19	1.8	4299.09	5727519.07
Courgette	14890.22	38.968	38.043	47600.65	12.51	4056.03	193069.62
Sugar cane	6339.96	7348.1874	7039.4312	50421619.53	71.63	619.78	31250469.38
Chili	15220.65	29.51	29.36	9249.46	3.15	18884.2	174668.67
Peach	10589.023	447.2086	416.4841	227421.64	5.46	6721.86	1528695.86
Bean	18859.06	669.1016	616.7546	38107.76	0.62	10878.93	414571.6
Maize*		6065.344	5680.594	1080462.01	1.9	3358.37	3628593.57
Apple	11092.35	612.1953	577.4295	584655.18	10.12	5564.08	3253065.86
Orange	4384.586	3393.8904	3345.7321	4051631.61	12.11	1203.71	4876987.94
Potato	8058.64	44.15	43.15	66377.86	15.38	6471.65	429574.04
Mexican hawthorn	3489.32	6.726	6.6947	4229.58	6.32	1504.13	6361.83
Wheat	11777.59	31.49	31.39	5179.51	1.65	1930.9	10001.1

Table 2
Considered species in agro ecosystems. There could be appreciate each one of the considered species by the different agroecosystem models. The value varies from 13 to 9 species. The X represents that the agricultural specie was included in the agroecosystem model (a, b o c), while the 0 represents that the specie did not have a suitable habitat within the agroecosystem model

			Avo-cado	Ama-ranth	Coffee	Cour-gette	Sugar cane	Chili	Peach	Bean	Apple	Orange	Potato	Mexi-can haw-thorn	Wheat	Rich-ness
Agroecosystem type	Scenarios	Present	X	X	X	X	X	X	X	X	X	X	X	X	X	13
Agroecosystem a) (Conicos)	A1B	2020	X	X	X	X	X	X	X	X	X	X	X	X	X	13
		2050	X	X	X	X	X	X	X	X	0	X	X	X	X	12
		2080	X	X	X	X	X	X	X	X	X	X	X	X	X	13
	A2A	2020	X	X	X	X	X	X	X	X	X	X	X	X	X	13
		2050	X	X	X	X	X	X	X	X	X	0	X	X	X	12
		2080	X	X	X	X	X	X	X	X	X	X	X	X	X	13
	B1	2020	X	X	X	X	X	X	X	X	X	0	X	X	X	12
		2050	X	X	X	X	X	X	X	X	X	0	X	X	X	12
		2080	X	X	X	X	X	X	X	X	X	0	X	X	X	12
	B2	2020	X	X	X	X	X	X	X	X	X	X	X	X	X	13
		2050	X	X	X	X	X	X	X	X	X	0	X	X	X	12
		2080	X	X	X	X	X	X	X	X	X	0	X	X	X	12
Agroecosys-tem b) (Elotes Cónicos)	A1B	2020	X	X	X	X	X	X	X	X	X	X	X	X	X	13
		2050	X	X	X	X	X	X	X	X	0	X	X	X	X	12
		2080	X	X	X	X	X	X	X	X	X	X	X	X	X	13
	A2A	2020	X	X	X	X	X	X	X	X	X	X	X	X	X	13
		2050	X	X	X	X	X	X	X	X	X	0	X	X	X	12
		2080	X	X	X	X	X	X	X	X	X	X	X	X	X	13
	B1	2020	X	X	X	X	X	X	X	X	X	0	X	X	X	12
		2050	X	X	X	X	X	X	X	X	X	0	X	X	X	12
		2080	X	X	X	X	X	X	X	X	X	X	X	X	X	13
	B2	2020	X	X	X	X	X	X	X	X	X	X	X	X	X	13
		2050	X	X	X	X	X	X	X	X	X	X	X	X	X	13
		2080	X	X	X	X	X	X	X	X	X	0	X	X	X	12
Agroecosystem c) (Tuxpeño)	A1B	2020	X	X	X	X	X	X	X	X	X	X	X	0	0	11
		2050	X	X	X	X	X	X	0	X	X	X	X	0	0	10
		2080	X	X	X	X	X	X	X	X	X	X	X	0	0	11
	A2A	2020	X	X	X	X	X	X	0	X	0	X	X	0	0	9
		2050	X	X	X	X	X	X	0	X	0	X	X	0	0	9
		2080	X	X	X	X	X	X	X	X	0	X	X	0	X	11

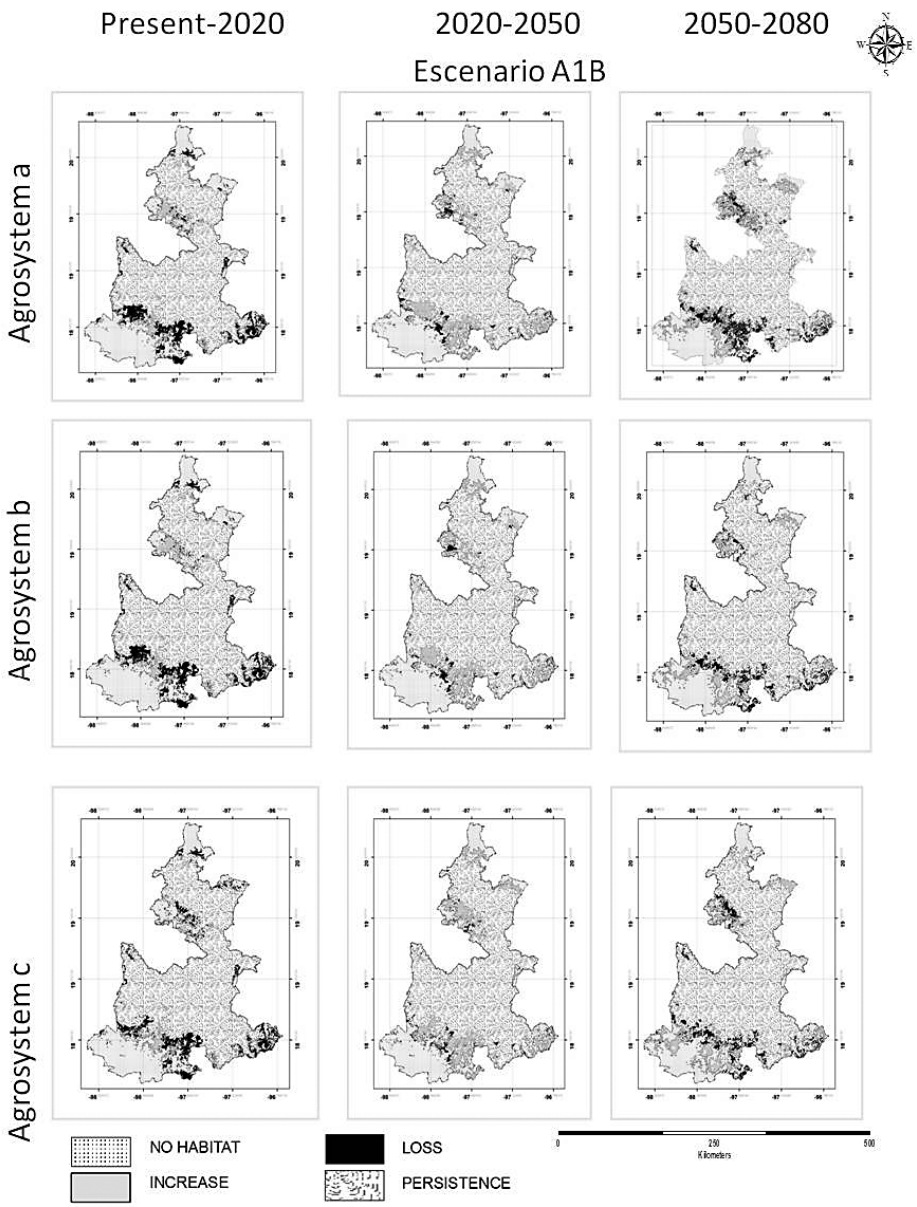

Fig. 3. Agroecosystem
a) Cónico; b) Elotes cónicos; c) Tuxpeño

matrices". KAPPA, which is a chance-corrected measure of agreement, is commonly used in ecological studies with presence/absence data (Farber and Kadmon, 2003; Garzon et. al., 2006; Mitchley and Xofis, 2005). KAPPA provides an index that considers both omission and commission errors. Landis and Koch (1977) proposed interpretation of Kappa statistics was used to interpret the results of the Kappa obtained in this study (Table 3).

In order to analyze the impact, four categories were used: No Habitat, Loss, Increase and Persistence. The first category shows that there is no suitable habitat for agroecosystems. The second (Loss) is the percentage where there was suitable habitat for agroecosystems, but not anymore. On the contrary, in the third one (Increase), there was no habitat for agroecosystems, but there is now. Finally in the last category (Persistence) there has always been favorable habitat for the distribution of agroecosystems.

Table 3

Interpretations of value of Index KAPPA

Kappa (K)	Degree of agreement	Complement
<0.0	Without agreement	Almost perfect
0.00–0.20	Insignificant	Substantial
0.21–0.40	Medium	Moderate
0.41–0.60	Moderate	Medium
0.61–80	Substantial	Insignificant
0.81–1.00	Almost perfect	Without agreement

Results

The distribution of species in the ecological niche

The quality of the three agroecosystem models included some of the most important maize types (*Zea mays* ssp. mays: Conico, Elotes Conicos y Tuxpeño) and 13 species of agricultural interest, through the Analysis Curve, using as receiver operating characteristic (ROC), the total number of occurrence points and the 19 bioclimatic variables for the MaxEnt modeling. Values higher than 0.90 (ROC) were obtained, because many occurrence points were used in the models.

Global change impact on agroecosystems

A1B scenarios

According to scenario A1B, it can be observed that there is a tendency for the No Habitat category to decrease in surface (Table 3). Causing the State of Puebla to have a widespread loss in this category for the three modeling agroecosystems (Table 4); 2050–2080 being the period of change representing the greatest losses in the three agroecosystems, where the Tuxpeño model (agroecosystem c) is the one having the smallest surfaces in the No Habitat category. These losses, in the No Habitat category, vary from 18.5 to 22% of State territory (between 6343.7 and 7852.4 km$^{2)}$. The No Habitat areas present a similar geographic pattern for the three agroecosystems, since northern and southern Puebla is where the largest areas of Not Habitat category are present, no matter the time period, except for the model of agroecosystem c (Tuxpeño) in the 2050–2080 period, where it can be appreciated that there is a change in the No Habitat category for the Increase category, which means that new conditions are created for this type of agroecosystem (Figure 3).

The Loss category (loss of habitat areas for the different agroecosystems) presents an irregular pattern, since the three agroecosystems have an increase (2020–2050), which is between 6.9% (2366 km^2) and 7.3% of State territory (Table 4), where agroecosystem c (Tuxpeño) is the one that lost more habitat area (7.3% equivalent to 2503.2 km^2). However, af-

Table 4

Analysis of changes in the distribution of the Agroecosystems in values of km^2. NH: No Habitat, L = Loss, I = Increase, P = Persistence, KI = Kappa Index Values (a = almost perfect with values from 1 to 0.81; b = substantial with values from 0.80 to 0.61) according to Abraira, 2000 Most models present a substantial change under different climate change scenarios

Agroecosystem	SRES	A1B					A2A					B1					B2				
	Categories	NH	L	/	P	IK	NH	L	/	P	IK	NH	L	/	P	IK	NH	L	/	P	IK
Agroecosystem a (Cónico)	Present–2020	22.9	3.4	6.9	66.9	b	21.8	4.5	5.2	68.6	b	22.1	4.2	4.8	68.9	b	21.9	4.4	3.6	70.1	b
	2020–2050	22.7	7.1	1.9	68.4	b	23.0	4.0	4.6	68.4	b	23.4	3.4	4.6	68.6	b	24.3	1.2	5.7	68.9	a
	2050–2080	20.3	4.2	4.2	71.3	b	24.2	3.4	5.5	66.9	b	22.6	3.2	5.5	68.8	b	26.8	3.2	3.2	66.9	a
Agroecosystem b (elotes cónicos)	Present–2020	22.6	3.4	6.7	67.3	b	21.5	4.5	4.8	69.2	b	21.3	4.7	4.4	69.6	b	21.7	4.3	3.5	70.6	b
	2020–2050	22.3	6.9	1.6	69.1	b	22.7	36	4.5	69.3	b	22.6	3.0	4.9	69.5	b	23.9	1.2	5.2	69.7	a
	2050–2080	19.7	4.2	4.0	72.1	b	23.9	3.3	5.4	67.5	b	21.3	6.2	2.5	70.0	b	26.2	2.9	3.2	67.7	a
Agroecosystem c (Tuxpeño)	Present–2020	22.2	2.7	7.1	68.1	b	21.0	3.9	5.5	69.6	b	20.8	4.1	5.4	69.7	b	20.5	4.4	4.0	71.2	b
	2020–2050	21.9	7.3	1.6	69.2	b	22.0	4.5	4.5	69.1	b	22.7	3.5	4.5	69.4	b	23.3	1.2	5.2	70.4	a
	2050–2080	18.5	5.1	4.5	72.0	b	23.1	3.5	6.1	67.5	b	21.9	5.2	3.1	69.7	b	25.0	3.5	3.1	68.4	a

ter this increase, there is a drop; (2050-2080) where agroecosystem c (Tuxpeño) is the most affected, losing a 5.1% (1748 Km^2) of State territory. At a geographic level, significant losses stand out in the southern and northern parts of the State for agroecosystem a (Conico) in the 2020–2050 period, while for the present–2020 period of agroecosystem b (Elotes conicos) the losses are located in the southwestern region (Figure 3).

The Increase category of A1B scenario, (places in which there were no favorable conditions for the establishment of the agroecosystems that became conducive for their development) presents a sharp decline in the 2020–2050 period for the three scenarios, but also with an irregular pattern because in the 2020–2050 period a drop of values can be appreciated, ranging between 1.6% (548.6 km^2) and 1.9% (651.5 km^2) of the territory, after having had nearby surfaces 7% (2400.3 km^2) of territory in the present – 2020 period. Finally, in the 2050–2080 periods, an increase is appreciated, but the values are never reached in the present – 2020 period. The agroecosystem c (Tuxpeño) presents the highest increase in the 2050–2080 period, reaching 4.5% (1543 1 km^2) of territory.

Regarding the increases, the highest values can be appreciated in the present-2020 period for the three agroecosystems, with the Tuxpeño agroecosystem, having the greatest advance (7.1% ≈ 2434.6 km^2); followed by a major drop in which the three agroecosystems have similar values, and ultimately there is an upturn where the increase values are similar (between 4.0 ≈ 1371.6 km^2 and 4.5% ≈ 1543.1 km^2). The southwest region is the most benefited by the increase of agroecosystem areas; and for agroecosystem a, (Conico) the present – 2020 period, is where this category is increased, while for agroecosystem a, it is the 2020–2050 period and for agroecosystem b, it is the 2020–2050 and 2050–2080 periods (Figure 3).

In all cases, the Persistence category is favored through the time, agroecosystem b (Elotes Conicos) becoming the one that gets more surface in this area. Geographically, the Persistence is observed in the central part of the State and to a lesser level in the southwest region for agroecosystems a (Conico) and c (Tuxpeño), while for agroecosystem b, the changes of this category are in the northern region. In all cases of A1B scenario, the KAPPA rating presented a substantial degree of agreement, which does not represent major changes.

A2A scenarios

In the No Habitat category, agroecosystem c (Tuxpeño) occupies an area of 21% (7200.9 Km^2), whereas agroecosystem occupies 21.8% (7475.22 km^2) and b 21.5% (7372.35 km^2) where the area of this category is increased. However, the No Habitat category increases over time as it is observed in the 2020–2050 period, where the maximum increase reaches 23% (7886.7 km^2) in agroecosystem a (Conico), followed by agroecosystem b 22.7% (7783.83 km^2), and the one with the least surface increase was agroecosystem c with 22% (7543.8 km^2). The same occurs in the 2050–2080 period, where the No Habitat category increases much more for the three agroecosystems, especially in northern (Sierra Norte) and southern (Mixteca) Puebla.

Moreover, in the Increase category, (increase of habitat areas) for the present–2020 period, agroecosystem c (Tuxpeño) has a 5.5% (1885.95 km^2) surface increase of State territory while agroecosystem a (Conico) has 5.2% (1783.08 km^2) and agroecosystem b has 4.8% (1645.92 km^2). At a territorial level, the areas with the greatest increase are: the northern for agroecosystems a and b (Sierra Norte) and the southwest (Mixteca) for agroecosystem a. However, the areas gained in the present – 2020 period are not maintained in the 2020–2050 period, since the Increase category is not preserved in quantity or territory. There is a variation between 4.5% (1543.05 km^2) and 4.6% (1577.34 km^2) in the three agroecosystems (Table 4). Finally, for the 2050–2080 period, the area of this category increases in territory for the three agroecosystems, especially for agroecosystem c with 6.1% of territory (2091.69 km^2), followed by agroecosystem a with 5.5% of territory (1885.95 km^2) and then agroecosystem b, which reaches the levels that it had already presented in the present-2020 period (Figure 4).

The Loss category, in this scenario, represents a 4.5% (1543.1 km^2) territory for the present–2020 period for agroecosystems – “a” and “b”, while for agroecosystem c, the percentage of this category is less than the previous two, with 3.9% (1337.3 km^2). Nevertheless in the 2020-2050 period, the opposite happens for agroecosystem c, because the loss percentage increases to 4.5% (1543.1 km^2), while agroecosystems “a” and “b” have a decrease in this category; 4% (1371.6 km^2) for agroecosystem a, and 3.6% (1234.44 km^2) for agroecosystem b. In the 2050-2080 period, the loss of territory is lesser than the previous period (2020-2050) since agroecosystems “a” and “c”f keep a loss rate of 3.4% (1165.86 km^2), while agroecosystem b represents 3.3% (1131.57 km^2) of the Loss category. At a territorial level, agroecosystem “a” presents the greatest loss in the southwest (Mixteca) and southeast (Sierra Negra) regions. However, the 2050–2080 period, also has losses in the northwest region of Puebla (Figure 4). Meanwhile agroecosystem “b” has losses in the southwest region (Mixteca) for the 2020-2050 period, these losses are accentuated in that same region along with the northern region (Sierra Norte) of the State. Furthermore, agroecosystem “b” has the greatest losses in

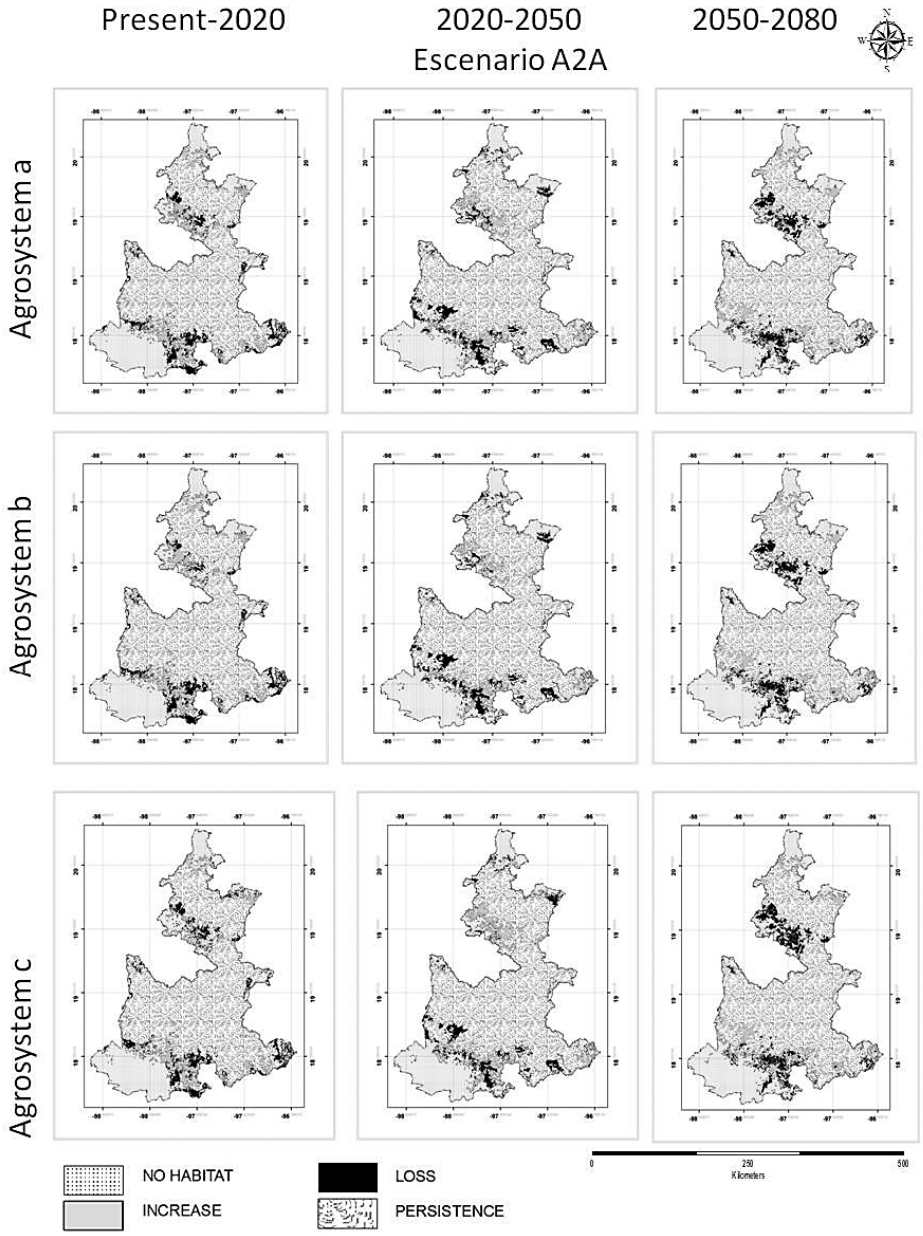

Fig. 4. Agroecosystem
a) Cónico; b) Elotes cónicos; c) Tuxpeño

the northwest (Sierra Norte) and southwest (Mixteca) regions, in the 2050–2080 period. As for agroecosystem c, it can be seen that in the present–2020 period the losses are located in the southeast (Sierra Negra) and northwest (Sierra Norte) regions. However, for the 2020–2050 period, these losses are recorded in the northeast region (Sierra Norte and the Southwest), while for the 2050–2080 period, the losses are mainly concentrated in the northeast region.

In the Persistence category, agroecosystem c (Tuxpeño) occupies approximately 69.6% of the territory (23867 km^2), in the present–2020 period, followed by the agroecosystem a (Conico) with an occupancy of 68.6% of territory (23522.94 km^2) and then agroecosystem "b" (Elotes Conicos), with an occupancy rate of 69.2% (23728.68 km^2). For the 2020–20150 period, persistent surface of different agroecosystems is similar to the previous period, noting that agroecosystem "a' is the one with less

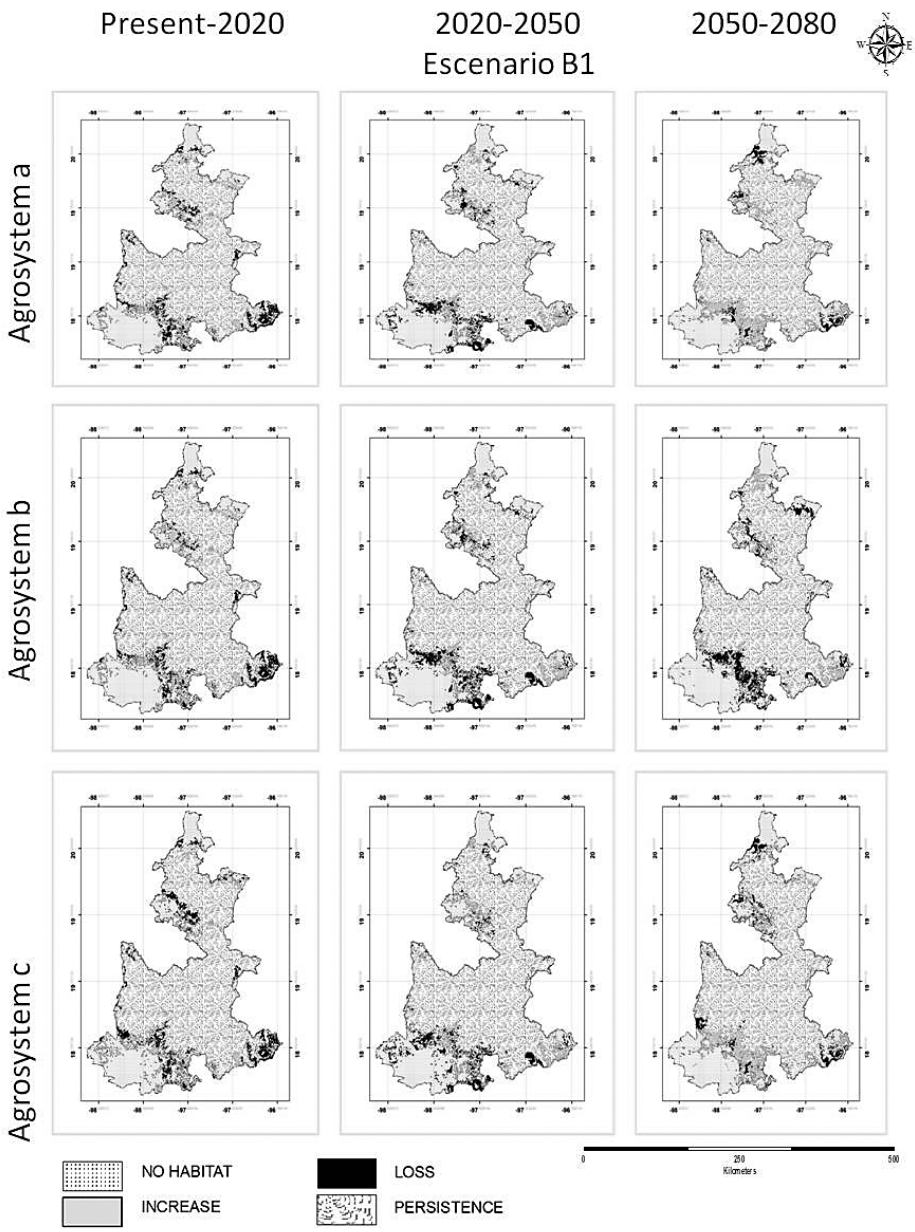

Fig. 5. Agroecosystem
a) Cónico; b) Elotes cónicos; c) Tuxpeño

persistence in the territory, occupying 68.4% of territory. In the 2050–2080 period, agroecosystem "a" (Conico) is the one with the lowest value, because Persistence category occupies 66.9% (22940.01 km^2) of territory, while agroecosystems b and c occupy 67.5% (23145.75 km^2) of the territory (Table 4). At a territorial level, in all agroecosystems, persistence excludes some portions of the northern region of the State, and a large portion of southwestern area (Mixteca), repeating this pattern for almost all analysis of periods (Figure 4). In all cases of the A2A scenario, as the previous scenario, the KAPPA Index occupied a substantial degree, because it does not represent big changes.

B1 scenarios

Under the B1 scenario, the No Habitat category has similar values to those established within the previous scenarios. Regarding the analysis of periods, in the present–2020 period it

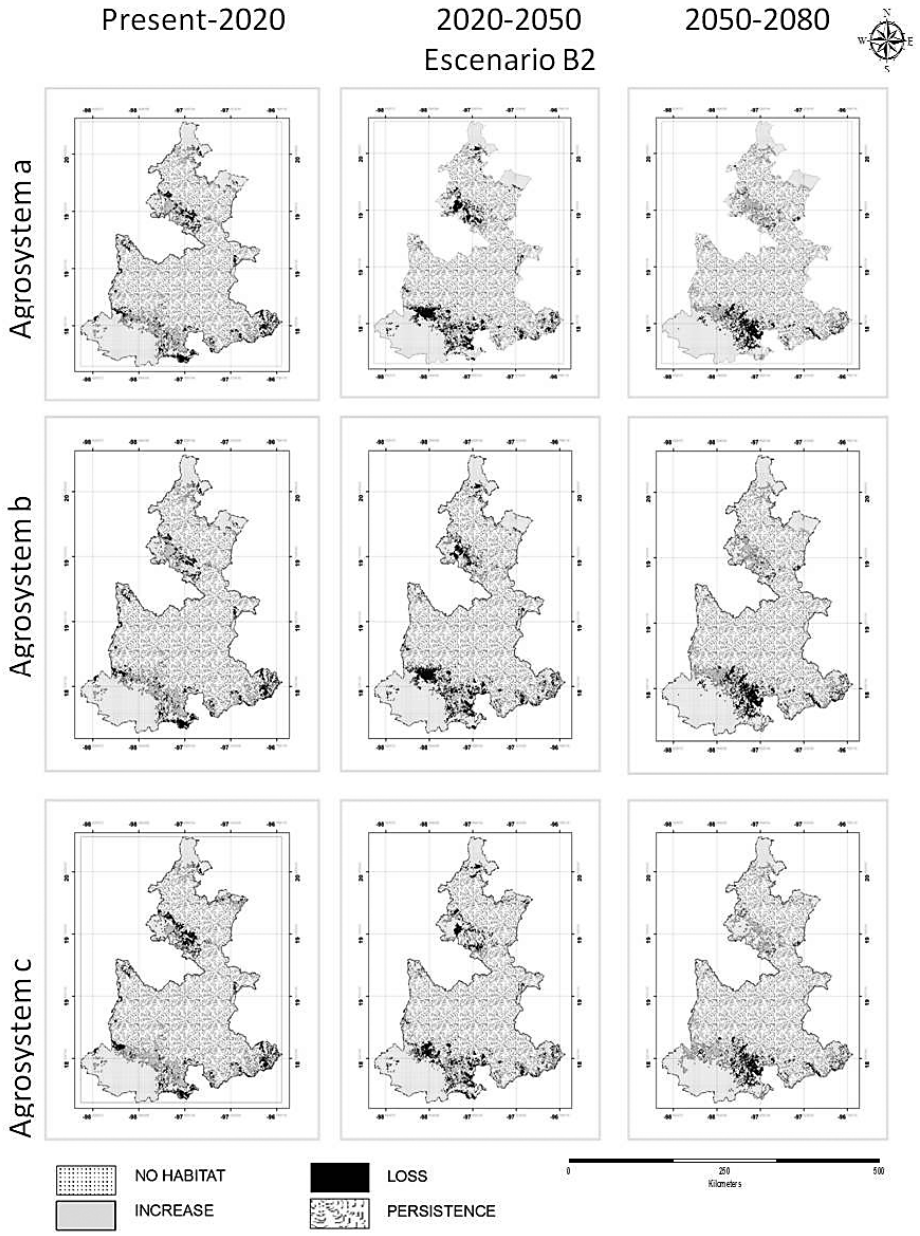

Fig. 6. Agroecosystem
a) Cónico; b) Elotes cónicos; c) Tuxpeño

is observed that agroecosystem "a" occupies 22% of territory (7543.8 km^2), followed by agroecosystem "b" with 21.3% (7303.77 km^2) and then agroecosystem c with 20.8% (7132.32 km^2). For the 2020–2050 period, as it can be observed in Table 4, the occupancy rates range from 22.6% (7749.5 Km^2 agroecosystem b) and 23.4% (8023.9 agroecosystem a). Finally, in the 2050–2080 period, the No Habitat category results in an increase in agroecosystem a, occupying 22.6% (7749.5 Km^2) of territory, while agroecosystem "b" has the lowest value of occupation in this category (21.3 % ≈ 7303.8).At a territorial level, the No Habitat category in all agroecosystems, is located in the northern region of the State (Sierra Norte) and in the southwest (Mixteca). However, agroecosystem c (Tuxpeño), in the present–2020 and 2020–2050 periods, in the southwest region, the category is not as continuous as the rest of the agroecosystems (Figure 6).

Regarding the Loss category, in the present – 2020 period, agroecosystem "b" (Elotes Conico) presents the highest values, because this category occupies 4.7% of territory (1611.63 km^2), followed by agroecosystem "a" (Conico) which occupies 4.2% of territory (1440.18 km^2), and agroecosystem c which occupies 4.1% of territory (1405.89 km^2). In the 2020–2050 period there were decreases in the surface of the Loss category, mainly for agroecosystem "b", occupying 3.0% of territory (1028.7 km^2), while agroecosystems a and c decrease having an occupancy rate of 3.4% (1165.86 km^2) and 3.5% (1200.15 km^2) respectively. Unlike the previous two periods, for the 2050-2080 period the loss of surface increases twice in the case of agroecosystem b reaching an occupancy rate of 6.2% (2125.98 km^2), followed by agroecosystem c with an occupancy rate of 5.2% (1783.08 km^2) and finally, agroecosystem a being the least affected by changes, occupying 3.2% of territory (1097.28 km^2) where the surface remains almost as in the 2020–2050 period (Table 4 and Figure 5). In the present – 2020 period, at a territorial level, the Loss category for agroecosystem "a" presents its largest increase in the southeast region (Sierra Negra). For the next period, 2020–2050, is the southwest region that presents larger areas of this category, along with the northwest region (Sierra Norte). Finally, in the 2050–2080 period, the increases in this category are found in the southwest (Sierra Negra) and northern (Sierra Norte) regions and for agroecosystem "b", at a territorial level, the biggest losses are recorded in the Southwest (Sierra Negra) for the 2020–2050 and 2050–2080 periods, while the southeast region is the most affected in the present–2020 period.

The Increase category in the present – 2020 period, has the highest values for the Tuxpeño agroecosystem occupying 5.4% (1851.7 km^2) of State territory, followed by the Conico agroecosystem occupying 4.8% of territory (1645.92 km^2) and finally agroecosystem b with 4.4% of the State territory (1508.76 km^2). For the 2020–2050 period, agroecosystems a 4.6% ≈ 1577.34 km^2 and (c) 4.5 % ≈ 1543.05 Km^2 present losses in the Increase category, but agroecosystem b shows an increase, reaching 4.9 % (1680.2 km^2) of territory (Table 4). Finally, the 2050–2080 period, shows that agroecosystem a presents a strong growth in the Increase category, reaching 5.5% (1886.0 km^2) of State territory, while agroecosystems b and c present strong remains representing 3.1% (1062.99 km^2) and 2.5% (857.25 km^2) respectively. At territorial level, this category presented the greatest increases in the southwest region (Mixteca) with some isolated spaces in the southeast region and Sierra Negra (agroecosystem c). For the 2020–2050 periods, the largest increases are observed in the northwest and southeast (agroecosystem "c") as in the southeast region and Sierra Negra (agroecosystem b). And finally, in the 2050–2080 period, where the major increases are observed in the southwest region or Mixteca (agroecosystem a) as in the southeast region or Sierra Negra (agroecosystem "c").

Persistence in the B1 scenario for the present – 2020 period, presents ranges of variation between different agroecosystems that are very low because it goes from 68.3% (23420.07 km^2 agroecosystem a) to 69.7% (23900.13 km^2 agroecosystem "c") of occupation of State territory. The pattern is repeated in all periods, where changes are not detected among agroecosystems higher than 1% (342.9 km^2) of the country. In all B1 scenario cases, the KAPPA Index occupied a substantial degree, because it does not represent big changes.

B2 scenarios

In B2 scenario, the No Habitat category in the present–2020 period, agroecosystem "a" occupies 21.9% of the State territory (7509.51 km^2), while agroecosystem b occupies 21.7% of the territory (7440.93 km^2), on the other side, agroecosystem c occupies 20.5% of the territory (7029.45 Km^2). However, the values of the No Habitat category increase for the 2020-2050 period, agroecosystem a presents the highest occupancy levels, with 24.3% (8332.5 km^2) of State territory, followed by agroecosystem b with an occupancy of 23.9% (8195.3 km^2) and finally agroecosystem c that occupies 23.3% (7989.6 km^2) of State territory. For the 2050–2080 period, the increase is maintained in the No Habitat category, reaching 26.8% (9189.72 km^2) of territory in agroecosystem a, followed by 26.2% (8983.98 km^2) in agroecosystem b, and finally agroecosystem c with 25% (8572.5 km^2) of State territory (Table 4 and Figure 6). At a territorial level, in the present – 2020 period, agroecosystems "a" and "b" present the largest areas of occupation in the southwest, which means in the Mixteca (Figure 6) and in the northern region, while agroecosystem c does not present continuous occupancy levels in the No Habitat category, because it is in the southwest region and the north region is the one that presents higher occupancy levels in this category. Nevertheless, agroecosystem c remains at a constant occupation surface in the 2050–2080 period, in the southwest region (Mixteca).

The Loss category in the present – 2020 period shows an occupancy rate of 4.4% (1508.76 km^2) of territory for agroecosystem a, this value coincides with agroecosystem c, while agroecosystem b presents an area of occupancy of 4.3% (1474.47 km^2). For the 2020–2050 periods, a big decrease in the Loss category is appreciated, since the three agroecosystems have an occupancy rate of 1.2% (411.48 km^2) of State territory. For the 2050–2080 period, the highest occupancy value is represented by agroecosystem c, with an occupancy

rate of 3.5 % (1200.2 km^2), followed by agroecosystem a, with 3.2% (1097.3 km^2) of territory and finally, agroecosystem b, with 2.9% ≈ 994.4 km^2 (Table 4).At territorial level, the losses in the present - 2020 period are mainly located in the northwest (Sierra Norte) and southeast (Sierra Negra) for the three agroecosystems (Figure 6). For the 2020–2050 periods, the category presents territorially the largest losses in the southwest region (agroecosystems "a" and "b") and in the northern region (all agroecosystems). Territorially in the 2050-2080 periods, all agroecosystems show losses in the southwest zone.

In the present – 2020 period, the Increase category presents the highest occupancy rates in agroecosystem c, with 4% of the territory (1371.6 km^2), followed by agroecosystem a with an occupancy percentage of 3.6% (1234.44 km^2) and agroecosystem b, with 3.5% of territory occupation (1200.15 km^2). The 2020–2050 period shows a marked increase in the category, because there is a reached value of 5.7% of the territory (1954.53 km^2) in agroecosystem a, followed by 5.2% (1783.08 km^2) for agroecosystems "b" and "c". For the 2050-2080 period, a decrease in the Increase category is shown for agroecosystems "a" and "b", that have the highest occupancy values, reaching 3.2% (1097.28 km^2), while agroecosystem c occupies 3.1% of State territory (1062.99 km^2). At territorial level, in the present 2020 period the largest increases are located in the southwest and northwest regions. In the 2020–2050 period at territorial level, increases are few and are not shown with much constancy sign in any of the agroecosystems, while for the 2050–2080 period, the increases signs are seen in the southwest and northwest (Figure 6).

Persistence in the present – 2020 period, presented the highest values in agroecosystem c with 71.2% of territory occupancy (24414.48 km^2), while in agroecosystem a there is a 70.1% (24037.29 km^2) occupancy and 70.6% (24208.74 km^2) for agroecosystem "b". However for the 2020-2050 period, there is a decrease in the percentage of persistence, since an occupancy rate of 70.4% (24140.16 km^2) is reached for agroecosystem c, while agroecosystem b reached 69.7% occupancy of the State territory (23900.13 km^2), and agroecosystem a reached 68.9% (23625.81 km^2). Finally, in the 2050–2080 period, there is a greater decline than in the previous period since under this category agroecosystem a decreased up to 66.9% (22940.01 km^2) b up to 67.7% (23214.33 km^2) and c up to 68.4 % of occupation State territory (23454.36 km^2). At a territorial level, in all periods, persistence is continuous in the center of the State, having variations in the northern and southwestern borders (Conico agroecosystem, in the 2020–2050 and 2050–2080 periods).

In cases of B2 scenario, in the present – 2020 period the KAPPA Index occupied a substantial degree, because it does not represent great changes; however, for the 2020–2050 and 2050–2080 periods, the Index presented a degree almost perfect, indicating that there were no changes in these time periods in all categories mentioned under these two periods (Table 4).

Discussion

Climate change has been poorly evaluated for a set of species (Sánchez et. al., 2000), that make up the agroecosystems, which play a very important role in the enrichment of our agricultural biodiversity (Zhang et. al., 2007). *A priori*, it could be said that the climate change will have a direct impact on many species. In addition, it is foreseen that there will be no additional indirect effects arising from changes in the spatio-temporal habitat availability and natural resources (Hulme, 2005). However, in the present study, it could be observed that the occupancy rate in the 2050–2080 period in scenario A1B begins to recover even though it does not overcome the percentages of the present–2020 period. In contrast the loss of surface decreases compared to scenarios A2, B1 and B2. Despite these fluctuations of temperature and precipitation, the three ecosystems show positive results by increasing the persistence. Although one of the main concerns is the impact of the increase of temperature, according to predictions, of various species of agricultural interest (IPCC, 2007b), according to Benites et. al., 1999; Nowak and Crane, 2002, it can be noted that the agroecosystems are highly productive, efficient and provide benefits for the global climate. This agrees with our main objective which is to assess the vulnerability to climate change of traditional Mexican agroecosystems.

For example, according to Gohari et. al., 2013, the behavior of scenario A2 stands out; it was observed that "the monthly variations of temperature are generally greater under scenarios A2A than B1 scenario for general circulation models, of all species of wheat, barley, rice, and maize". However, even though the A2A scenario presents a greater climate impact, (by increasing temperature and decreasing precipitation), according to CEPAL reports in 2011. Agroecosystems b and c, in the No Habitat category, do not present major changes, nonetheless as is the case with agroecosystem "a" for the present–2020, 2020–2050 and 2050–2080 No Habitat increases are observed. Even though there is a substantial reduction in the loss percentage of agroecosystem c and that there is an increase in the area of occupation in the 2050–2080 period, the persistent surface is kept homogeneous and these losses or gains (increments) are barely noticeable since there is some decrease in the 2050–2080 pe-

riod regarding the persistence of the three agroecosystems. It can be said that the impact of climate change may negatively affect certain crops, as Islam et al. (2012) mention, by exceeding the limit of optimal temperature However, according to Altieri and Nicholls (2009), and what was observed in the previous scenario, the management of agroecosystems is important to maintain the occupation surfaces and, in particular, the sustainability of the agricultural landscape. Another specific case presented under the B1 scenario, in which a temperature rise was expected, although, with regards to precipitation there are no significant changes (CEPAL, 2011), it was observed that agroecosystems b and c were favored, the first one only in the 2050-2080 period and the second one in the present–2020 period. Even though there are changes in the various categories and time periods, the diversity within the agroecosystems tends to be homogeneous.

Finally, in the case of the B2 scenario that poses a medium level of impact (CEPAL, 2011), and according to Meza (2008), the changes are less drastic, however, in this scenario, there are substantial changes as shown in the percentage decrease of increase and persistence, as well as the increase of surface loss of the three agroecosystems. These results are similar to the work of Ballesteros et al., 2011, where there is an occupation reduction of 16% for the year 2020. The potential areas of maize crops at the national level; in the present study (locally), an average reduction of 4.3% was observed for the three agroecosystems. In particular it is noted that the persistence of the agroecosystems decreases substantially, especially for agroecosystems "a" and "b", while agroecosystem c remains roughly constant. So the importance of persistence has to be emphasized as it can be related to tendencies in the abundance of species or their probability of persistence in certain areas as Araujo and Williams (2000) put it. In addition to the above, a correspondence is observed in the percentage increase of No Habitat in a crescent way for the present–2020 to 2050–2020 and 2050–2080, even though the percentage of surface loss is a lot less for these last two periods and the surface increase is greater than in the present–2020 and 2050–2080 periods. However, in comparison to Ballesteros et al. (2011), which a reduction of 34% in 2050 is observed, in the present study under the 2020–2050 period the loss percentage decreases and for the 2050–2080 period the agroecosystems tend to regain surface. So despite these impacts, the agroecosystems can tolerate certain temperature increases (FAO, 2006; Mercer et al., 2012; Timmerman et al., 1999).

In particular the three agroecosystems under the four climate change scenarios are very dynamic. First of all the Mixteca area presents a subhumid-warm climate, but it is also one of the most deprived areas in the State of Puebla. Secondly the Sierra Norte presents humid to sub-humid climates, however, this region becomes more arid, and finally Sierra Negra presents warm-humid to sub-humid and wet-warm climates, and it is also a deprived area. This makes these areas the ones with the greatest vulnerability to climate change for the agroecosystems.

The estimate of these impacts on agriculture are of great importance (Gohari et al*.,* 2013), and although the scenarios of climate change are influenced by modification patterns in basic climate factors (temperature and precipitation), the distribution of the different agroecosystems (Perales et. al., 2003), according to Vandermeer and Perfecto (1995), the complexity, stability and the level of internal regulation depends on the function of the biodiversity components (Altieri, 1999). Under this premise, it was observed that the agroecosystems may constitute a mosaic of landscape elements that may also be linked by a series of discharges (materials, energy, organisms, etc.). But also, we should not dismiss the idea of the importance of the different global crops that are derived from wild species that have been modified through selective breeding, domestication, and hybridization (Altieri, 1999; Altieri and *Nicholls,* 2000). Most of the diversity hot-spots contain populations (variable and adaptable) varieties, which provide valuable genetic resources for the improvement of crops (Vandermeer and Perfecto, 1995; Altieri, 1999). Although the interactions between agriculture, environment and society are very complex and multifaceted, they are necessary to acknowledge that in the ecosystems, they are still the main raw material because they play an important role in the enrichment of agricultural biodiversity (Zhang et al., 2007), thanks to the great variety of ecological or environmental services they perform (Altieri, 1999; Dale and Polasky, 2007), at a landscape level, beyond food production. So, agroecosystems and the influence of traditional knowledge (Brush et al., 2007; Toledo, 2010), exhibit internal strategies of adaptation (Altieri and Nicholls, 2008), contributing options to mitigate the climate change, and therefore be able to face this phenomenon (Baidu et al., 2012). This is why rural communities, dominated by traditional agriculture, seem to handle the situation despite the extreme climate fluctuations (Monterroso et al., 2011).

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