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The climatic-environmental significance, status and socio-economic perspective of the grown-shade coffee agroecosystems in the central mountain region of Veracruz, Mexico

La importancia climático-ambiental, el estatus y la perspectiva socioeconómica de los agroecosistemas de cafetales cultivados en la región montañosa central de Veracruz, México

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Abstract. Climate and vegetation coexist in a dynamic equilibrium. However, lack of vegetation can cause local and regional climate changes. Grown-shade coffee agroecosystem provides resources, environmental services and socio-economic benefits. We found that coffee production has decreased but its economical value has increased; however, the socio-economic indicators decreased. High deforestation rate is causing changes in the precipitation patterns and fog frequency, contributing to an environmental and socio-economical crisis in the region. This work presents an analysis of the influence of local and regional climate on the grown-shade coffee in central Veracruz, and the factors involved in land-use change with the respective consequences for the coffee producers.

Key words: Agroecosystems, *Coffea arabica*, cherry coffee, grown-shade coffee, production units, income and producers welfare

Resumen. El clima y la vegetación coexisten en un equilibrio dinámico. Sin embargo, la falta de vegetación puede causar cambios climáticos locales y regionales. Los agroecosistemas del café de sombra proveen recursos, servicios ambientales y beneficios socio-económicos. Se encontró que la producción de café ha disminuido pero su valor económico ha incrementado; sin embargo, los indicadores socio-económicos han disminuido. La alta tasa de deforestación está causando cambios en los patrones de precipitación y en la frecuencia de niebla, lo que contribuye a la crisis ambiental y socio-económica de la región. Este trabajo presenta un análisis de la influencia del clima local y regional en el café cultivado a sombra en el área central de Veracruz, así como los factores que intervienen en el cambio de uso de suelo con las respectivas consecuencias para los productores de café.

Palabras clave: Agro-ecosistemas, *Coffea arabica*, café cereza, café cultivado a la sombra, unidades de producción, ingresos y bienestar de los productores.

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INTRODUCTION

Mexico occupies the twelfth place among the countries with the highest deforestation rate, spanning from 2,600 to 3,480 km^2/year in the period 1990-2005 (CONAFOR, 2006; FAO, 2007), and the annual rate of deforestation of primary forests for the period 2010-2015 was 0.1% (FAO, 2015), despite the forest's environmental significance. Tropical forests provide resources and environmental services, regulate the water cycle, conserve biodiversity, provide soil stabilization (Daily *et al.* 2000; Bruijnzeel, 2004; Ruiz Pérez *et al.* 2007), and through carbon sequestration they help to mitigate global climate change (Chazdon *et al.*, 2016).

It is expected th at global climate change will impact severely Mexico and Central America, where temperature change will have the most severe effects (IPCC, 2014). Climate change will affect all ecosystems, including those manage by humans, and assessing the impacts of climate change on crop productivity is nowadays a priority (Challinor *et al.*, 2009). For instance, in the state of Veracruz in Mexico, by the next mid-century it is expected to have a reduction of 22-27% of the coffee productivity due to climatic changes, including increment of temperature and decrement of precipitation (Gay *et al.*, 2004). And this scenario does not consider the effect of deforestation.

Since the late nineteenth century, Veracruz has been subject to an extensive and systematic change of land-use. Currently, these changes include natural ecosystems being replaced by forest systems, extensive animal husbandry and farming, and agricultural systems (García-Romero *et al.*, 2010). The highest deforestation rate was reported for the period 1984-2000, where 40% of the territory had an advanced erosion level, representing and important soil loss (García-López, 2009). In the central mountain region of the state, in Cofre de Perote, deforestation rates are ca. 2 km^2/year, with a drastic forest reduction up to 56.8% of the original area. Natural ecosystems in the region have been replaced mainly by agriculture lands, and improved and cultivated pasture, covering 27 and 15% of the total area respectively (Garcia-Romero *et al.*, 2010). Further, within the region, at La Antigua River, the land use and cover changed dramatically for the period 1990-2003 mainly caused by deforestation of natural and fragmented forest due to the advance of agricultural and animal husbandry practices (Muñoz-Villers and López-Blanco, 2008).

The coffee production in Veracruz has a long history, dating back to the late 18th century in Córdoba. Small farmers (landholdings between 2 and 3 ha) have traditionally represented over 80% of the coffee producers in the region. In the 1980s, coffee was one of Mexico's principal agricultural exports; representing ca. 35% of the total agricultural export value (Fox Quesada, 2004). And because of its importance, grown-shade coffee has been extensively studied demonstrating its environmental importance (Castillo-Campos *et al.*, 2011; Olguin *et al.*, 2011; Ruelas-Monjardín *et al.*, 2014). For instance, the shade trees associated to coffee plantations play an important role in carbon sequestration (Pineda-Lopez *et al.*, 2005; Tscharntke *et al.*, 2011), and these coffee systems act as reservoirs of biodiversity (Contreras Hernandez, 2010; González Zamora et al., 2016; Mayoral *et al.*, 2016). Plant composition in these "agroecosystems" is mostly comprised by trees (e.g. *Inga jinicuil* and/or *I. leptoloba*) and shrubs (orange, guava, banana) that maintain soil fertility by reducing soil erosion, providing organic matter (Jimenez-Avila, 1982), and fixing atmospheric nitrogen (Roskoski, 1982).

Unfortunately, currently the main vegetation characteristic in the region is the large surface area of seasonal agriculture and grown- and induced-pasture (grassland) with 4,708.4 km^2, 61% of the total area (7,693.8 km^2). Tropical forest covers an area of 109.13 km^2 (1.4%), similar to urban areas (101.13 km^2), whereas fir, pine and pine-oak temperate forests occupy an area of *ca.* 1,009.3 km^2 with a proportion forest/grassland of 21%. Mixed forest represents only the 10% of the total area (770.72 km^2). As for the grown-shade coffee plantations and the cloud forest relicts, these have an area of ca. 975.84 km^2 (Figure 1).

This work presents an analysis of the economical importance and current situation of grown-shade

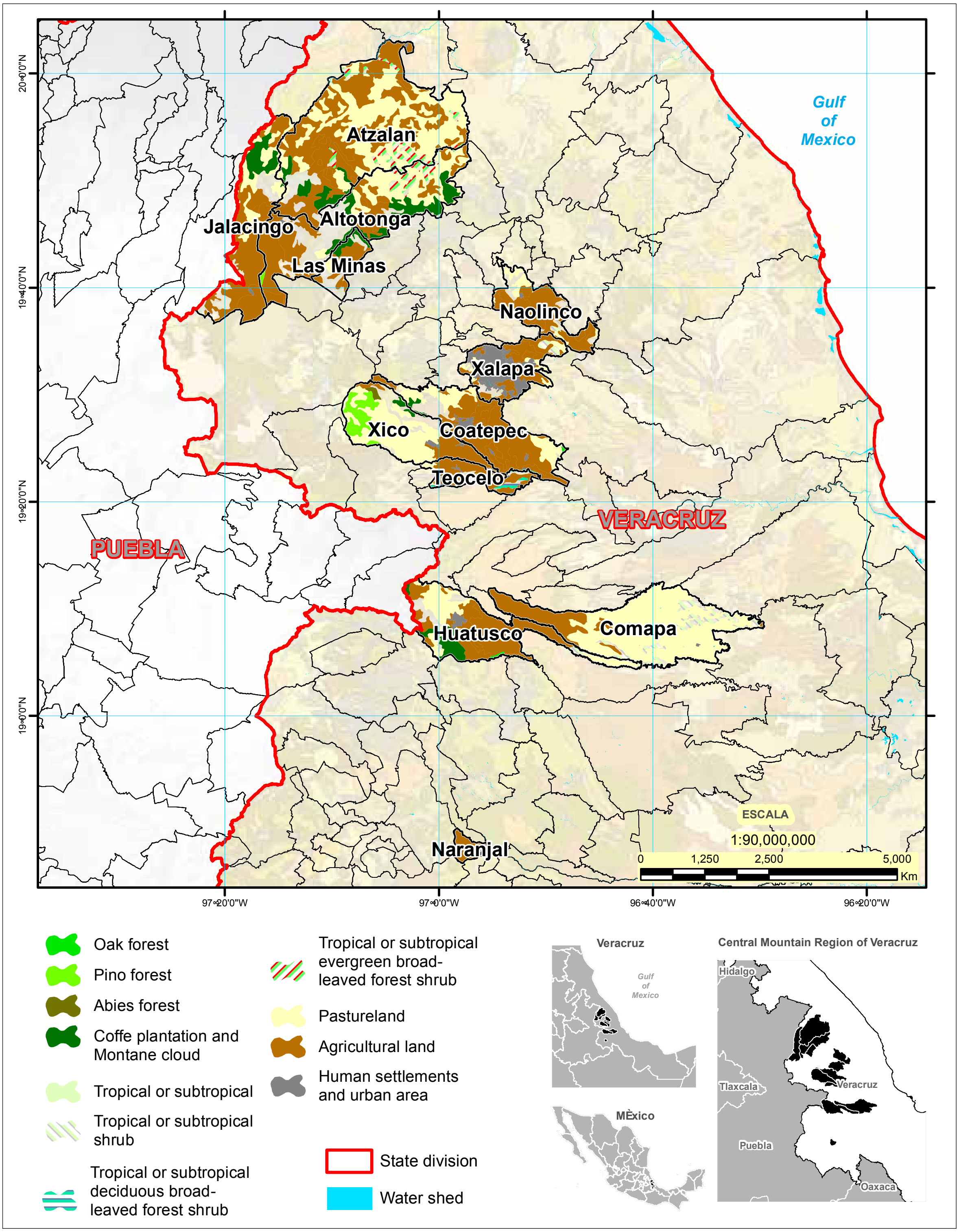

Figure 1. Study area, vegetation types and municipalities studied of the central mountain region of Veracruz (This map was built with data from INEGI, 2013).

coffee agroecosystems in the central mountain region of Veracruz, Mexico. We analyzed some climatic and environmental conditions affecting these systems, the repercussions in changes of land-use and vegetation cover, and explore some of the socio-economic consequences for their inhabitants, particularly the cherry coffee (*Coffea arabica*) producers.

A CASE STUDY: THE GROWN-SHADE COFFEE AGROECOSYSTEMS IN THE CENTRAL MOUNTAIN REGION OF VERACRUZ, MEXICO

Study area

The central mountain region of Veracruz is located in the south-central part of the state (Figure 1). The region is part of the Neovolcanic Ridge and the Sierra Madre Oriental. Abrupt topography is the main characteristic of the region with a pronounced altitudinal gradient from the sea level to up 5,500 m asl in a distance of *ca.*100 km. Vegetation types go from tropical montane cloud forest to semi-arid and arid communities (Barradas, 1983; García-García and Montañez, 1991). Average annual temperatures range between 10 and 29 °C, and annual precipitation varies from 600 to 1,200 mm, with a maximum of 3,000 mm in the wetter regions.

Climate in the region is the result of a complex interaction of the prevailing synoptic systems (tropical systems at summer and the mid-latitude at winter), the displacement of the north-south-north anticyclone of Las Azores-Bermuda, the topography-orography, the plant-atmosphere interaction, and the great proximity to the Gulf of Mexico (Barradas *et al.*, 2010). Recent studies in the region report important changes in precipitation varying across t,he mountain rage (Esperón-Rodríguez *et al.*, 2016). The fog frequency has been diminished in some levels (Barradas *et al.*, 2004), and the consecutive dry days have increased in some regions (Esperón-Rodríguez and Barradas, 2015). Regarding temperature, there is evidence of local variations as well, with some regions getting warmer (Esperón-Rodríguez *et al.*, 2016). Climate in the region indeed contrast among sites depending on the location of the mountain system, as it can be seen in the precipitation and fog frequency trends in the region (Table 1). However, we must acknowledge that although most of these trends are not statistical significant, they provide evidence of local climate changes. The lack of statistical significance of most trends might mean that the estimation has been performed over a time frame too short to detect a signal above the noise; nevertheless, no statistically significant trend does not necessary means 'no trend'.

Current vegetation distribution in the region

In figure 1, obtained through the Geographic Information System (ArcGIS 10.1) by the set of Vector Data Land Use and Vegetation (INEGI, 2013), we show the current vegetation distribution upwind of the mountain. The main feature is the large surface area of seasonal agriculture and grown- and induced-pasture (grassland) with 4,708.4 km^2, 61% of the total area (7,693.8 km^2). Tropical forest covers an area of 109.13 km^2 (1.4%), similar to urban areas (101.13 km^2), whereas fir, pine and pine-oak temperate forests occupy an area of ca. 109.3 km^2 with a proportion forest/grassland of 21%, and only 10% of the total area (770.72 km^2). Grown-shade coffee plantations and

Table 1. Trends in rainfall (mm yr^{-1}, Tp_p), and fog frequency (T_{FOG}) in the central mountain region of Veracruz. The positive sign refers to an increase in the trend, and negative sign a decrease (modified from Barradas *et al.*, 2010).

Locality	TPp	Locality	TFOG
Ciudad Serdán	0.40	Altotonga	T+
Tecamachalco	0.30	Atzalan	T+
Tlacotepec	0.30	Huatusco	T+
Altotonga	1.10	Jalacingo	T+
Jalacingo	0.80	Coatepec	T-
El Coyol	-0.60	Perote	T-
Elotepec	-0.60	Las Minas	T-
Xalapa	-1.24	Los Pescados	T-
Naranjal	-1.00	Tembladeras	T-
Naolinco	-0.80	Teocelo	T-

cloud forest relicts have an area of ca. 975.84 km^2, with 20% of the proportion forest/grassland.

Production of cherry coffee

We gather all data available concerning the production of cherry coffee for a period of 31 years spanning from 1980 to 2011 from different free and available sources: 1) Servicio de Información Agroalimentaria y Pesquera (SIAP, Service for Food and Fisheries Information); 2) the Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA, the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food); 3) Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT, Secretariat of Environment and Natural Resources); and 4) Comisión Nacional Forestal (CONAFOR, National Forestry Commission).

We also took data regarding local population from: 1) Instituto Nacional de Estadística y Geografía e Informática (INEGI, National Institute of Statistics, Geography and Informatics); 2) Consejo Nacional de Población (CONAPO, National Population Council); and 3) Consejo Nacional de Evaluación de la Política de Desarrollo Social (CONEVAL, National Council for the Evaluation of Social Development Policy).

DATA ANALYSIS AND DISCUSSION

The cherry coffee production

Climatic extreme events, such as droughts, floods, frosts and heat waves have and will affect the coffee production in Veracruz (Conde *et al.*, 2006). Since 1997, extreme weather has caused volatile prices regarding the coffee production in Mexico (Gay *et al.*, 2006; Tucker *et al.*, 2010), and low prices have affected the rural economies and threatened the biodiversity associated with the traditional coffee production (CEPAL, 2002; IADB, 2002). The changing structure of the global coffee commodity chain has caused a decrease in prices paid to local producers (Bacon, 2005), especially because coffee is mainly produced by large corporations whose owners do not necessary form part of the poorest segments of society, and by small-scale farmers (Valkila *et al.*, 2010).

The unstable prices and the extreme weather events raised the question among coffee producers of how the future impacts of climate changes will affect the economic variability (Tucker *et al.*, 2010; Estrada *et al.*, 2011). For instance, in the period 1999-2003 during a drought period, the international coffee prices fell to historical levels (Tucker *et al.*, 2010). Changes in the market conditions and prices affect local coffee producers, particularly concerning to their capacity to engage in traditional climate risk management practices and livelihoods (Tucker *et al.*, 2010). The economic crisis and natural disasters will potentially increase the livelihood vulnerability (Combes and Guillaumont, 2002; Moser, 1998) and also will have impacts on human health (Greenough *et al.*, 2001; McMichael *et al.*, 2006).

The analysis of the last 31 years (1980-2011) from the integrated database of SIAP (2013) shows that nationwide the area planted and harvested increased by 54 and 45%, respectively, and the production and economical value increased by 10 and 67%, respectively. However, these increments have not been equal for the 15 coffee-producing states of Mexico (Chiapas, Veracruz, Puebla, Oaxaca, Guerrero, Hidalgo, Nayarit, San Luis Potosi, Jalisco, Colima, México, Tabasco, Morelos, Queretaro and Michoacán). For the period 2000-2011 there were decrements nationwide, where the volume of cherry coffee production declined from 1,836,883 to 1,287,643 Mg at national level, and for Veracruz decreased from 514,500 to 335,483 Mg (-35%) (SAGARPA, 2013). During the period 1980-2011, Veracruz had a decrease in tons per hectare harvested from 3.0 to 2.3 (-23%); however, production value increased considerably from 202,492.21 to 143,987,538.90 USD (700%) (Figure 2). Furthermore, in Veracruz during the period 2000-2011, despite the production's decrease, its volume of the national domestic production, put the state as the second largest domestic producer, with 26% of the national production in 2011, only below Chiapas, with a production of 42% (Rice, 1997; Olguin *et al.*, 2011).

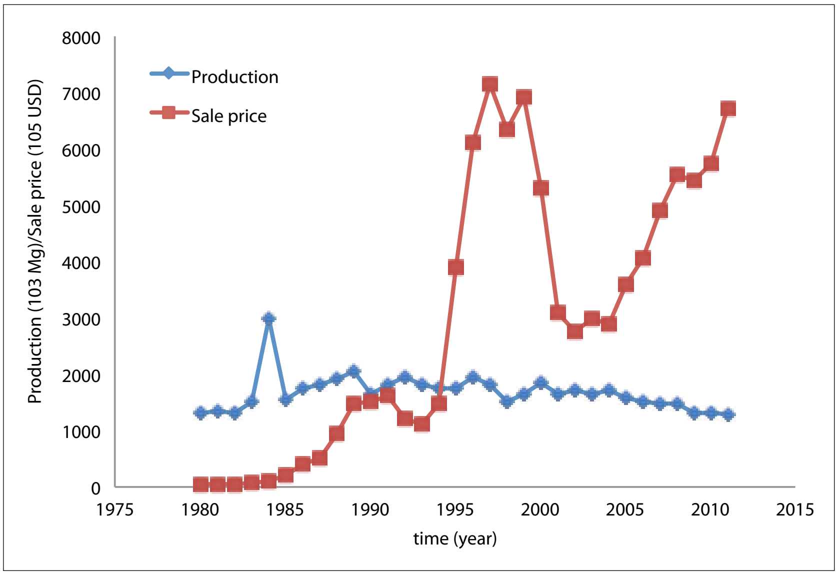

Figure 2. Production and sale price in US dollar of cherry coffee (*Coffea arabica*) in central Veracruz in the period 1980-2011.

Regarding the areas cultivated during the period 2003-2011, the national production volume fell from 1,621,938 to 1,287,643 Mg (-20%), and in Veracruz the production decreased from 343.912 to 335.483 Mg (-2.5%). However, in our study region there was a production increase from 87.327 to 96.125 Mg (10.1%), where the municipalities of Atzalan, Coatepec and Huatusco contributed in 25, 23 and 16.9 %, respectively. In 2011, the study region contributed with 29% of the state's production, with three municipalities being the highest produces: Atzalan (7.1%), Coatepec (6.6%) and Huatusco (4.9%) (SAGARPA, 2013). As for the value of coffee production, nationwide the value of coffee production for the period 2003-2011 increased from 231,210.7 to 530,831.7 USD (over 200%). For Veracruz, the increase was from 36,717.133 to 143,911.1 USD (~400%), and in the study region increased from 8,875.6 to 45,500.7 (over 500%), where the municipalities of Atzalan, Coatepec and Huatusco contributed with a 26.7, 25.0 and 13.23%, respectively (SAGARPA, 2013).

Production Units (PU) of cherry coffee in Veracruz

According to the SIAP (2013) in 2011, 102 municipalities were devoted to coffee production. For our analysis, we selected the 12 most important municipalities regarding coffee production in the region (Figure 1). Mostly all municipalities engaged in the coffee industry in Veracruz are located in the coffee region of Coatepec, followed by Atzalan and Huatusco, and thus Atzalan, Huatusco, Coatepec, and Altotonga concentrate the highest number of communities, farms and producers dedicated to this activity (SIAP 2013) (Table 2). However, for those municipalities the irregular and unpredictable income in regards to coffee PU is reflected in the fact that only 165 (2%) of the 79,840 PU registered in the state, reported contract production (INEGI, 2009), and only 1% has guaranteed an income before the production until the delivery of the same, although this income can be lost because of different types of risks, including systemic, financial, credit and climatic risks. If climate changes occur in the region as it is expected (Esperón-Rodríguez *et al.*, 2016), the activity performance in the PUs will be at risk of income losses, and probably increases in cost of inputs and services. Additionally, other repercussions might include difficulties in accessing credit and contract production programs, which ultimately affects and reduces the income of farmers and their families.

Table 2. Selected municipalities, communities, farms, producers (people) and area devoted to the coffee industry by region in Veracruz during the coffee cycle 2009 (source SIAP, 2013).

Region	Municipality	Community	Property	Producers	Cultivated area (km^2)
State	94	1388	130,385	86,164	1331.4
Zone	12	245	30,923	18,898	299.32
Atzalan	Altotonga	19	2,267	1,418	16.63
Atzalan	Atzalan	110	9,732	5,762	77.31
Atzalan	Jalacingo	7	527	359	4.66
Atzalan	Las Minas	3	119	89	1.16
Coatepec	Coatepec	22	4,295	2,532	46.23
Coatepec	Naolinco	13	1,454	948	11.16
Coatepec	Teocelo	10	1,834	1,153	16.42
Coatepec	Xalapa	9	2,128	1,247	17.17
Coatepec	Xico	10	2,028	1,226	18.18
Córdoba	Naranjal	10	677	503	6.91
Huatusco	Comapa	3	1,781	1,025	27.82
Huatusco	Huatusco	29	4,081	2,636	55.67

Producer's welfare

It is known that farmers with their experience can operate with some degree of variability in the local climatic conditions, and they are able to develop strategies from their own knowledge to cope with climate variability (Agrawal *et al.*, 2008; Tucker *et al.*, 2010). Still, contemporary climate change is occurring too fast and stochastically (Ohlemüller, 2011) and this may generate changes in the climate conditions that may exceed the limits of the farmers' coping strategies (Smit *et al.*, 2000).

Further, coffee producers in Veracruz have shown a limited capacity to adapt to climatic and economic stressors, and this capacity will probably decrease in the future if governmental policies and international market conditions prevail (Gay *et al.*, 2006). People's vulnerability to the falling prices depends upon their access to assets land, credit, employment, and social networks (Bacon, 2005), but also in their location and the climate variability affecting their lands. Coffee producers are involved in other productive activities besides coffee production, such as agriculture and livestock; these activities generate income sources for the inhabitants in the region.

The 12 selected municipalities hold 13.7% of the employed population reported for Veracruz in 2010 (INEGI, 2011). Six municipalities are mainly engaged to economic activities related to the primary sector (agriculture, forestry, hunting and fishing), whereas the other six are devoted mainly to the service sector (transportation, government and other services). The income of the working population in the region barely reaches the minimum salary (4.85 USD), a situation that is accentuated in the six least urbanized municipalities (INEGI, 2011). Also, in 2010, 12% of the state's population was located within the study region. The more urbanized municipalities concentrated the greatest population with predominance of women (95 men per 100 women) (INEGI, 2011). Also, it was reported that the majority of the producer's income for 2007 came from the PU activity (INEGI, 2009).

In 2010, poverty indicators, including educational lag, access to health services, access to social security, quality and housing spaces, basic housing services, and access to food, determined that 58.4% of the state's population lived in poverty, presenting at least one social deprivation (particularly access to social security), with an income less than the economic welfare line. For the study region, excluding Coatepec and Xalapa, over 50% of the population lived in poverty, highlighting Las Minas (90%), Comapa (87%), Jalacingo (85%), Altotonga (83%), and Atzalan (81%) as the municipalities with the highest poverty percentage (CONEVAL, 2011).

This information is even more critical considering that the CONEVAL (2013) recently updated the minimum welfare lines and wellness, saying that the wages of Mexican workers lost 40% of its power purchasing in seven years, and in both, urban and rural areas, minimum wage is insufficient to meet basic needs of food, goods and services; therefore, it might be noted that the population living below the minimum welfare line has probably increased. Such poverty levels are also correlated with indicators of marginalization at national level, where in 2010, Veracruz ranked fourth in the most marginalized states list (CONAPO, 2011).

The climate change scenario

The production and marketing of cherry coffee placed Mexico as an international producer par excellence (SIAP, 2013). This has as a repercussion a considerable increase in the production value of over 700%. However, this increment does not seem to have affected or improved the socio-economic indicators of the producers of the 12 municipalities (INEGI, 2009, 2011, 2012; CONAPO, 2011; CONEVAL, 2011). This situation has caused the development of alternative income sources. One of these alternatives threatens to replace the grown-shade coffee (multiple crops) by one crop such as sugarcane, which represents the possible reduction of tree cover (Figure 1). This land-use change also threatens the persistence of natural ecosystems, such as the cloud forest (CONABIO, 2010). In this forest, the presence of coffee agroecosystems (multiple crops) conserves the ecosystem's structure and functioning, and acts as a reservoir of biodiversity (Manson *et al.*, 2008; Gonzalez Zamora *et al.*, 2016).

Climate and vegetation coexist in a dynamic equilibrium, which could be affected by disturbances in either of these two components (Shukla, 1990; Barradas *et al.*, 2010). For example, presence of vegetation attenuates air temperature through the evapotranspiration mechanism (Barradas and Fanjul, 1986; Ballinas *et al.*, 2015). In a pioneer study Barradas and Fanjul (1984) found that temperature increased considerable as a direct result of transforming coffee agroecosystems (multiple crops/diversified farming systems) to agrosystems (one crop/mono cropping). They compared changes in temperature in two coffee plantations under different conditions (shade vs. sun) finding that plantations where coffee grown at sun, maximum temperature increased up to 8.0 ºC and minimum temperature decreased up to 2.6 °C, compared to grown-shade coffee plantations. Although these data might not be a reflection of the current micro-climatic conditions in the region, it highlights the importance of tree cover acting as a temperature buffer.

Other variables affected by changes in tree cover are solar radiation, humidity and wind. Wind changes dramatically with presence of vegetation reducing its intensity because of high friction (Barradas and Fanjul, 1984; Lancaster and Baas, 1998; Burri *et al.* 2011). Air humidity, unlike wind, it is higher beneath the canopy or in areas without vegetation because of the reduced transportation caused by the wind (Ballinas *et al.*, 2015). In places without vegetation the amount of incident solar radiation is higher. This radiation heats the soil surface, and therefore the air in contact with it; whereas in areas with vegetation, incidence of radiation decreases because most of it is stored in the upper strata (Barradas and Fanjul, 1984; Akpo and Grouzis, 1996). Irradiance is an important variable because it is related directly to photosynthesis (Aasamaa and Sõber, 2011), and also because species have differential growth responses under different irradiance conditions (Araya et al., 2000; Gao *et al.*, 2004). The effect of vegetation on macro- and micro-climatic conditions has been described in detail elsewhere (eg. Chen *et al.*, 1999; Kröel-Dulay et al., 2015; Kolbe *et al.*, 2016; Whitbeck *et al.*, 2016).

From this point of view, vegetation can be considered as a climate attenuator in a given region. However, when vegetation is scarce because of deforestation, it can contribute or cause climate change by two major mechanisms. The first mechanism relies on the fact that vegetation is a carbon reservoir that is lost and deposited in the atmosphere increasing the greenhouse effect (Tscharntke *et al.*, 2011). And the second mechanism consists in the plant-atmosphere interaction modulating regional climate (Shukla *et al.*, 1990; Lawton et al., 2001; Pielke *et al.*, 2007; Barradas *et al.*, 2010).

Studies in Mexico recognize a relationship among regional climate change, extreme weather events, and land-use and land-cover change (LU/LC change). LU/LC change alter the fluxes of solar and thermal infrared radiation, sensible, and latent heat, the movement of water between the sub-surface and atmosphere (Mahmood *et al.*, 2014), and they can affect regional and global processes of climate change making communities more vulnerable to extreme events (O'Brien, 1998). However, well-directed LU/LC changes (i.e. promoting agroecosystems), may also help to mitigate the effects of climate change by preserving local biodiversity (Gonzalez Zamora *et al.*, 2016), and can help smallholder farmers to adapt more efficiently to the changing conditions (Verchot *et al.*, 2007)

It is likely that changes in precipitation and fog frequency occurring in the region (Barradas *et al.*, 2004; Barradas *et al.*, 2010; Esperon-Rodriguez *et al.*, 2016) will enhance more severe climate changes at regional and local level. These changes will affect the integration of natural and human ecosystems in the area, particularly and most likely, ecosystems at lower altitudes that would be exposed to an increased solar radiation in deforested areas. This radiation excess would heat the soil surface and consequently the air in contact with it, increasing evaporation, and increasing significantly the sensible heat flux that would also shift clouds to higher altitudes (Barradas and Fanjul, 1984; Barradas *et al.*, 2010). But also, it must be highlighted that recent studies place the high-altitude ecosystems (such as mountain ecosystems) as the most vulnerable to climate change (Nogues-Bravo *et al.*, 2007; Colwell *et al.*, 2008).

LU/LC changes favoring sugarcane could be critical, particularly in low and high areas. It is expected that even preserving the grown-shade coffee plantations, precipitation will decrease by 1.24 mm/year, and this decrease could increase another 0.5 mm/year if tree cover changes for sugarcane (Barradas *et al.*, 2010). Unfortunately, the sugarcane sector in Veracruz in the last 33 years has reported higher earnings and revenue (794.159 millions USD only in 2011) compared to the coffee sector (144 million USD in 2011), and the area devoted to this crop has increased from 214,000 in 1980 to 280,510 Mg in 2011 (SIAP, 2013). Also, burning is the strategy to get rid of the waste from the sugar sector. This strategy will impact the regional and local climate not only by the loss of the grown-shade coffee increasing greenhouse gases, but also increasing the vulnerability of cherry coffee farmers and their families by switching into a more profitable crop, but whose impacts most likely affect other agricultural and livestock products, and would enhance possible fire frequency, which would be greater in the driest areas.

Also, LU/LC changes contribute to biodiversity loss. In this regard, specific studies at Veracruz (Benitez *et al.*, 2009; Gutierrez Bonilla *et al.*, 2009) have already advanced some regional impacts on agriculture and livestock, where rural populations will have to find alternative food supply to complement their nutrition; and given the possible low or null field productivity, it would be expected an intensification of migration affecting the producers' families (Uribe *et al.* 2012). However, migration can be considered as a form of economic diversification, enhancing household income stability and wealth, and in many cases providing funds for investment in agricultural resources (Adger *et al.*, 2002; Desipio, 2002). Nevertheless, related to environmental hazards such as drought, migration can also be an indicator of significant vulnerability and the collapse of the social-ecological integrity (Watts, 1983; Finan and Nelson, 2001).

The status and socio-economic perspective of the coffee sector should be reassessed and addressed urgently through a set of reforms that will contribute to a more just and equitable society, and a strong and stable economy, particularly in the central highlands of Veracruz.

CONCLUSION

Rethinking the development model

It is required more evidence to conclude if climate variability can be perceived as a threat to the coffee production in the central mountain region of Veracruz, Mexico. However, we found pertinent to raise some ideas. Firstly, it is necessary to improve the gestation, formulation, implementation and evaluation of environmental policies. Furthermore, it is necessary to predict the environmental effects of the irregular urban-growth, which has not been a priority for the national development strategy (SEMARNAT, 2008), and has not considered protection and conservation of natural areas. Secondly, it is necessary to determine the most vulnerable areas and communities to local climate change. Previously, Esperon-Rodriguez *et al.* (2016) determined these areas where local trends indicate that temperature is increasing and precipitation is decreasing. Further, in areas with those climatic characteristics, Rivera-Silva (2013) estimated a potential loss of ca. 10% of the coffee production by the mid-century. However, more studies are required to understand the causes of the local climate variability to make more accurate and precise climate future projections.

This studies should be oriented to promote local adaptation and to locate climatic suitable areas for coffee production, because regardless the changing climate conditions, the demand for high quality coffee will continue to grow, and therefore producers will need to locate the most suitable areas for cultivation in the future and how the suitability of these areas will change over time (Ovalle-Rivera *et al.*, 2015). It should be considered a priority to promote and increase the potential of the coffee systems by defining the future areas and optimal conditions for growing high quality coffee (Hernandez *et al.*, 2008).

The social and economic crisis that the region might be facing includes poverty, lack of opportunities and extreme inequality for the local population. The unequal productivity and income will impact the employment rate, low wages, lagging infrastructure and rural economy in crisis, among others. This evidences the urgent need to reconfigure the social policy, recovering the ethical responsibility in order to protect the most vulnerable, as well as understanding and including the complexity and the environmental interaction with the social and economic factors that influence the development of human populations.

Here we support the idea that it should be reoriented the current development style factor eliminating the false premise that growth (= GDP) automatically generates social development, inclusion, wellness and sustainability. In this work we found that this premise is false. We observed that despite the 700% increase in the coffee production value, the producers were not affected or improved their socio-economic indicators. The approach should be orientated to work with small-scale coffee producers to increase access to land, build stronger producer organizations, participate in alternative markets, increase government investments in rural health and education, and diversify production and commercialization channels (Bacon, 2005). Opportunities for coffee producers may depend largely on the development of appropriate marketing strategies, and design and implement policies that endorse the production growth.

This paper aims to provide logic and objective data to resize the environmental impact on social and economic dimensions. If we continue with the current trends of development without changes or adaptations, we will increase the population inequality and the environmental crisis.

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