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Assessing food security and environmental protection in Mexico with a GIS-based Food Environmental Efficiency index

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ABSTRACT

Trends in food security and environmental protection are usually reported separately and at national level, which may be a great limitation to the assessment of regional policies seeking to improve food self-sufficiency, reduce poverty, and at the same time conserve biodiversity. In this study, a spatially explicit, quantitative index relates national and regional trends of food security with trends of land use change in Mexico. Food security was estimated through aspects of food self-sufficiency (production and consumption patterns of basic staple crops and livestock) and food access (based on the marginalization level of households). Land use change was estimated from the official INEGI Land Use and Land Cover cartography. The Food Environmental Efficiency (FEE) Index was calculated for each ecoregion of Mexico over the past 40 years based on an arithmetic count of significant correlations between food security and land use change. Trends at national level suggest a continuous environmental degradation and no improvement in food security except for maize self-sufficiency. At ecoregion level, the FEE index indicates that livestock expansion in the three most affected ecoregions is associated with a decrease in food security and that extensive cropland expansion is associated with an increase in food security in only one of them. The FEE index proved useful for the assessment of land use policies, since it can weigh regional contributions to food security and environmental tendencies.

1. Introduction

The urgent need to address food security in less industrialized countries has led to policies and instruments that may undermine another urgent need, which is to preserve biodiversity and ecosystem services (Verburg et al., 2013; Fuss et al., 2015; Peng et al., 2015). The demand for food, prime materials and biofuels is the main driver of land use changes in the world (Smith, 2013; Verburg et al., 2013; Mbow et al., 2014; Van Wikj, 2014), and has led to the loss of forest to agriculture (Smith, 2013). Food security involves access by all people at all times to food of sufficient quantity and nutritional value for them to lead a healthy and active life (FAO, 2006). This definition includes concepts such as food availability (which requires a balance between population growth and food production), food access (which requires sufficient income to buy a range of goods to guarantee survival), food use (the actual consumption of food) and food stability (regular access to food) (Santos et al., 2014; Frayne and McCordic, 2015). Food security should be considered within an environmental context, especially regarding the consequences of climate change and environmental impacts on the biodiversity and soils (Fuss et al., 2015; Peng et al., 2015; Krishnamurthy et al., 2014). Production practices that drastically affect biodiversity, soil fertility and environmental services are counterproductive in the long run: food production in marginalized areas will decrease, and the risk of extreme natural events will increase (Verburg et al., 2013; Knoke et al., 2013; Mbow et al., 2014; Crist et al., 2017). The negative impacts of food production on ecosystem services must be restricted: future demand for food should be met without extending croplands and grazing lands, and this will entail highly productive agricultural systems that sustain biodiversity (e.g. agro-ecological farming systems; Perfecto et al., 2009). On the other hand, it is argued that poverty of the household has the most direct effect on the environment because it influences the ability to use technology and

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investment for the intensification of cropping where there is a land access constraint (Fisher et al., 2013; Reardon and Vosti, 1995).

Because of its importance in international agendas (e.g. the Zero Hunger Challenge by the United Nations), food security has been assessed and monitored at a range of scales, especially at national level. This can involve various approaches: the balance between availability of food and needs of the population as influenced by production, imports, exports, wastes and aid (FAO, 2012); nutrients and required daily caloric intake (Warren et al., 2015); a combination of the two approaches (Peng et al., 2015); the Global Food Security Index (The Economist Intelligence Unit, webpage 2016) based on production capacity, food distribution, nutritional quality and the ability of the population to pay for food; and adaptation to climate change (e.g. Fuss et al., 2015). In Mexico, food security has achieved prominence with the "Crusade against Hunger" launched by the Federal Government in 2013. This campaign aims to improve food supply to extremely marginalized populations by subsidizing local crop production and increasing smallholder crop yields. A major goal of Mexican land use policy has been, over the past three decades, to increase food security (e.g. Mexican Food System program in 1981; Yúñez et al., 2013) and to reduce activities that contribute to global environmental change (e.g. General Law of Ecological Balance and Environmental Protection 1988). Much debate remains, however, with respect to the rationality of subsidizing some major food production systems while at the same time claiming to protect major biodiversity hotspots (Muñoz-Piña et al., 2008; Schmook and Vance, 2009; Sarukhán et al., 2015). Indeed, the expansion over the past four decades of extensive agricultural land and its impact on highly biodiverse regions has been widely documented (Velázquez et al., 2003; Mas et al., 2004; Bonilla-Moheno et al., 2013; Moreno-Sanchez et al., 2014). This debate tends to overgeneralize contradictions across the Mexican territory. In order to solve for this overgeneralization, we argue that food security and environmental analysis should be spatially disaggregated into coherent ecogeographical units and that spatial indices based on standard national databases should be developed.

Ecoregions (spatial units with similar ecosystem functions, resources and human activities; McDonald et al., 2005) are a useful concept in conservation and planning (Olson et al., 2001; McDonald et al., 2005; Dvorak and Volder, 2010). Seven of the fifteen ecoregions identified in North America are represented in Mexico (Koleff et al., 2011; Fig. 1; Table 1). We propose to develop the Food and Environmental Efficiency (FEE) index, based on food access, food self-sufficiency, and land use/land cover tendencies over the ecoregions of Mexico.

We first estimated food security by the use of proxies for food self-sufficiency and food access, all of which have been used in institutional indicators, for example the Food Security Index from the FAO Hunger Target Global Monitoring (food stability through per capita food production and per capita food supply are employed through food self-sufficiency) and the Global Food Security Index of The Economist Intelligence Unit (food affordability is employed, through marginalization as a proxy of the proportion of the population under the global poverty line). We also estimated Land Use Change Processes (LUCPs) at a national level in Mexico using the Land Use and Vegetation Cover (LUVC) maps produced by the National Institute of Statistics and Geography (INEGI), the official source of land use information in Mexico. The FEE index was based on a correlation analysis between the estimated food security and land-use changes.

This research addresses the following questions: In what ecoregion (s) occurred the greatest advance in food security and did this correspond to the largest expansion of extensive production systems? And: How are the increments or decrements in food security associated with environmental impacts? For example, a hypothesis to be verified in the context of ecosystem degradation would be that an increase in food security (food access, food self-sufficiency, or both) counterbalances a negative environmental impact. In order to answer these questions, we assessed lack of food access through a marginalization index, and food self-sufficiency from data related to annual production and per capita consumption. Then, these variables were correlated with the expansion of extensive agricultural systems derived from the INEGI records of land use and vegetation cover (1976, 1993, 2002, 2007, and 2011).

2. Method

A major purpose of this research is to propose a pragmatic method to estimate environmental efficiency for Food Security policies/tendencies (Fig. 2). The first step was to approximate food security through two major, complementary concepts: food access (or lack of access) and food availability (via food self-sufficiency). One reason for selecting these aspects was the feasibility of their quantitative estimation in a timeframe compatible with the land use data. Second, land-use changes were estimated per ecoregion from national-level cartography. In a third step, food security indicators were related to land-use changes, at national and ecoregion levels, using trend analysis and momentum correlation analysis. Next, a discrete Food Environmental Efficiency (FEE) index was built in each ecoregion as a function of the correlation strength between food security tendencies and environmental preservation tendencies. The index increases with food security increments and with lower environmental damage to the biosphere. Each step of the method is detailed in the following paragraphs.

2.1. Food access

The marginalization concept is related to social exclusion caused by economic growth and inequality (CONAPO, 2012). The marginalization index (MI) is computed by the National Population Council in Mexico (CONAPO, 2012) and is based on indicators associated with population distribution, housing conditions, education level, and labor income. The relationship between marginalization and access to/consumption of food has been acknowledged internationally (Ramos Peña et al., 2007; Cuéllar, 2011), and MI has been the major criterion of Mexican federal programs for the alleged goal of incrementing food access (e.g. the Strategic Project for Food Security; SAGARPA aid programs DICONSA and PROCAMPO). To support this view, it is argued that 80% of the families associated with high and very high marginalization, have an income equal to or lower than the threshold of food poverty (Peralta et al., 2016). Because our food security index is meant to assess the goals of food security policies, we estimated the lack of access to food on the basis of the Marginalization Index. MI was downloaded from the CONAPO website for the following time sequence: 1980, 1995, 2000, 2005 and 2010 (see Table 2). In all dates but 1980, the data was available at locality level. In 1980 we used the information at municipality level. Finally, in each ecoregion, a proxy for food access was computed as the inverse of the average MI.

2.2. Food self-sufficiency

Food self-sufficiency is defined as *"the extent to which a country can satisfy its food needs from its own domestic production"* (FAO, 1999); in this sense, a country tends to food self-sufficiency if it can produce sufficient food to cover its own needs (Clapp, 2017). Based on this concept, food self-sufficiency can be estimated comparing the amount of food production versus the amount of food consumption. Food production was estimated from the annual yields of major crops and livestock (further explained below) obtained at municipality (local government) level, and made available by the Information Service for Agriculture, Food and Fisheries in Mexico (SIAP, 2016). Maize, wheat, rice and bean were the major crops considered in this study, and bovine and ovine the major livestock categories, because of their strategic value for food security and sovereignty in Mexico: They are listed in the Mexican Law of Sustainable Rural Development and Article 180 in this law specifies that their production and supply will be the axes of the