Assessment of Land Use Effect on Climate Change Sensitivity on the Northern Coastal Zone of Honduras

Arie Sanders, Denisse McLean, and Alexandra Manueles

Lincoln Institute of Land Policy
Working Paper

Lincoln Institute Product Code: WP13AS1

Abstract

In this paper we examine the effect of land use and land use change on climate change sensitivity on the north coast of Honduras. To reach this objective, we ran simulations to analyze the spatial and temporal variations on sensitivity derived from land use differences and their implications on the use of land use policy as a tool for climate change adaptation in integrated coastal zone management. We developed two scenarios (trend and normative scenarios) for different spatial development trends for the 2010–2050 period. The biggest change in the trend scenario, current situation, would be a decrease in pasture (19.4%) and forestry (8.1%) as result from an increase in palm oil plantations. There would be more fragmentation and the region will become more vulnerable to climate change. In the case of the normative scenario we expect a 50.2% decrease in extensive livestock activities and an 18.3% increase of the broadleaved forest area, making the region less vulnerable to climate change. The national and local governments have a decisive role in assuring the implementation of their land use policies (normative scenario) to protect the region against climate change impact.

Keywords: land use and climate change, Honduras, coastal zone planning

About the Authors

Arie Sanders is associate professor in the Department of Environment and Development at Zamorano University in Honduras. He received his MSc from Wageningen University in the Netherlands. He worked for eight years as consultant-researcher at the Centre for Rural Development Studies of the Free University (Amsterdam) in Costa Rica. Currently he is working as an associate professor and the head of the Department of Environment and Development at Zamorano University in Honduras. In addition to teaching, Mr. Sanders is actively involved in research on rural and agricultural development and is coordinator of the NOAA-financed Socioeconomic Monitoring initiative in coastal zones of the Spanish-speaking Caribbean. He has recently collaborated on studies on firewood consumption in rural Honduras (CEPAL), the socioeconomic impact of transgenic corn (IFPRI), and economic analysis of coastal communities in northern Honduras (NOAA). Contact: asanders@zamorano.edu

Denisse McLean is a research scholar for PIPRA at the University of California, Davis. She received a BSc. in Socioeconomic Development and Environment and worked for four years as a research assistant for the Department of Environment and Development at Zamorano University in Honduras. She participated in the coordination of the scenario and capacity-building component to model land use change and biodiversity in Central America using the mean species abundance indicator (CBD). She also participated in the development of a disaggregated economy-wide household model for coastal communities in northern Honduras (NOAA). Her current project analyzes the case of Honduras as a developing-country model for the adoption of GM crops. Contact: mclean.denisse@gmail.com

Alexandra Manueles is the coordinator of the Geographic Information Systems (GIS) Unit and assistant professor in the Department of Development and Environment at Zamorano University. She received a Master's in Geographic Information Systems from Alcala University in Madrid, Spain. Currently she teaches the GIS class and coordinates the GIS activities in the Learning by Doing module on topography. Since 2008, Ms. Manueles has been involved in different research projects related to spatial analysis, including land use change scenarios, soil and water modeling, climate change scenarios and biodiversity modeling (CBD). Contact: amanueles@zamorano.edu

Acknowledgements

We would like to acknowledge the support of the "Programa de gestión de los recursos naturales y cuencas del Corredor Biológico Mesoamericano en el Atlántico Hondureño (PROCORREDOR) who gave us access to their geographic database. We are also grateful for the advice and financial support provided by the Lincoln Institute of Land Policy for the implementation of this study.

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Introduction

Due to its geographical location, the north coast of Honduras is one of the most vulnerable areas in the Caribbean Basin to storms and hurricanes (IPCC 2007). However, climate change (CC) has made extreme climate conditions more frequent and intense. Projected impacts from CC on the Caribbean region include rising sea levels, stronger tropical cyclones, altered rainfall, storm surges and increasing sea temperatures. According to Schatan et al. (2010), the scenarios on climate change effects in northern Honduras forecast that climate conditions will become increasingly extreme. Additionally, the region's vulnerability is made more severe by the lack of effective governance structures, high population growth rates and urbanization, as well as poor land use planning, which results in environmental degradation and habitat destruction.

The rapid development in northern Honduras during the last decades has drastically changed the geographical landscape. The lack of spatial planning has not only created competition and conflict between the different uses, such as residential, industrial, recreational and agricultural activities, but has also deteriorated existing ecosystems' capacity for resilience in the face of CC. Despite ongoing conservation efforts by the national government, deforestation levels of broadleaved forests and mangroves as a result of agricultural activities and urbanization remain high. Further ecosystem degradation may result in changes to the north coast, including reduced precipitation and increased droughts, which will make the region vulnerable to CC.

In recent years, there have been growing calls for a more integrated management of the Honduran north coast as a fundamental prerequisite for sustainable development. A good example is the Biological Corridor Project (PROCORREDOR) managed by the Ministry of Environment (SERNA) to establish and implement a comprehensive management plan for the protected areas on the north coast. However, little attention has been paid to land use conversion driven by human activities and climate change, which leads to serious forms of environmental degradation and habitat destruction on the north coast.

Even with the recognized importance of CC effects on the vulnerability of human populations, climate-related assessments in Honduras have mostly addressed sensitivity to natural phenomena under their normal rates of occurrence (Argeñal 2010; COPECO 2010). Assessments carried out by the Permanent Contingency Commission (COPECO) explore sensitivity to river floods, landslides, droughts and forest fires at the municipal level for some of—but not all—the country's municipalities. Only modest progress has been achieved on exploring climate change extreme weather patterns and their implications for human settlements.

The few CC assessments that have been undertaken in Honduras concentrate on the impacts on water resources and on watershed adaptation strategies (MIRA 2005; SERNA 2006a 2006b 2007). Nevertheless, the determinants of human response to weather anomalies are related not only to the response of natural systems but to the economic, social and cultural characteristics that shape human populations (Klein *et al*, 1999). Those characteristics are reflected in the ways communities make use of their available resources. One evident manifestation of this is a region's land use patterns and land use changes over time.

The land use characteristics of a population in given geographical area directly reveal the main activities undertaken, their intensity level, their relative importance and the competition and potential conflict between them. Indirectly, land use patterns reveal a population's priorities, habits and associated opportunity cost. Moreover, given each location's natural suitability for certain land uses, alternative arrangements of land use distributions can influence the state and productivity of the interrelated natural, economic and social systems. Thus, land use provides a suitable framework to analyze a population's characteristics and how they shape the population's ability to cope with extreme weather events.

Therefore the objective of this paper is to examine the effect of land use and land use change on climate change sensitivity on the north coast of Honduras. To reach this objective, we ran simulations to analyze the spatial and temporal variations on sensitivity derived from land use differences and their implications on the use of land use policy as a tool for climate change adaptation in integrated coastal zone management (ICZM). By combining land use change scenarios with land use sensitivity data, this study will analyze how climate change could affect the region in the near future. Specific research questions derived from the underlying hypothesis addressed in this study were: a) Is there a relationship between land use and sensitivity to climate change; b) If so, what are the magnitudes and directions of the influence of each land use category on climate change sensitivity; c) Given a particular land use composition within an area, is there a relationship between alternative land use arrangements and sensitivity to climate change; and d) From the findings above, which adaptive measures could authorities adopt to reduce their climate change vulnerability?

The remainder of the paper is organized as follows. Section 2 describes the methodology and the scenarios that are used for the model simulations. We use a mix of different approaches for land use analysis and include an expert judgment elicitation to estimate land use sensitivity to climate change. Section 3 presents the main characteristics of the northern coastal zone of Honduras. Section 4 presents and interprets the results of the model simulations. We simulate two scenarios to account for different spatial development trends for the 2010–2050 period. Section 5 discusses policy implications and summarizes the major conclusions.

Methodology

Climate Change Sensitivity

Dealing with climate change and land-use change in a coastal zone management context involves a wide range of concepts, tools and analytical approaches. For this study we have chosen to limit our focus to simulating the expected climate change scenarios developed by IPCC for coastal zones and determining the implications for the region's vulnerability. The conceptual framework adopted is IPCC's definition of vulnerability to climate change and related terms such as Exposure—Sensitivity—Adaptive Capacity Approach (IPCC 2007). Climate exposure refers to the nature and degree to which ecosystems are exposed to environmental changes, such as rising sea levels and changes in weather patterns. The definition of sensitivity is the degree to which a human-environment system is affected by environmental change, either adversely or beneficially. Adaptive capacity refers to the potential to implement planned adaptation measures.

In this study we considered three kinds of plausible climate change derived impacts for the region: Sea level rise (SLR), mean temperature change (MTC), and mean precipitation change (MPC). Approximately 85% of the disasters in Central America are related to floods and droughts (CEPAL 2010). The climate change scenarios for Central America suggest that depending whether it is rainy or dry season, the possibility of a higher frequency of floods and droughts, respectively, is very likely (CEPAL 2010). The National Strategy for Climate Change (SERNA 2010) estimates sea level increases of up to 0.6m for Honduras by the year 2100. The A2 and B2 IPPC scenarios adapted for Honduras by Argeñal (2010) explored the effects of climate change on mean monthly temperature and mean monthly precipitation. Results for the Department of Atlántida showed that by the year 2050 mean monthly temperature was expected to increase by between 1.4 and 1.9^{o}C, and mean monthly precipitation was expected to decrease by between 2 and 25%, depending on the month of the year.

The latest land use map for the area, elaborated by the National School of Forest Sciences (ESNACIFOR) for the PROCORREDOR Project in 2010, was used as the basis for the study. 300 ground control points were determined using a high precision GPS along the main road of the study area for field verification. Different land use intensities in areas with similar cover were disaggregated into additional land use categories to allow for a better estimate of climate change sensitivities. The road and administrative maps were also validated.

Based on emergent recommendations from local experts during introductory meetings, an improved land use/land cover map was developed through photographic interpretation of the 0.3 meter resolution aerial photographs provided by PROCORREDOR. The land use classification employed in the interpretation was based on the CORINE Land Cover methodology. The improved land use map was developed at a 1:1,500 scale, with a smallest mapping unit of 225 square meters.

SLR exposure was simulated using a flood model projecting a sea level increase of 0.5m by 2050. Using the elevation points obtained from the PROCORREDOR photogrammetric flight from, a 5-meter resolution Digital Elevation Model (DEM) was developed. From this DEM, all pixels with 0 or 1 meter of elevation were selected as floodable areas for the year 2050. Following Yoo et al. (2001), SLR sensitivity was estimated as the percentage of flooded area within each land use category, municipality and village in the department in order to identify the most vulnerable entities at different scales, so that:

$$SSLR_i = {}^{FA_i}/_{A_i} * -1$$

Where:

$SSLR_i$ = Sensitivity to sea level rise of land use, municipality or village i
FA_i = Flooded area in land use, municipality or village i
A_i = Total area of land use, municipality or village i in landscape

MTC and MPC sensitivity were estimated through expert judgment elicitation, a qualitative research technique used in decision making and risk analysis to predict the occurrence of future events and the consequences of decisions based on experts' opinions, knowledge and experiences (Keeney et al. 1991; Lannoy & Procaccia 2001; Martin et al. 2012) The methodology is usually employed in areas where information about model parameters is uncertain or incomplete and where empirical evidence is unavailable.

Guidelines provided by ACERA (2007; 2008; 2010) and EPA (2011) were used to develop the questionnaire, select the expert panel, design and conduct the elicitation and aggregate the results from the study. Explicit considerations to minimize overconfidence, anchoring, motivational and accessibility biases were included in the questionnaire and elicitation protocol. Given the diversity of disciplines needed in the expert panel and the location and availability of the selected experts, an electronic single-phase elicitation protocol was employed to better capture the breadth and depth of information regarding the different land use categories.

Eleven experts from universities, public and non-governmental organizations working in the fields of natural resources, protected areas, agriculture, coastal zones, water resources, and urban areas in the Department of Atlántida completed the questionnaire. Expected MT and MP change levels based on estimated climate change scenarios for Honduras by Argeñal (2010) were provided as background information during the elicitation. Experts were requested to provide ordinal estimations of MTC and MPC sensitivities for the different land use categories. For each category, estimations transformed into their scalar equivalents were averaged using the self-assessment of the experts' confidence level about their knowledge per land use category as weights, based on the following equation:

$$SCS_{jk} = \sum_{l=1}^{n} [(SCS_{jkl}] * CL_{kl}) \Big/ \sum_{l=1}^{n} CL_{kl}$$

Where:

SCS_{jk} = Sensitivity to climate stimuli *j* for land use *k*
SCS_{jkl} = Sensitivity to climate stimuli *j* for land use *k* elicited by expert *l*
CL_{kl} = Confidence level on knowledge on land use *k* elicited by expert *l*
n = Total number of experts

Responses were scaled from between –1 to +1 with –1 meaning land use extremely affected and +1 meaning land use extremely benefited by the reviewed climate stimuli. Municipalities and village MTC and MPC sensitivity indices were estimated through an area weighted addition of the land use category sensitivity scores, based on the following equation:

$$SCS_{ji} = \sum_{k=1}^{m} \left(SCS_{jk} * {}^{A_{ki}}\!/_{A_i}\right)$$

Where:

SCS_{ij} = Sensitivity to climate stimuli *j* for municipality or village *i*
SCS_{jk} = Sensitivity to climate stimuli *j* for land use *k*
A_{ki} = Area occupied by land use *k* in municipality or village *i*
A_i = Total area of municipality or village *i*
m = Total number of land uses

To test a land use based adaptive strategy, sensitivity was assessed under current land use conditions and for two scenarios for 2050: (1) an exploratory scenario projecting expected land use trends; and (2) a normative scenario involving firm land use regulation for urban, agricultural and natural areas. To design these scenarios, during the elicitation exercise experts were requested to provide their best estimates of the expected changes in the area occupied by each land use category in the future, with an associated degree of uncertainty. Changes per land use category were determined for the first scenario based on the confidence-weighted estimates provided by the experts according to the following formula:

$$\boldsymbol{\Delta}_k = \sum_{l=1}^{n} [(\Delta_{kl}] * CL\Delta_{kl}) \Big/ \sum_{l=1}^{n} CL\Delta_{kl}$$

Where:

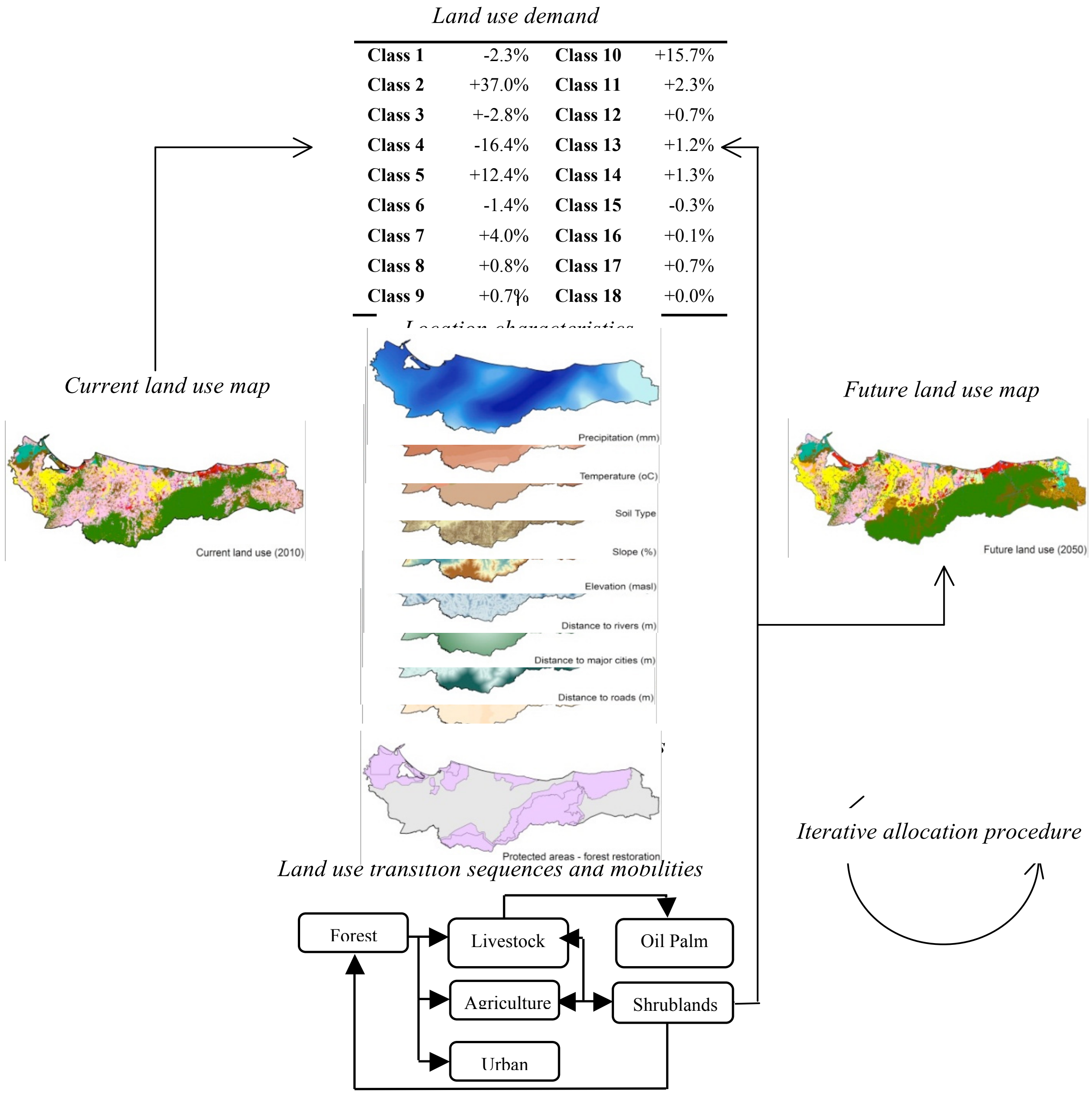
Δ_k = Expected change in land use k
Δ_{kl} = Expected change in land use k elicited by expert l
$CL\Delta_{kl}$ = Confidence in elicited change interval for land use k provided by expert l
n = Total number of experts

For the second scenario, changes per land use were determined based on the zonation scheme from the regional territorial ordering plan being developed for the Department of Atlántida by PROCORREDOR (2012).

CLUE Model

The CLUE (Changes in Land Use and its Effects) methodology was used to allocate the estimated land use changes from the scenarios, subject to spatial rules and restrictions (Verburg et al. 1999; Verburg and Overmars 2009). Starting with the current land use map and distribution, the CLUE model executes a dynamic allocation process based on the competition between the future demands for the different land uses (established by a land use demand table) and the spatial constraints originated by the factors that determine the suitability of each land unit for a particular land use. These factors include the geographic, climatic, demographic and accessibility characteristics of an area (established by a series of binary logistic regression models), the spatial policies that restrict or encourage land use patterns in a certain area (established by the use of land use restriction maps and rules), the natural sequences of transition among land uses (established by a transition allowance matrix) and the relative mobility of the different land use categories (established by an indicator of conversion elasticities). The model combines a non-spatial module where the qualitative and quantitative scenario descriptions, the aggregate demands for each land use and other model parameters are specified, with a spatial module that simulates the dynamic competition and distributes the land use demands according to the defined rules (Figure 1).

Figure 1: Methodological Framework for Future Land Use Modeling with CLUE



Land use demand

Class 1	-2.3%	**Class 10**	+15.7%
Class 2	+37.0%	**Class 11**	+2.3%
Class 3	+-2.8%	**Class 12**	+0.7%
Class 4	-16.4%	**Class 13**	+1.2%
Class 5	+12.4%	**Class 14**	+1.3%
Class 6	-1.4%	**Class 15**	-0.3%
Class 7	+4.0%	**Class 16**	+0.1%
Class 8	+0.8%	**Class 17**	+0.7%
Class 9	+0.7%	**Class 18**	+0.0%

To characterize the occurrence of each land use category, the location factors were plotted as independent variables against the current distribution of each land use in the binary logistic regression models. The regressions identified which characteristics of an area were significant for determining the occurrence of each land use type (assuming that the current land use pattern represented the allocation for the highest suitability). The model represented the suitability of the area by estimating the probability of occurrence of each land use category based on the logistic regression coefficients for every surface grid cell, using the following equation:

$$\log\left(\frac{P_{ku}}{1-P_{ku}}\right) = \beta_0 + \beta_1 X_{1,k} + \beta_2 X_{2,k} \dots + \beta_n X_{n,k}$$

Where:

P_{ku} = Probability of occurrence of land use k on grid cell u
X = Location geographic, climatic, demographic and accessibility factors included in the regression
β = Binary logistic regression coefficient for the corresponding factors

This determined which land use was more likely to be established on the surface grid cells according to their characteristics. To allocate the land use changes specified as future demands in the scenarios for each time step, the model first identified which cells were allowed to change according to the restriction rules and the transition matrix. Then, the total probability for the occurrence of each land use class for every grid cell was estimated by combining:

$$TP_{ku} = P_{ku} + ELAS_k + ITER_k$$

Where:

TP_{ku} = Total probability of occurrence of land use k on grid cell u
P_{ku} = Probability of occurrence of land use k on grid cell u estimated based on the logit model
$ELAS_k$ = Conversion elasticity for land use k added *only* when grid cell u is already under land use k
$ITER_k$ = Iteration variable for land use k

The $ELAS_k$ conversion elasticity parameter for each land use varies between 0 and 1, where 0 indicates that the conversion is readily reversible (the land use can be easily relocated from one location to another) and 1 indicates that the conversion is difficult to reverse (the use is harder to relocate). It was used as a measure of the tendency of an area to maintain its current land use. The $ITER_k$ iteration parameter represents the competitive strength of each land use. It started with the same value for all land use types, when the model allocated the land use with the highest preference on every grid cell. The model then compared the allocated area with the specified demand and modified the iteration parameter to assign the highest preferences for the uses where the former was lower than the latter and vice versa. The procedure was repeated in successive iterations until the allocated area matched the specified demand for every time step in the simulation.

Future land use maps obtained from the CLUE model for each scenario were used to reassess climate change sensitivity using the methodology described in the section above. By comparing the current state with the future scenarios, the main trends in changes in climate change sensitivity were identified. By comparing the sensitivities among scenarios, the effect of alternative land use based adaptive strategies on the magnitude and distribution of sensitivity changes were explored.

Fragmentation

To assess the landscape fragmentation in the current state and future land use scenarios, a set of fragmentation metrics were estimated for the natural land use categories using the FRAGSTAT Spatial Pattern Analysis Program, version 4 (McGarigal & Cushman 2012). These metrics included total number of patches, patch density (number of patches per unit of area), mean patch area, proportion of like adjacencies and the proximity, connectance and cohesion indices.

Based on McGarigal & Cushman (2012), percentage of like adjacencies was estimated as:

$$PLADJ = \left(g_{kk} \middle| \sum_{k=1}^{n} g_{ko}\right)(100)$$

Where:

g_{kk} = Number of like adjacencies or joints between grid cells of the same land use k
g_{ko} = Number of adjacencies between grid cells of land use k and all different land uses o

The index ranges between 0 and 100 from maximum disaggregation (no like adjacencies, i.e. one-celled patches surrounded by patches of different land use categories) to maximum aggregation (like adjacencies only, i.e. landscape comprises a single land use allocated in one patch).

The proximity index was estimated as:

$$PROX = \sum_{a=1}^{n} A_{ab} \big/ d_{ab}^{2}$$

Where:

A_{ab} = Area of patch a within specified neighborhood of patch b, a & b being patches of the same land use.
d_{ab}^{2} = Squared distance between patch a and b computed from cell center to cell center.

The index ranges from 0 and up, where 0 represents a patch with no neighbors of the same land use class within the specified neighborhood. The upper limit of index depends on the neighborhood radius, which is user specified (200mts for the purpose of this study).
The connectance index was estimated as:

$$CONNECT = (\Sigma_{\downarrow}(a=b)^{\uparrow}n \equiv C_{\downarrow}abk \mid ([n_{\downarrow}k\ (n_{\downarrow}k-1)])/2))(100)$$

Where:

C_{abk} = Joinings between patch a and b (1 if joined, 0 otherwise) of the corresponding land use k
n_i = Number of patches of land use k in landscape

The index ranges between 0 and 100 and represents the percentage of functional joinings of patches of the same type from the maximum possible connectance given the number of patches in the land use class. The threshold distance that defines a functional joining was user specified as 200mts.

Finally, the cohesion index was estimated as:

$$\left[1 - \left(\sum_{a=1}^{n} p_a \middle| \sum_{a=1}^{n} p_a \sqrt{A_a}\right)\right] \Big/ \left(\left[\left(1 - 1\middle|\sqrt{Z}\right)^{-1}\right]\right)(100)$$

Where:

p_a = Perimeter of patch *a* (number of surface grid cell)
A_a = Area of patch *a* (number of surface grid cell)
Z = Total number of grid cells in landscape

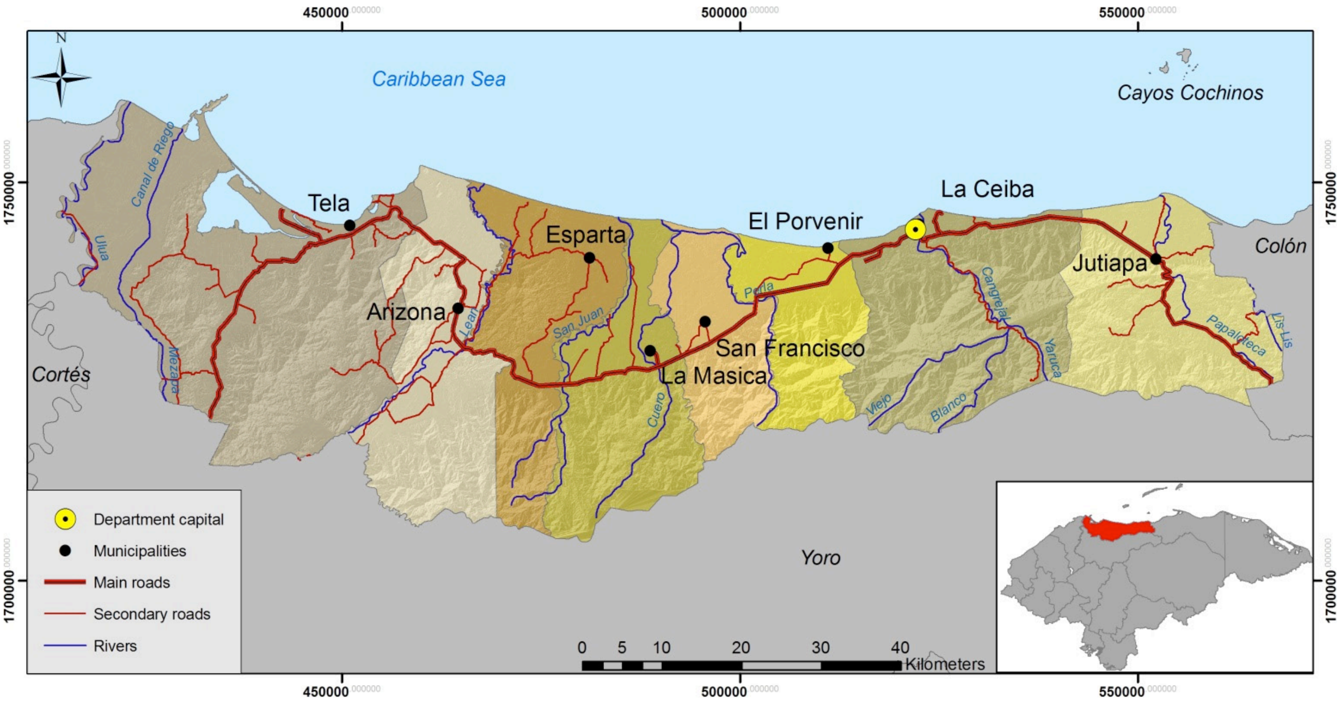
The index ranges between 0 and 100, where 0 represents land use entirely subdivided and physically disconnected and increases as the landscape becomes more aggregated.

Study Area

The study area compromises the Department of Atlántida in Northern Honduras which fronts the Caribbean Sea. With 344 thousand inhabitants, Atlántida is characterized by its economic and environmental importance at a national level. It includes part of the Mesoamerican Biological Corridor and the city of La Ceiba, the largest coastal city in Honduras characterized by its unregulated expansion (Rubio 2012).The department has three contrasting natural regions: the coastal plain, the mountain zone and an intermediate hillside zone (Buckles et al. 1999). The flat terrain of the coastal plain, a narrow strip along the coast that is less than 100 m above sea level, has the best agricultural land in the region. Slopes are typically less than 10% and never exceed 20% throughout the zone. This is where the area's urban growth has taken place, alongside the development of large agro-exporting industries like banana, pineapple and oil palm. The hillside zone—below 600 m asl—is less suitable for agriculture than the coastal plain because of the very steep slopes, yet corn and bean production (subsistence crops) is concentrated in this hillside zone. The mountain zone is generally unsuitable for agriculture as it has very steep slopes and thin undeveloped soils. Very humid subtropical mountain forest is the primary vegetation type at 800–1800 m asl, and cloud forest still predominates at higher elevations where access is difficult and where the slopes are mostly steep.

The department has been subject to major land cover changes as a result of various social and economic processes. The economic conditions are influenced by a long tradition of banana plantation agriculture, which has dominated the Honduran northern landscape and commerce throughout the first decades of the twentieth century. In the sixties commercial agriculture replaced the banana plantations in importance. The growing demand for beef in the United States increased extensive livestock production. According to the latest 1993 agriculture census, more than 50% of the farmland was composed of natural and cultivated pasture (Baumeister and Wattel 1996; Sunderland and Rodriguez 1996). In her study about the "cattle boom" in northern Honduras, Humphries (1998) analyzed the rapid growth of ranching in the region from the 50s to the 90s. During this period, the cattle population in Atlántida expanded from 27,583 to 147,233 head, representing an increase of 434%. This growth rate was possible with loans and special projects from the World Bank and USAID (Sunderland and Rodriguez 1996). At the same time, forests in this area declined from 945,200 hectares in 1962 to 258,700 hectares in 1990, representing a 72.6% decrease over the period (*ibid*).

Figure 2: Map of the Municipalities of the Department of Atlántida, Honduras



Owing to the availability of plantation employment alternatives, favorable agro climatic conditions and relatively good infrastructure, the Atlantic Coast has been an attractive migrant destination for farmers from less-favored zones in the country, strongly influencing agricultural development (Jansen *et al*, 2006). As a result of fluctuations in the labor needs of the agricultural plantation sector in combination with large-scale migration in the country beginning in the 1970s, farmers were increasingly forced to resort to cultivation of the steep hillsides of Atlántida (Porch *et al* 2007).

In the 80s, to restrict the use of some of the important and vulnerable areas in the department, the Honduran government established reserves and national parks. In the Atlántida area there are seven terrestrial reserves and parks with a total area of 187.8 thousand hectares (43% of the total land area). The reserves and national parks are co-managed by local non-governmental organizations, which in general lack the financial resources for effective protection of the areas. As in other national parks in the country, due to the lack of financial resources and institutional support, the effectiveness of the protected areas is limited. In most of the protected areas, you will find agriculture and livestock activities, as well as illegal dwellings.

The north coast is an area of high demographic pressure with a population growth rate of 2.3% (UNDP 2009) and increasing built-up areas. As consequence of national migration, there has been rapid urbanization and accelerated urban sprawl around the two main cities of La Ceiba and Tela and next to the highway between those cities. Most of the urbanization is less than 20 km from the coast, and more than 50% of the population of Atlántida is living in this area.

The climate of northern Honduras is classified as humid tropical with temperatures between 25 and 28°C with high annual precipitation in a bimodal distribution (2000–3000 mm per year).

However, Honduras lies within the hurricane belt, and the Caribbean coast is particularly vulnerable to hurricanes and tropical storms that travel inland from the Caribbean. Although the climatic conditions in northern Honduras are always wet, during the last decennials precipitation has varied periodically.

Porch et al. (2007) found an increase of 0.022°C/year for minimum temperature and 0.018°C/year for maximum temperature for Honduras. They also analyzed the average yearly rainfall, and although a negative slope was found, changes in precipitation were not statistically significant. Warmer weather will cause a series of other events, such as a greater number of warm spells/heat waves over most land areas, more frequent intense tropical cyclones, a greater number of extreme high sea level events and severe drought (CEPAL, 2010). According to Schatan et al. (2010), the scenarios on climate change effects in northern Honduras agree that climate conditions will become increasingly extreme.

Land Use Changes in Northern Honduras

Land Use Categories

The disaggregated land use map contained 18 land use categories, and their definitions are given in Table 1. For the forest area we distinguished the categories broadleaved and pine forests, which include all kinds of classes, including secondary, open and fragmented forest. The permanently flooded forest areas at the shore line are classified as mangroves. Livestock activities can be classified as extensive cattle raising and intensive dual purpose systems. The former system can be characterized as large natural grassland areas that are extensively used for livestock grazing, while the latter refers to man-made and/or natural grasslands with a higher grazing density, generally used by dual purpose cattle systems (milk and beef production) and located in the more urbanized areas. In total, eight agricultural land cover classes were established, including shrub land. Shrub land habitats are temporary non-used agriculture land or pasture with natural or semi-natural woody vegetation. Generally those areas are left fallow for 1–5 years to recover soil fertility. The category intensive agriculture refers mainly to horticulture, including pineapple, while the category extensive agriculture refers to annual crops like corn and beans (subsistence crops) and sugar cane.

Table 1: Land Use Categories for the Department of Atlántida 2010

Land use categories	Brief description	Land use categories	Brief description
Natural vegetation		**Agriculture**	
Mangroves	Forestry in flooded areas	Shrub lands	Land with potential for agriculture but not under use.
Broadleaf forest	Primary and secondary forest (open and closed)	Extensive agriculture	Arable land used for growing annual crops (horticulture).
Pine forest	Secondary pine forest	Intensive agriculture	Arable land used for growing crops, both annual and perennial (corn, beans, sugar cane, etc)
Water bodies	Surface water	Banana/Plantain	Intensive monoculture plantations
Beaches		Fruit crops	Including oranges and other citruses
		Pineapple	Intensive monoculture plantations
Human settlement		Coffee	Monoculture and shaded plantations.
Discontinuous human settlement	Isolated dwellings and small settlements in the rural areas.	African oil palm	Monoculture plantations
Continuous human settlement	Urban and small towns.	**Livestock (pastures)**	
Commercial and industrial areas	Area in use for commercial and productive activities.	Extensive livestock	Natural grazed grassland in the more isolated areas in use for cattle raising.
		Intensive livestock	Cultivated pasture and natural grazed pastures in less isolated areas.

Our study assesses the changes of a relatively a large group of land use classes because these allow us to evaluate the potential geographical spread of increasing agriculture and livestock production and expanding urbanization throughout the department. However, the land use categories included in the CLUE model for the study are fewer than those in the original land use map. Certain categories had to be aggregated since the model is unable to adequately allocate land use categories and land use changes of relatively small magnitude (less than 1% of the total area). Fruit crops, pineapple and coffee plantations were aggregated into a single category. The intensive agriculture and banana land uses were also grouped since the area covered by banana was too small for the model to run, but its changing rate was similar to that of intensive agriculture. A category including beaches and water bodies was established and remained constant through the modeling period. After running the allocation model, these categories were disaggregated into their original components.

Table 2 shows the land use categories with their factor coefficients integrated into the study's regression model at a 95% confidence level. To test the robustness of the inference of the regression from the available data, a Relative Operating Characteristic (ROC) curve analysis of the predicted probabilities was performed. The ROC values for the models range from 0.68 to 0.99, suggesting that the models are capable of explaining the spatial variation of land use patterns.

The logistics models estimate the spatial variation in occurrence of the different land use types. The model results for all land uses indicate that land locations are jointly determined by biophysical parameters (elevation, slope and soil type), climate (precipitation and temperature) and socio-geographic characteristics, such as distance to major roads, rivers, urban areas and population density. The models demonstrate that the remaining mangroves are influenced by all of these factors with the exception of population density. Mangroves are found in low flat areas where the temperature is generally higher than in the other areas. The location and distribution of broadleaved forests is highly related to the biophysical parameters. They are found in elevated and sloped areas with poor soils and lower temperatures. These areas are distant from main roads and human settlements. Pine forests have similar characteristics, but are found in areas with lower elevations and higher temperatures.

The analytical results showed that agricultural and livestock activities are multifaceted and influenced by both physical and socio-geographic characteristics, particularly by temperature, slope and soil conditions. Extensive agriculture, the production of corn and beans by small scale farmers, is concentrated in areas with poor soils distant from main roads and cities. The locations of extensive livestock are influenced by all of the factors. The regression results indicate that extensive livestock activities are influenced by natural conditions (slope and soil conditions) and human activities (distance from human settlements). Intensive agriculture activities, including palm plantations, fruit crops and pineapple, are located in the flat lowlands with favorable soil conditions. The regression results confirm that each location possesses specific soil characteristics and slopes that influence the potential for natural and agricultural vegetation.

Continuous human settlement is constrained by slope, soil type and socio-geographic conditions. Originally, human settlements were based in the more favorable areas of fertile soil and low elevations and slopes. New settlements are influenced by all factors except for slope. Soil type, road distance and population pressure have negative coefficients, implying that population pressure caused the expansion of new settlements to more remote and less fertile areas.

Table 2: Regression Analysis Results

	Mangroves	Broadleaf forest	Pine forest	Scrublands	Extensive agriculture	Intensive agriculture/Banana	Fruit crops/Pineapple/Coffee	African oil palm	Extensive livestock	Intensive livestock	Discontinuous human settlement	Continuous human settlement	Commercial and industrial areas	Water bodies/Beaches
Distance to roads	-.000053		-.002046	-.000052	-.000096	-.000179	-.000427	-.000240		-.001046	-.000078	-.000721	-.000604	-.000247
Distance to mayor cities	-.000031	-.000047	-.000146	-.000043	-.000035	-.000036	-.000134	-.000034	-.000011		-.000073	-.000142	-.000109	-.000041
Distance to rivers	.000323	-.000495	.	-.000266	-.000392	-.000477	-.000388	-.000385	-.000275		-.000317			
Elevation	-.013711	.000399	.007545	-.000568				-.000756	-.000215		-.000607		-.001284	-.000729
Slope	.012346	-.004662	.011473				.009079	.003177	.003662		.006475	.008802	.014842	.005349
Precipitation	.002263	.000368		-.000799	-.000342	-.001516	-.000825	-.001056	-.001186	-.002026	-.001002	-.001738	-.002002	-.000764
Temperature	2.548431	-.027884	-.671127	-.191195	-.153103	.	-.453168	-.515114	-.211647	-.223245	-.178367	-.287265	-.541462	-.226972
Soil type	-.352582	.415313		.021789	.141678		-.164085	-.195475	.076650			-.235422	-.334024	-.047801
Population density		-.000253		.000017	-.000157		-.000390		-.000025		-.000107			
Constant	-69.619151	-3.819141	6.572128	5.150401	.788105	-.353826	11.954605	15.062477	7.097964	5.179017	4.016541	10.285466	16.850190	4.081739
ROC	.967524	.876632	.996252	.687000	.758620	.796243	.846005	.766662	.784001	.904329	.734988	.823204	.838086	.675377

Land Use Change Scenarios

Based on the logistic regression models, land use demand and land use conversion rules, the CLUE model was applied to simulate two scenarios to account for different spatial development trends for the 2010–2050 period. The first scenario assumes the continuation of present trends of land use change determining demand (trend scenario) with no implementation of spatial policies with respect to the allocation of agricultural, livestock and urban expansion. The second scenario is based on the same overall expansion rate for agriculture, livestock and urbanization. However, we have assumed a spatial policy of land use as defined by the national and local government to ensure the protection of the declared protected areas and the implementation of reforestation projects and planned urbanization (normative scenario).

In the case of the trend scenario (E1), a decrease in pasture (19.4%) and forestry (8.1%) would result from an increase in palm oil plantations. A change from pasture to palm oil plantation would create pressure on the other land use categories, creating more pressure on the protected and/or state owned areas. Cultivated land losses in the La Ceiba and Tela area are mainly caused by competition between cultivated land and urbanization. This type of land use conversion is indirectly related to the productive capacity of the land because both cities are situated in the lower and more fertile areas. The total urban area, including industrial and commercial areas, will increase by 1.6%. Increases in horticultural and fruit areas are expected in the more fertile areas between Tela and La Ceiba. The results of this scenario forecast that nearly a fifth (19.2%) of the current land use will be changed by 2050, especially in areas with relatively good soils and low elevations.

Compared to the trend-scenario, the E2 scenario shows some important differences. With local and national government implementation of their land use management plans, broadleaved forest in the department would increase by 18.3%. Palm oil would register the same increase as in the trend scenario, but the expansion would basically involve replacement of grazing areas. The most drastic change would be a 50.2% decrease in extensive livestock activities. Because of increasing land pressure and the inability to open “new land” in the protected areas, land use intensification with more profitable crops per hectare would be the expected result. A good example is the case of Jutiapa, the most eastern municipality where extensive livestock would lose its importance and would be replaced by banana and citrus plantations and to some extent by reforestation.

Figure 3: Observed and Simulated Land Use for Scenario E1 and E2

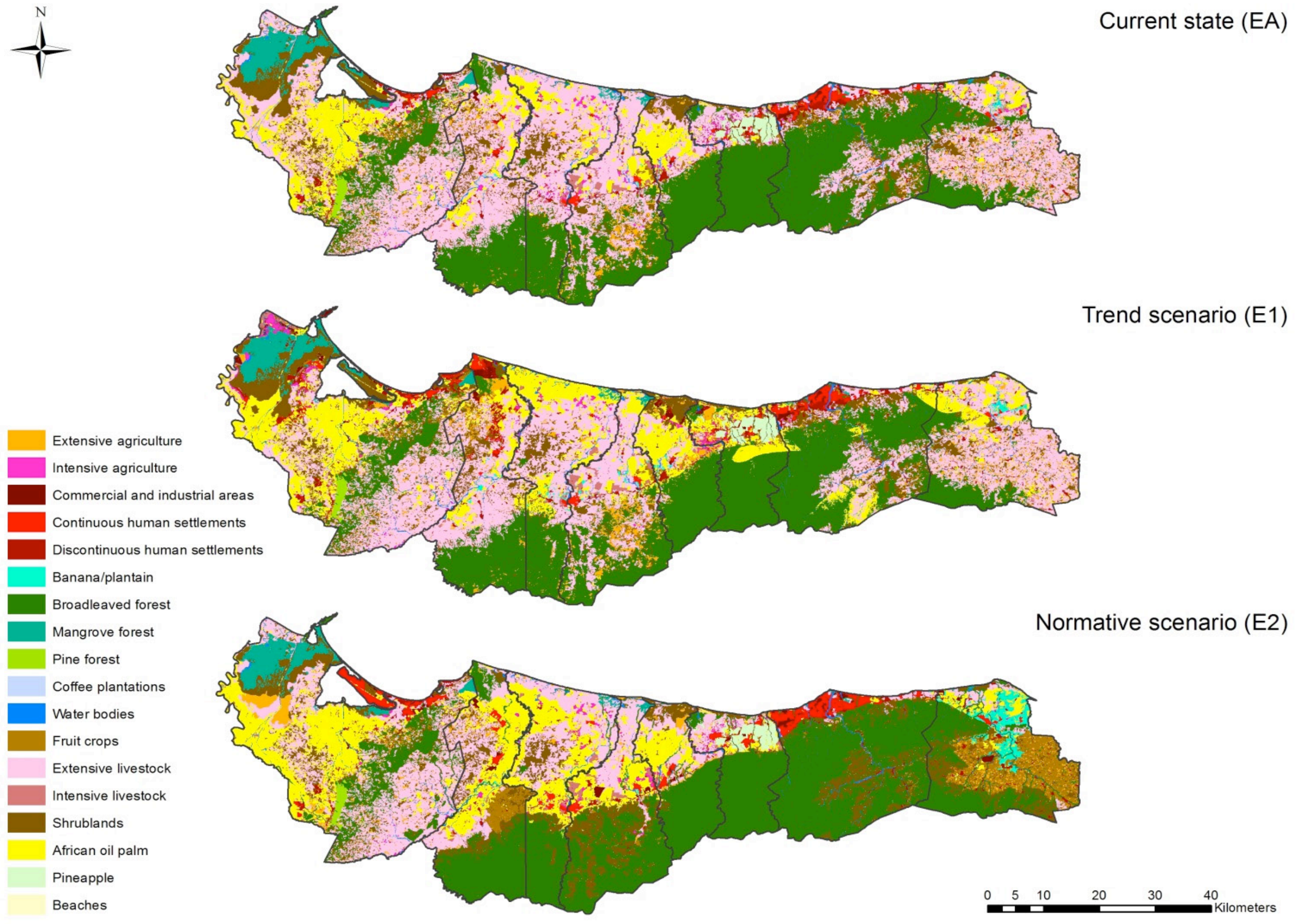
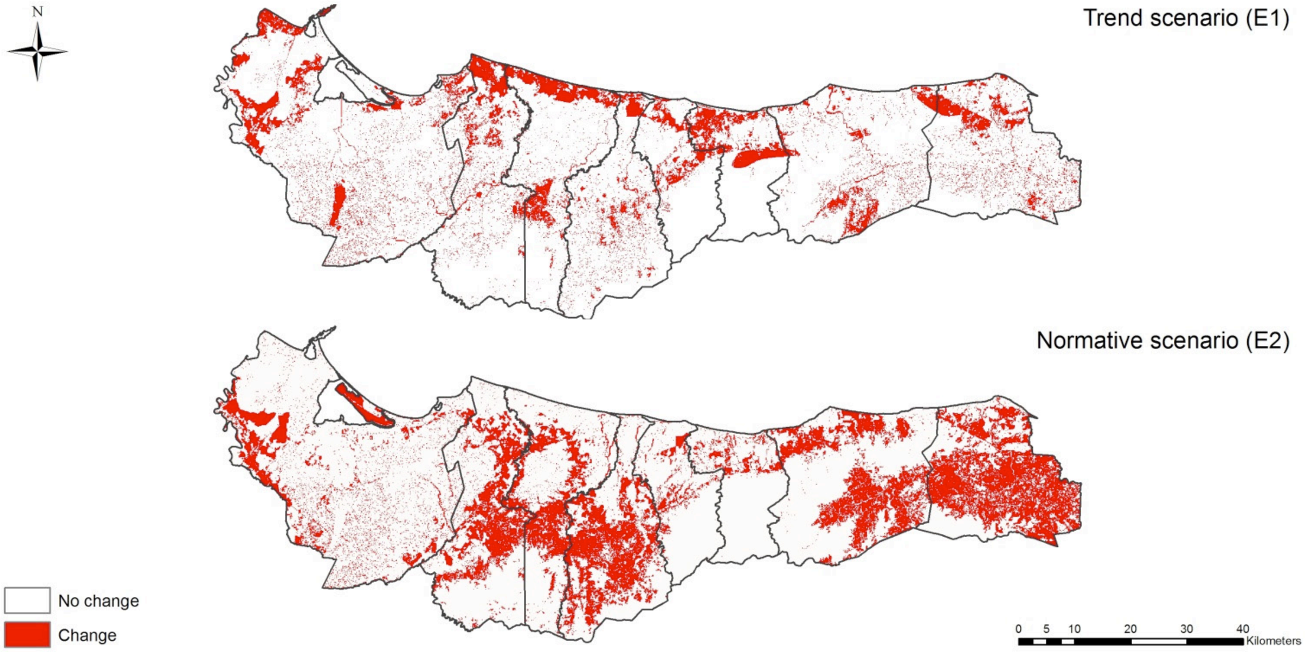


Figure 4 shows the resulting maps of each land use change between 2010 and 2050 for each of the two scenarios. The land use changes between 2010 and 2050 demonstrate that the most extensively changed areas are located in the central and eastern parts of the department, especially in areas with extensive livestock and low elevation.

Figure 4: Land Use Change between 2010 and 2050; Trend Scenario E1 and Normative Scenario E2



Sensitivity of Land Use Categories to CC

Because of their complexity, it is difficult to estimate the expected climate change effects like land degradation for each land use pattern in quantitative terms or other values scores. These effects are often diverse and not always direct and are therefore also hard to measure. As mentioned in the methodology section, to estimate land use sensitivity to climate change (temperature change and reduced precipitation), we used expert opinions. Based on these expert opinions, we constructed a sensitivity value for each of the land use patterns per category (Table 3). The categories are as follows: natural land cover; non-natural land cover (human intervention); human settlements; and livestock. In the short term, the experts do not expect major climate change impact on temperature and precipitation for each of the land use patterns. However, heavy rainfall and increasing storm surges during the last decennia could be linked to climate change. In the long term the impact of CC is expected to be substantial. The extent of CC effect is related to the kind of land use.

According to the experts, in the category of natural vegetation, beaches and water bodies are most sensitive to CC. Climate change, as result of rising sea levels and temperatures raise and drought, will lead to coastal erosion and tend to degrade or remove natural protective features (e.g. mangroves and sand). That in turn will increase extreme water levels and hence the risk of coastal flooding. However, as with other considerations about coastal degradation, it is difficult to separate the effects of human-induced forces from those that result directly from climate change (Nichols *et al*, 2009). The immediate effect of CC for water bodies in coastal areas is submergence and increased flooding, as well as saltwater intrusion into surface waters and wetland loss.

Many aspects of projected climate change will likely affect forest growth. The experts classified the sensitivity of broadleaved forests as high. Rising temperatures could increase the length of the growing season. Species may be at risk if conditions in their current geographic range are no longer suitable. In this specific case, some of the species in the Pico Bonito National Park may disappear because they cannot shift to a higher altitude. Although many trees are resilient to some degree of drought, increased temperatures could make future droughts more damaging than those experienced in the past. In addition, drought increases the risk of forest fires, a widespread problem in most of the Honduran forest areas.

Non-natural land use, mainly agriculture, is highly dependent on specific climate conditions. Trying to understand the overall effect of climate change is complicated. Increases in temperature can be beneficial for some crops in some places; crops tend to grow faster under warmer conditions. However to realize these benefits, water availability, fertility and other conditions must also be present. According to the experts the crops most vulnerable to higher temperatures are coffee, fruits and vegetables, while crops like fruits and African palm are more sensitive to droughts. The general effects of CC also need to be considered along with other factors that affect agricultural production, such as farming practices, property rights and technology.

The experts classified livestock activities as not very sensitive to CC. However, changes in climate could affect livestock activities both directly and indirectly. Direct effects are heat stress, which increases animal vulnerability to disease and, in the case of cattle, CC reduces milk production during the dry season. Longer and more intense droughts, resulting from higher dry season temperatures and reduced precipitation, could reduce the amount of forage available to grazing livestock. At the same time, CC may increase the prevalence of parasites and diseases that affect livestock.

The sensitivity for human settlements and built up areas are valuated at an intermediate level compared with other land uses. Both main cities, Tela and La Ceiba, are located near the coast line and are vulnerable to rising sea-levels, extreme weather events and flooding. In recent years, both cities have suffered substantial damage to physical infrastructure—buildings, roads, drainage and energy systems—which in turn has impacted the welfare and livelihoods of its inhabitants. In both cities, the population continues to grow in the absence of effective urban planning, and more than 65% of the population is poor and vulnerable. Their *barrios* are located in the low-lying areas which are most exposed to the effects of CC. Poor household not only have low incomes, but normally also live in poor quality housing, which provides poor resistance to natural disasters. The situation of industry and commercial activities is less sensitive because most of them are located in areas with less risk and in general their physical structures meet Honduran housing codes.

The climate change implications for discontinuous settlement in northern Honduras involve settlements in rural areas. Rural Honduras is characterized by high poverty levels; 70% of the rural population lives in poverty, and people rely on weather dependent rain-fed agriculture for their livelihoods (World Bank 2006). The impact of higher temperatures and drought can be linked for example to decreasing drinking and irrigation water sources in wells and springs, especially in the more northern part of the department.

Table 3: MTC and MPC Sensitivities Estimated per Land Use Category

less < Level of sensitivity > more

MTC sensitivities		MPC sensitivities	
Natural Vegetation			
Beaches	-0.80	Beaches	-0.76
Water bodies	-0.73	Water bodies	-0.75
Mangroves	-0.58	Broadleaved forest	-0.54
Broadleaved forest	-0.52	Mangroves	-0.49
Pine forest	-0.49	Pine forest	-0.33
Agriculture			
Coffee plantations	-0.54	Extensive agriculture	-0.54
Shrublands	-0.54	Fruit crops	-0.53
Fruit crops	-0.51	African oil palm	-0.52
Intensive agriculture	-0.50	Intensive agriculture	-0.47
Extensive agriculture	-0.48	Banana/Plantain	-0.44
Banana/Plantain	-0.45	Pineapple	-0.41
African oil palm	-0.39	Shrub lands	-0.26
Pineapple	-0.32	Coffee plantations	-0.19
Livestock			
Extensive livestock	-0.50	Extensive livestock	-0.44
Intensive livestock	-0.45	Intensive livestock	-0.43
Human settlements and built up areas			
Continuous human settlement	-0.60	Continuous human settlement	-0.54
Discontinuous human settlement	-0.54	Commercial and industrial areas	-0.45
Commercial and industrial areas	-0.50	Discontinuous human settlement	-0.38

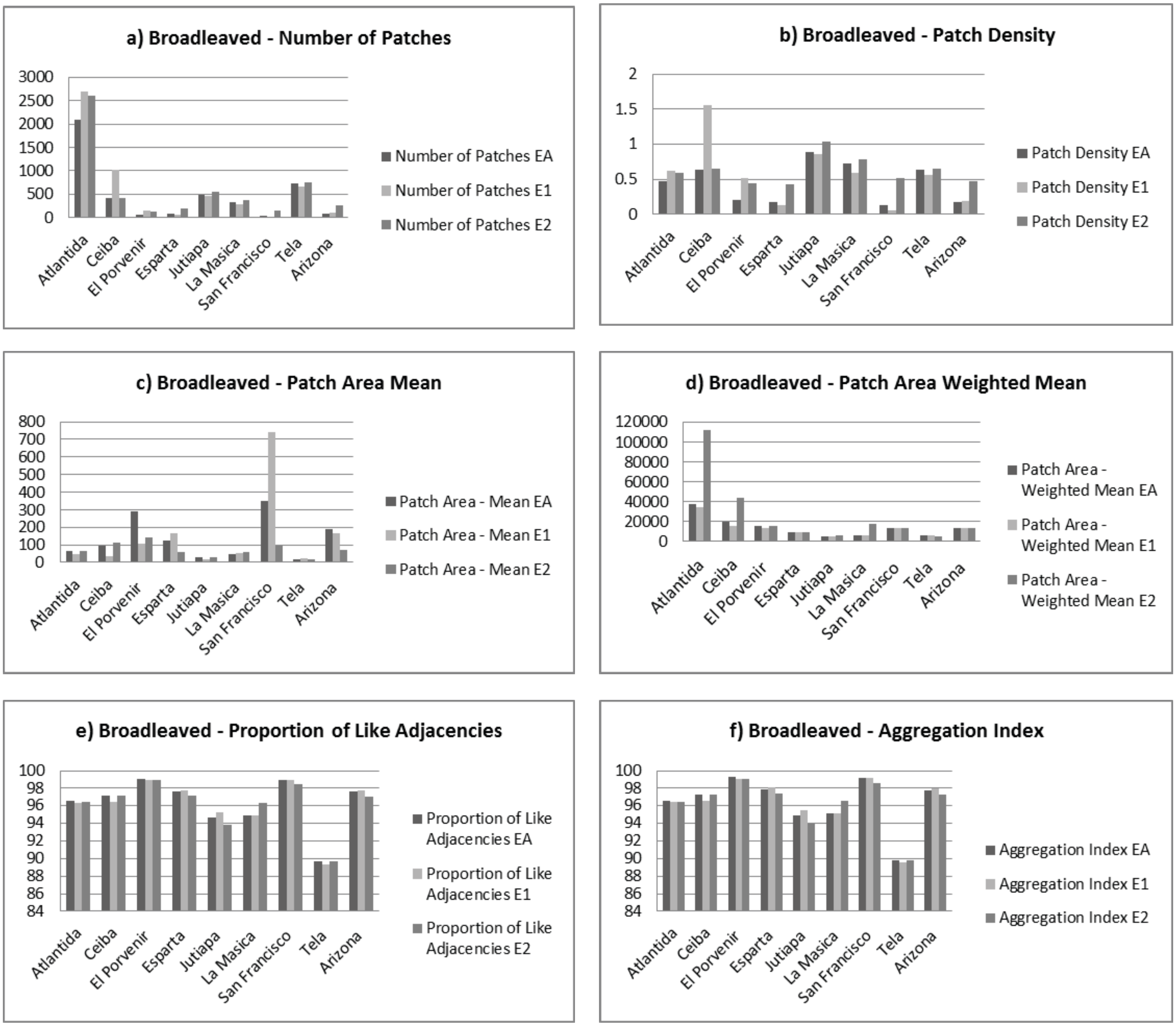
Fragmentation

Land use changes not only reduce or increase the land cover of a specific category, but can also lead to habitat fragmentation in which a large patch of natural habitat is divided into smaller patches. Habitat fragmentation might increase CC impacts because it not only blocks the ability of species to expand their range as a response to shifting suitable climate zones, but also reduces the resilience capacity of the local region to climate change impact. We analyzed the fragmentation of the broadleaved forest area under different land use scenarios. We used five fragmentation indices including number of patches, patch density (number of patches per unit of area), mean patch area, proportion of like adjacencies and the proximity, connectance and cohesion indices.

The number of patches for a particular habitat may affect a variety of ecological processes; under both scenarios the number of patches will increase, but the impact is less severe for the normative scenario (Figure 5a). The patch density measures the spatial heterogeneity. Landscape with greater patch density is considered more fragmented than a landscape with a lower patch density of a given patch type (Figure 5b). At the regional level, no differences were found, but the trend scenario forecasts an increase in the patch density for the La Ceiba area, which indicates more spatial heterogeneity in the specific municipality. A landscape with a smaller mean patch size for the target patch type than another landscape might be considered more fragmented (Figure 5c). In the case of the Municipality of San Francisco, the forest patch has a greater mean patch size than the other patch types in the municipality so it might be considered that the forest area in this specific municipality is less fragmented. By weighting patches according to their size, larger patches are weighted more heavily than smaller patches in calculating the average patch mean, which is useful when characterizing the landscape structure. The normative scenario favors the creation of greater forest areas and will reduce the fragmentation of current forest areas (Figure 5d).

The proportion of like adjacencies is the percentage of cell adjacencies involving the corresponding patch type that are like the adjacent patch type. An increasing percentage of like adjacencies implies greater aggregation of the patch type (Figure 5e). The results for both scenarios indicate that the expected changes will be small. The municipality with the lowest index is Tela, which implies a smaller aggregation of the forest areas. The aggregation index is directly related to the fragmentation index, and it is expected to decrease with the increasing number of patches. This is because increasing a class on a landscape, in this specific case forestry, increases the probability of forming larger (more aggregated) patches, and AI decreases if patch size remains unchanged. The results were as expected; Tela reports the lowest level of aggregation and has the most fragmented forestry habitat (Figure 6f). Moreover, the AI of broadleaved forest in scenario E2 increases slowly in La Masica and La Ceiba, but decreases in the other municipalities.

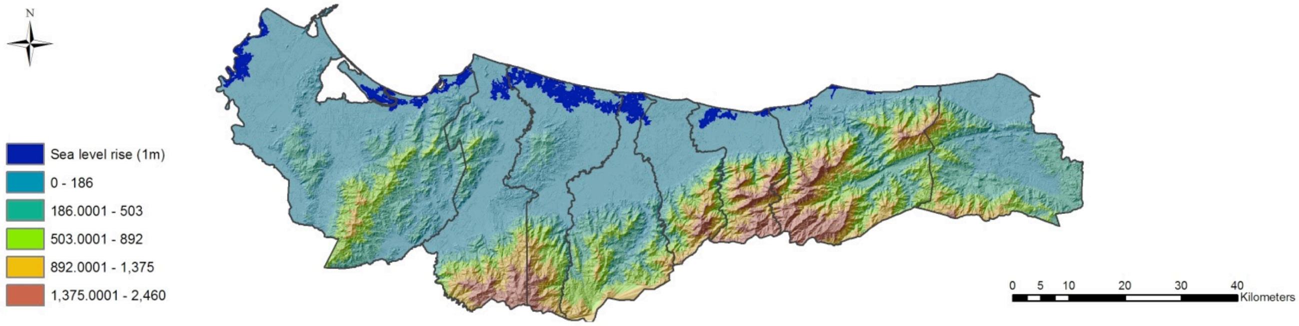
Figure 5: Landscape Metrics for Land Use Change Patches



Sea Level Rise

The municipalities most sensitive to sea level rise by 1 meter are shown in figure 6. According to the elevation contour, 11,608 hectares or 2.6% of the department is estimated to be flooded by the year 2050. This flooding would mostly occur in villages from the municipalities of Esparta, La Masica and Tela. Those municipalities have many low areas, resulting in higher proportion of flooded area with sea level rise.

Figure 6: Digital Elevation and Sea Level Rise Model of the Department of Atlántida 2050



The maximum elevation obtained from the DEM corresponded to 2,460 meters above sea level. The proportion of the department located between 0 and 20 meters above sea level was estimated at 26%. This surface is mostly occupied by productive land uses and human settlements.
The municipalities in Esparta and La Masica are not densely populated, and their land use involves a very large proportion of agricultural lands, especially oil palm cultivation, which suggests that there is an urgent need to prevent and manage flooding in agricultural fields in this area. The cities La Ceiba and Tela are also affected by sea level rise; the area affected in those municipalities was about 25% of the total flooded area. In summary, a higher sensitivity to sea level rise was observed in the lower areas where land use is dominated by oil palm cultivation, and the population density is relatively low.

Climate Change Sensitivity

We present two kinds of maps to analyze the CC impact for each land use cover. Figure 7 presents the current state and the results for both scenarios based on land use cover with changes in land use for the scenarios analyzed at patch level. In Figure 8 we calculated a weighted average for all land use categories at village level. Villages with more sensitive land use cover will present a higher sensitivity to climate change. In both figures, sea level rise is presented as an independent variable and not linked with the CC variables of temperature and precipitation. Figure 6a shows that under the current situation, 60% of all land use cover is considered as highly sensitive to CC. The most sensitive area is in the western part of the department where extensive livestock and agriculture activities dominate the area. On average, the villages in the municipality of Esparta are the most sensitive to CC, including flooding.

For the E1 scenario, the “business as usual approach”, we assumed that land use change would continue as in the past. During the 2010–2050 period, we estimate that 18.9% of the total land use will change. According to Figure 6b, this change will occur on the sea coast and in areas of the municipalities of Jutiapa, Tela and El Porvenir. The expected changes for 2050 are mainly a further expansion of oil palm replacing pasture and other agriculture crops. The total impact of the land use change on sensitivity to climate change on a municipality level depends on whether the replaced land cover was more or less sensitive to CC than the new land cover. According to our analysis, nearly 80% of the land cover change for 2050 involves conversion to oil palm cultivation. As can be seen in Figure 7b, the municipalities where oil palm is expanding will be less sensitive to CC in 2050 than in 2010 because oil palm is not very sensitive to temperature rise and is relatively resistant to droughts.

The normative scenario, Figures 7c and 8c, presents a more optimistic outlook. The land use plans developed by the national and local governments would control the expansion of agriculture activities to the protected areas located in the higher part of the department. The total land use cover change will be 38% by 2050. The natural areas, especial broadleaved forests, will expand by 18%. The model forecasts a dramatic reduction in extensive livestock and agriculture activities (52% and 25% respectively). African oil palm will grow at the same rate (15.7%) as in the trend scenario, but the replacement impact (crowding out the replaced agriculture activities to protected areas) will be limited.

Figure 7: Climate Change Sensitivity at Land Cover Level

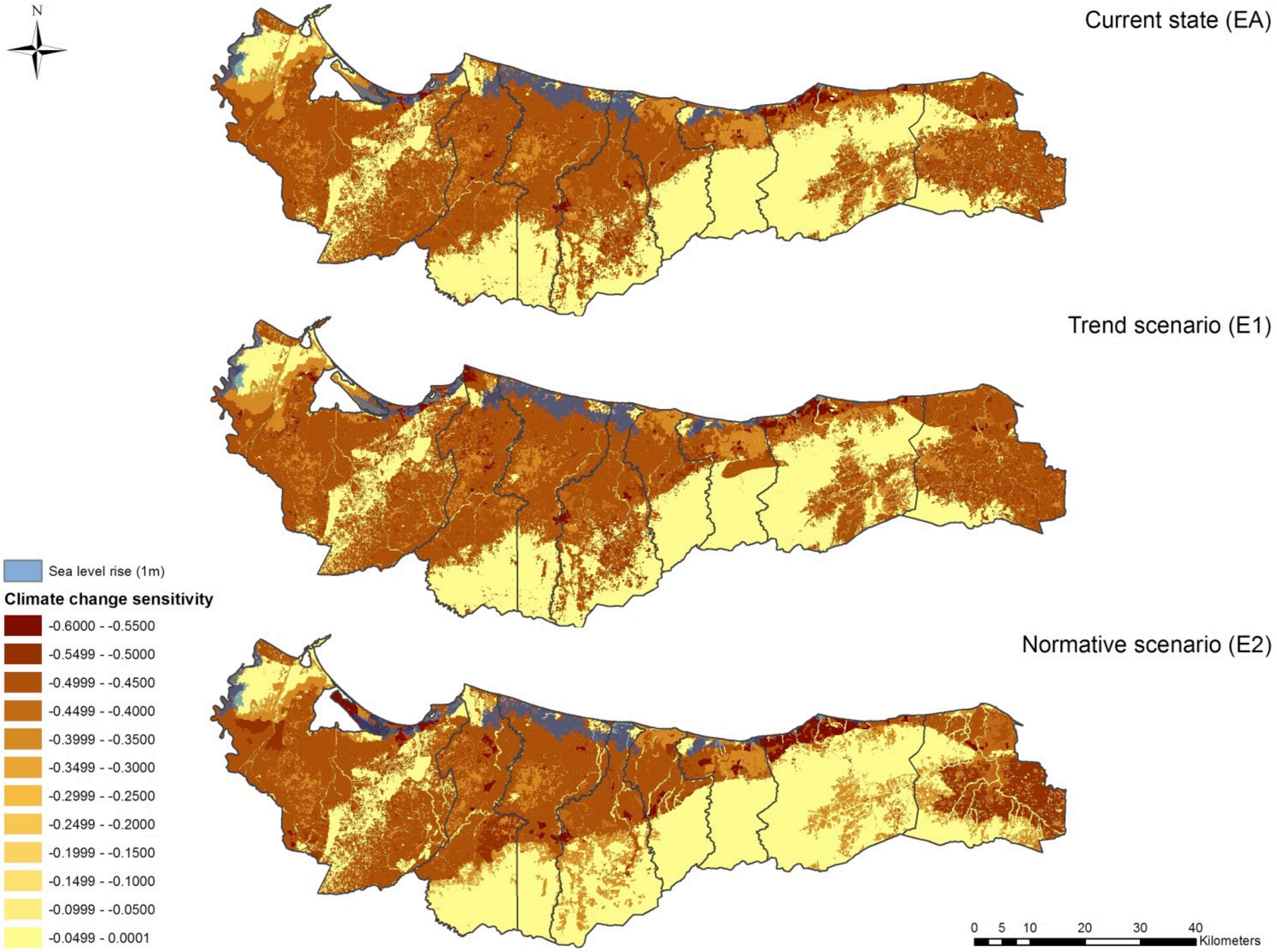
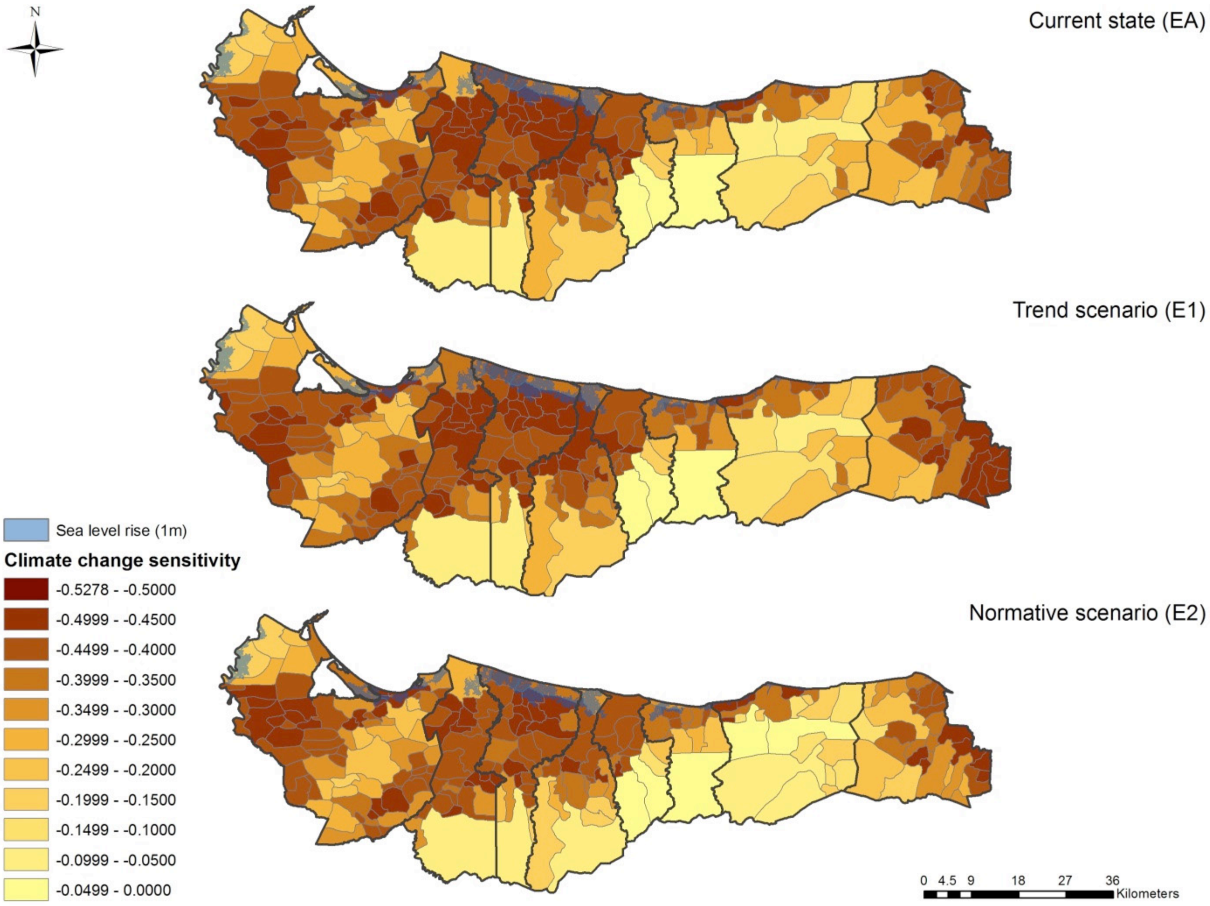


Figure 8: Climate Change Sensitivity at Village Level



Discussion

By combining land use patterns with climate change sensitivity for each land use cover, it is possible to analyze the Department of Atlántida's sensitivity to climate change over the next 40 years. In this context, important climate changes include a change in the length of the growing season, which is related to both rainfall and temperature and is a major factor determining agricultural productivity. A number of climate models agree that in much of Honduras the growing season is projected to decrease by between 5% and 15% by 2050, with particularly negative effects in the dryer areas of south Honduras (IPCC 2007). Over the last 30 years Honduras has already shown a gradual increase in both mean maximum and mean minimum temperatures. Although the average temperature shows an increasing trend, the data is highly variable (Argeñal 2010). In the case of precipitation patterns, more variation and decreasing mean annual rainfall is expected; this will have a significant impact on crop yields. Research by Porch *et al* (2007) found that shorter growing seasons and higher temperatures represent important production constraints for bean farmers in the department

The results of our logistic models for all land use categories explain that the location and expansion of agriculture and livestock activities and urbanization are determined by biophysical parameters (altitude, slope and soil type), demographic characteristics, such as distance to major roads, cities and rivers, and population density and climate variables (precipitation and temperature). Those driving factors shaped the current land use cover and are the main factors that will shape future land use.

The CLUE methodology was applied to associate land use demand and possible trends to simulate land use scenarios for the 2010–2050 period. As we could observe, land use change is directly linked to biophysical, climate and demographic variables (E1 scenario), but can be influenced by effective policy measures to protect specific areas (E2 scenario). Simulation results indicated that land use changes for the E1 scenario occur more frequently on the coast and in areas with low elevations. More dramatic changes were found for the E2 scenario; the effect of replacing extensive livestock with African oil palm was less harmful for the protected areas. However, it is plausible to expect that the replacement of natural forest areas with pastures will occur in other areas with less control than the protected areas (departments of Cortes and Gracias a Díos). The reduction of natural areas will make the region more vulnerable to climate change. However, the replacement of different kinds of crops and livestock activities with African oil palm will make the region less vulnerable to climate change.

By using landscape metrics it was possible to evaluate and compare before and after conditions in a landscape plan for a particular landscape, in our case the forestry area. At the landscape level, the E1 scenario would lead to a more fragmented forestry area during the simulation period than the E2 scenario. Fragmentation would not only reduce the critical threshold for species' survival, but would also affect the forest's resilience to recover from severe disturbances and to maintain the rates of supply of goods and services to the region (Thompson *et al* 2009). To reduce the further fragmentation of the forest area, conservation policies could have an important impact on the forest area patch patterns, making the region less vulnerable to CC.

The one-meter projection of sea level rise could increase flooding, particularly in the lower areas near the coast line. Sea level rise will probably increase the biophysical and demographic vulnerability of the area. However, it is in this area where we expect increasing population growth and further expansion of the main cities in the region, Tela and La Ceiba. In recent years, flooding has affected especially the poorest populations because they are concentrated in the more hazardous areas.

The combination of flooding with a decrease in rainfall could increase the inland penetration of salt water, affecting the quality and availability of fresh water. Also it could impact the natural wetlands and lagoons (*Laguna de los Micos* and *Cuero y Salado*); those areas are protected by low barrier beaches, and sea level rise could induce overtopping and affect the ecosystems. African oil palm plantations and other agricultural activities could be at risk of flooding and soil salinization. In general, the results stress the biophysical and demographic vulnerability of settlements and agricultural activities located in the very low areas near the coast line.
Without active land use planning for the coming years, the increasing development pressures from a growing population and expanding agriculture activities could impact the capacity of ecosystems to adapt to climate changes, making the region more vulnerable. The essence of land use analysis is to show policy makers how possible land use cover changes could impact future land use. The current land use plans of local and national governments will have a decisive role

in determining the most appropriate land use for the upcoming 40 years. It is important to find a balance between conservation of crucial areas and economic and agricultural development. Although trends of oil palm expansion will continue, it is important to limit further agriculture expansion in the protected areas. Reforestation and the adoption of REDD projects could be important measures to protect the region against climate change.

Conclusions

The coastal zone of northern Honduras is highly exposed to the potential impacts of climate change. In particular, the region is vulnerable to sea level rise and to changes in temperature and precipitation. The potential effects of CC, which can include significant socioeconomic implications for the population, and the relation with land use cover change is complex. Changes in land use due to such activities as agriculture, urban sprawl and transportation infrastructure are generally recognized in the literature as major causes of increasing vulnerability to climate change. Assessing land use sensitivity is important as it enables the identification of at-risk areas and the threats posed by a decrease in or loss of such resources that could threaten future sustainable development in the region (Berry et al. 2006).

The aim of this study was to analyze sensitivity variations derived from spatial and temporal land use differences and their implications on the use of land policy as a climate change adaptation tool in integrated coastal-zone management. In the case of northern Honduras, agricultural expansion is the most important proximate cause of land use change, followed by deforestation and infrastructure development. Growing export demand for palm oil and increasing numbers of subsistence farmers on hillsides have been the primary drivers for converting natural areas (directly or indirectly) into land for agricultural and extensive livestock use. The total land cover change for the next 40 years will be about 18.9% of the total area. Those land cover changes will not only affect the biophysical landscape, but will also influence the agrarian structure—more land will become concentrated in fewer hands.

According to the experts, some specific land use patterns are more sensitive to climate change than others. Specifically, beach areas, water bodies and broadleaved forests are considered as highly vulnerable to higher temperatures and drought. In general, crops are vulnerable to CC, which will likely combine to reduce yields and increase production risks in the region. However, the economic drivers that are causing the ongoing land use changes from agriculture and livestock to primarily oil palm production seem to be effectively mitigating climate change. Oil palm is less sensitive to CC than other crops and adapts relatively well in the region. The main problem of the expansion of oil palm is the pressure on other crops and natural areas. While oil palm is less sensitive to CC and we found no direct linkage between the expansion of oil palm cultivation and deforestation, indirectly oil palm production leads to the conversion of natural areas into cropland or pasture because of the increasing land pressure on lower-lying areas. These results have important implications for future land use policies. For instance, future conversion from cropland to other land types could cause increased sensitivity (particularly through urbanization and deforestation) while future expansion of cropland could also cause improved CC adaptation, particularly through the expansion of less sensitive corps like oil palm into marginal areas. However, the increasing land pressure caused by palm oil production has a potential negative impact on natural areas, causing deforestation and making the whole region more vulnerable to climate change over the next 40 years. National and local governments have a decisive role in assuring the implementation of their land use policies to protect the region against climate change impact.

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