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Abstract

Mexico is a biologically megadiverse country, but its biodiversity is endangered due to high deforestation rates. Impacts of land-use/cover-change and climate change are unevenly distributed, which hinders the execution of conservation practices. Consequently, an adequate spatial conservation prioritization is crucial to minimize the negative impacts on biodiversity. Global and national efforts to prioritize conservation show that >45% of Mexico should be protected. This study develops an applicable spatial conservation prioritization to minimize impacts on biodiversity, under three scenarios. They integrate exposure to land-use/cover-change and climate change scenarios, adaptive capacity to deal with the exposure, and the distribution of endemic species on risk of extinction. Our results show that by 2050 between 11.6%, 13.9% and 16.1% of Mexico would reach score ≥50 in vulnerability (VI), under the optimistic, BAU, and the worst-case scenarios, respectively. By 2070, these figures would rise to 11.9%, 14.8% and 18.4%. Amphibians are the most threatened vertebrates with 62.2% of endemic species being critically endangered or endangered, while 39.2%, 11.8%, and 8.5% of endemic mammals, birds and reptiles are endangered or critically endangered. The distribution of these amphibians accounts for 3.3% of the country's area, while mammals, birds, and reptiles represent 9.9%, 16.2%, and 28.7% of Mexico. Moreover, seven municipalities (0.39% of the country) represent 30% of the most vulnerable areas (VI=70). This study offers relevant information at the levels of municipality and species to help decision-makers prioritize national efforts for the conservation of ecosystems and biodiversity under land-use/cover and climate change. This study is replicable in other regions which aim to adapt decision-making and land management for biodiversity conservation.

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I. Introduction

Humanity has to address efforts to stop "biological annihilation" based on population decline and species extirpation, which has negative cascading consequences on ecosystem functioning and services (Ceballos et al., 2017; Monsarrat et al., 2019). The loss of biodiversity is the result of several drivers and their interactions, including land-use/cover-change (LUCC), climate change (CC), species invasion and disease (Brook et al., 2008; Sala et al., 2000). However, the effects of CC on the LUCC process and their combined effects on biodiversity are uncertain (Monsarrat et al., 2019; Oliver and Morecroft, 2014). In the tropics, LUCC is expected to be the major force of change, but other studies have suggested that CC may play an important role, particularly for mammals (Paniw et al., 2019).

Moreover, most of the global biodiversity loss is concentrated in nine countries (Australia, Brazil, China, Colombia, Ecuador, Indonesia, Malaysia, Mexico, and the USA). These elements highlight the necessity for those nations to implement effective monitoring and policy enforcement for species conservation (Alroy, 2017). Mexico is one of the richest countries in biological diversity worldwide. It occupies fourth place in the group of 17 megadiverse countries, whose biodiversity represents around 70% of known species (Mittermeier et al., 1997; Mittermeier et al., 2011a). However, in the last century it has halved its natural vegetation (Velázquez et al., 2002) due to agricultural and livestock expansion (Bonilla-Moheno, 2012; Mendoza-Ponce et al., 2018). LUCC and CC impacts, as well as affecting biodiversity, are unevenly distributed. Therefore, spatial conservation prioritization is crucial, particularly in megadiverse countries (Brooks et al., 2006), mainly in those countries that suffer from possessing limited technical and economic resources to implement sustainability actions (IPBES, 2019).

Spatial conservation prioritization refers to the use of quantitative techniques to generate spatial information to inform decision-making about an environmental problem. The problem involves choices about spatial allocation to restore or protect important biodiversity areas (Ferrier and Wintle, 2009). Spatial conservation prioritization allows quantitatively ranking locations for conservation purposes (Wilson et al., 2009). For this study, spatial conservation prioritization was implemented to identify the most important regions, ecosystems, and municipalities for species conservation. This process included pragmatic concepts and quantitative approaches based on the criteria of irreplaceability and vulnerability (Margules and Pressey, 2000; Pressey et al., 1994). The irreplaceability of a site has been defined in two ways (Ferrier et al., 2000; Pressey et al., 1994): 1) the likelihood that a site will be required to meet a given set of conservation targets; and 2) the extent to which these targets can be achieved even if the area is lost. These two elements are key for biodiversity conservation. However, the complexity of the term irreplaceability, particularly in biodiversity, should not be reduced to signifying only the number of species, because several areas can share the same number of species. Alternatively, it has been suggested to use endemic species due to their uniqueness (Krupnick and John Kress, 2003; Mittermeier et al., 2011b). Here we evaluate the irreplaceability based on the endemicity of vertebrate species, as has been used in other studies (Loyola et al., 2007). Moreover, vulnerability to climate change is defined as a function of exposure, sensitivity, and adaptive capacity (Adger, 2006), and it expresses the propensity to be adversely affected (IPCC, 2014). However, this definition as well as the vulnerability framework focus especially on human systems (Fortini and Schubert, 2017). Others have defined biological vulnerability as the predisposition to which a species, population or ecosystem is threatened (Dawson et al., 2011). It is important to note that both approaches face practical and theoretical limitations to evaluate the vulnerability of biodiversity.

The following definitions are adopted to evaluate the vulnerability of biodiversity: 1) *Exposure* is defined as the degree, duration, and/or extent to which a system, or a part of it is in contact with harm (Adger, 2006); 2) *Sensitivity* is understood as the susceptibility of an element to be harmed (IPCC, 2014). From a biodiversity perspective, sensitivity was evaluated in terms of the endemicity of the species due to the fact that threatened small-ranged species face larger threats from anthropogenic pressures than more abundant species (Dawson *et al.*, 2011); 3) *Adaptive capacity* refers to the ability to adjust to current or future conditions (IPCC, 2014). In a socio-ecological context, adaptive capacity integrates biophysical and social or socioeconomic elements.

Over the last decades, different efforts have been undertaken to prioritize biodiversity conservation such as Crisis Ecoregions (Hoekstra et al., 2005), Endemic Bird Areas (BirdLife-International, 2017; Stattersfield et al., 1998), and Important Birds and Biodiversity Areas. The Endemic Bird Areas established that 4.5% of the Earth is of high priority for broad-scale ecosystem conservation (Stattersfield et al., 1998). Endemic Bird Areas considers ~2,500 endemic species, restricted to an area smaller than 50,000 km^2. In Mexico there are 22 Endemic Bird Areas and 182 Important Birds Areas and Biodiversity Areas. Endemic Bird Areas represent 1 million km^2 with five out of the 22 being shared with neighboring countries. Complementarily, Important Birds and Biodiversity Areas cover an extent of 312,000 $km^{2,}$ representing 15.5% of the country (BirdLife-International, 2019); The United Nations Environment Program, the International Union for Conservation of Nature and the World Wide Fund for Nature developed a project to identify Centers of Plant Diversity (UNEP-WCMC, 2013). The result was that 234 sites were identified, of which 12 are in Mexico, covering ~256,000 km^2 (12.8% of the country). Another important effort is Biodiversity Hotspots, which consists of 34 sites that cover 23.5% of the Earth's land surface with an extent of ~24 million km^2 (Mittermeier et al., 2011b; Myers et al., 2000). There are three Biodiversity Hotspots in Mexico, and they represent 5% of the global area of the Biodiversity Hotspots, and 45% of the total area of Mexico (Californian Floristic Province, Madrean Pine-Oak Woodlands and Mesoamerica). Besides, there is the project focused on wetlands through the RAMSAR convention; Mexico has 142 RAMSAR sites which together comprise 86,570 km^2 (4.5% of Mexico) (RAMSAR, 2015). Moreover, there are national efforts to prioritize biodiversity conservation. The National Commission for the Knowledge and Use of Biodiversity (CONABIO et al., 2007) proposed that up to 43% of Mexico should be protected. Other Mexican efforts include the Priority Terrestrial Regions (n=152, 27% of Mexico), Priority Marine Regions (n=70, 71% of Mexico), Priority Hydrological Regions (n=110, 40% of Mexico), and Important Areas for Bird Conservation (n= 219, 16% of Mexico). In terms of prioritization, Priority Terrestrial Regions and Important Areas for Bird Conservation together, propose to conserve ~43% of the country's terrestrial area. There is also another prioritization exercise focused on restoration, which proposes to restore 15% of the country (Tobón et al., 2017). However, these global and national efforts face three important difficulties: 1) the coarse spatial information makes implementation of any strategy for species conservation difficult; 2) they propose large-extent areas that are unrealistic to address efforts for biodiversity conservation at, and 3) they fail to include future threats such as LUCC and CC.

Mexico has highly heterogeneous ecosystems, climates, and cultural diversity. This context sets a challenge for biodiversity conservation. Therefore, the objective of this study was to identify priority sites for biodiversity conservation, considering two of the most important threats to biodiversity, LUCC and CC. To reach this objective we posed the following key questions.

(Q1) To what extent is the vulnerability and the irreplaceability framework an alternative to reduce the total protected area proposed by the previous global and national efforts to prioritize biodiversity conservation?

(Q2) What are the key ecosystems and regions that may drive major species extinctions under LUCC and CC scenarios?

II. Methodology

This section is divided into two parts. The first focuses on the modeling of land-use/cover-change (LUCC) under socioeconomic and climate change (CC) scenarios. The second part shows the development of the prioritization steps under the vulnerability and irreplaceability framework. This framework includes exposure to LUCC and CC, sensitivity, and adaptive capacity. The study considers the terrestrial part of Mexico (1,932,524 km^2) at a 1-km^2 resolution and three contrasting LUCC and CC scenarios that represent an optimistic one, a business-as-usual one (BAU), and an optimistic and worst-case scenario.

II.1 LUCC modelling

The LUCC models were developed using Dinamica EGO (version 3.0.17.0). This software was selected due to its capacity to implement dynamic processes, including feedbacks between LUCC and CC. The models included calculations of transition matrices, colinearity of the variables, the estimation of the weights of evidence of explanatory variables, short-term projection for validating the model and long-term projections. The estimated models were independently validated by comparing the observed and the simulated maps, following the approach of Soares-Filho et al. (2009), based on an exponential and multiple-window constant decay function.

The land-use/land-cover classification maps come from the most complete and detailed information source in Mexico. These maps were developed by the National Institute of Statistics and Geography (INEGI) for the years 1985, 1993, 2002, 2007, 2011 and 2015. All of the maps were reclassified in thirteen common land-use/land-cover classes. These classes consisted of eight natural covers (cloud forest, grassland, hydrophilic vegetation, scrubland, temperate forest, tropical evergreen forest, tropical dry forest, and other vegetation types); four anthropogenic covers (pastures, irrigated agriculture, rainfed agriculture and urban); and one for barren land (Mendoza-Ponce et al., 2018).

A set of 24 explanatory variables (13 socioeconomic and 11 biophysical; Table A.1) were selected to represent the main drivers of change. The socioeconomic data consist of population and Gross Domestic Product and were obtained from the national census from INEGI while the projections for these variables are from the International Institute for Applied Systems Analysis (IIASA, 2016). The future socioeconomic information (Shared Socioeconomic Pathways - SSPs) was downscaled at the municipality level by assuming a constant representation over time, based on the mean historical share of each municipality. Finally, all of the historical climatic variables and the CC scenarios based on the Representative Concentration Pathways (RCPs) were downloaded from Worldclim (Fick and Hijmans, 2017). Three combinations of socioeconomic and climate scenarios were considered for this study: a business-as-usual (BAU) which includes the combination of the SSP2 and RCP4.5; an optimistic scenario which integrates the SSP1 and RCP2.6; and a worst-case scenario that combines the SSP3 and the RCP 8.5.

Each LUCC projection was modeled by integrating the corresponding socioeconomic and climatic variables, and differential LUCC rates. The optimistic, the BAU, and the worst-case climate scenarios (RCP2.6, RCP4.5, and RCP 8.5) include four General Circulation Models (CNRMC-M5; GFDL-CM3; HADGEM2-E5; MPI-ESM-LR), and two time horizons: 2050s (average for 2041-2060) and 2070s (average for 2061-2080) (Mendoza-Ponce et al., 2018). The set of General Circulation Models was selected to match those used in the current national climate change technical documents (INECC, 2019). The rates of deforestation were calculated using the Food and Agriculture Organization recommendations (FAO, 1995), and using the national land-use/cover maps available at the most aggregated categories (Mendoza-Ponce et al., 2018).

Future maps of land-use/land-cover were produced from each General Circulation Model, and the level of agreement between the projected patterns of change was evaluated. The evaluation of agreement between the maps considered deforestation, regeneration and permanence. The same process was applied to each combination of SSP and RCP scenarios described above. The level of agreement between the models is expressed in percentages for each of the pixels. Values between 75% and 100% denote concordance in projected deforestation, regeneration or permanence of any modeled transition of LUCC in at least three out of four General Circulation Models.

Business-as-usual (BAU) scenario

This scenario uses the SSP2 assumptions – defined as “middle of the road” – in which social, economic, and technological trends do not change markedly from historical patterns (O’Neill et al., 2017; Riahi et al., 2017). In terms of demography, Mexico is considered a low fertility country (O'Neill et al., 2017), with moderate mortality and migration (Kc and Lutz, 2017; O'Neill et al., 2017). Similarly, economic growth is moderate, with significant contrasts across the country. These factors promote the likelihood that the LUCC trends fall within the middle of the historical records. To incorporate the LUCC trajectories quantitatively, we considered the national land-use maps (INEGI, 1985, 1993, 2002, 2007, 2011, 2015) to estimate the mean rates of change from all the combinations of every single transition (Table A.2). This process was implemented to define the baseline trajectory and to minimize the bias of selecting a specific time period (Pana and Gheyssens, 2016). All the climatic data were updated to correspond to the scenario and the time horizon (2050s and 2070s) to model (Fick and Hijmans, 2017).

Optimistic scenario

The SSP1 storyline is considered a sustainable path (O'Neill et al., 2017) characterized by a consumption-oriented transition toward low materialistic growth with efficient use of resources and energy, with a significant reduction of tropical deforestation (Popp et al., 2017). The SSP1 socioeconomic scenario depicts low fertility, mortality, and migration leading to a rapid demographic transition for countries like Mexico (Kc and Lutz, 2017; O'Neill et al., 2017). In terms of economy, SSP1 reflects shifts toward a broader emphasis on human wellbeing. The GDP growth is lower than in the SSP2 scenario, but the low population growth of the SSP1 results in a reduction of the inequality. The SSP1 scenario is combined with the RCP2.6 for climate projections. The optimistic scenario also assumes the lowest historical deforestation rates of all the ecosystems and the highest historical regeneration rates (Table A.3). As such, this scenario supports an optimistic development within feasible social and economic trajectories and integrates possible national policies to reduce deforestation and degradation, as well as to promote regeneration as a biodiversity conservation strategy.

Worst-case scenario

The SSP3 refers to a fragmented world with an emphasis on security at the expense of international development (Riahi et al., 2017). Population will grow rapidly in developing countries, including Mexico, but slowly in rich OECD countries. This scenario assumes high mortality and low education (Kc and Lutz, 2017). In terms of land-use, the SSP3 assumes high deforestation rates and large expansions of cropland and pasture land, as compared with SSP1 (Fujimori et al., 2017). The SSP3 scenario is combined with the RCP 8.5 which assumes the highest levels of greenhouse gases emissions. This scenario projects the worst deforestation rates and the lowest regeneration rates for all the ecosystems in Mexico (Table A.3) based on the need for agricultural and pastureland expansion to fulfill food demand.

II.2 Exposure

The exposure to LUCC was estimated considering the propensity of an area to change from natural cover to anthropogenic cover for both scenarios and for all of the General Circulation Model projections. To identify the changing areas over time (2011-2050 and 2011-2070), the LUCC models were reclassified (natural *vs* no-natural). The resulting integrations identify the permanence of natural covers or anthropogenic covers, loss of natural vegetation, and regeneration. These transitions are related to an exposure value, where a value of 100 refers to areas that are prone to be converted to anthropogenic covers, while a value of 50 relates to areas prone to regeneration, because these areas are more predisposed than old-forested lands to being deforested again, as suggested by Rudel *et al*. (2005). Meanwhile, a value of zero identifies areas with permanence of natural vegetation, where, consequently, there is a null exposure to LUCC.

The exposure to CC was estimated as the difference between current and future scenarios of each of the two climatic variables: 1) Mean annual temperature (BIO1), and 2) annual precipitation (BIO12). The resulting values were normalized between 0 and 100 (Equation 1), where 100 denotes the largest future difference in relation to the current values and zero refers to no change. The integration of the exposure to LUCC and CC was estimated by equally weighting both exposures.

Eq. 1.

$$N = \frac{(X_i - X_m)}{(X_M - X_m)}$$

Where N is the normalized value between 0 and 100, X_i is the observed value, X_m is the minimum value observed and X_M is the maximum value observed in the data set (Monterroso and Conde, 2015).

II.3 Sensitivity and adaptive capacity

We use IUCN's biodiversity spatial data for terrestrial vertebrates (mammals, reptiles, amphibians) (IUCN, 2017) and birds (BirdLife-International, 2017). All the information was rasterized to a spatial resolution of 1-km^2, and from this we calculated: 1) the total richness and richness by group, and 2) the number of endemic and critically endangered or endangered species. For each group, we normalized the data between 0 and 100, where a value of 100 refers to the areas with the highest number of endemic species that are critically endangered or endangered.

Adaptive capacity was estimated using the Conservation Risk Index proposed by Hoekstra (2005). We selected this index because it expresses the capability of a region to face the challenges to overcome the impacts of the anthropogenic pressures. This index is the ratio of the percentage of converted area (natural to anthropogenic), and the percentage of protected areas. The adaptive capacity was estimated at the finest possible resolution which is the municipality level for the current and future conditions based on the BAU and the optimistic scenarios. The final ratio was normalized between 0 and 100. The highest value refers to the municipalities with an absence of protected areas, which suggests the lowest adaptive capacity to cope with biodiversity loss. Values close to zero denote municipalities in which deforestation is equal to or smaller than the total extent of the protected areas within the same municipality.

II.4 Vulnerability

The vulnerability index was calculated as a mean of exposure, sensitivity, and adaptive capacity (Eq.2). Values close to 100 refer to areas prone to be converted from natural to anthropogenic covers with the largest changes in the climatic variables (temperature and precipitation), absence in protected areas and with the presence of endemic and endangered vertebrates. In contrast, figures close to zero refer to sites that will face low risk of deforestation, with small changes in climate and with no endemic and endangered vertebrates.

Eq. 2

$$Vulnerability = \frac{Exposure + Sensitivity + Adaptive\ Capacity}{3}$$

III. Results

III.1 Exposure

Exposure to land-use/cover-change (LUCC) shows that natural vegetation accounted for up to 72.2% of Mexico's area in 2011. However, according to the business-as-usual (BAU) scenario, by 2050 and 2070, natural covers would cover 62.9% and 60.5% of the country, respectively. In the worst-case scenario only 14.1% and 12.2% of Mexico would remain as natural cover. In contrast, the optimistic scenario shows a slight recovery for 2050 and 2070, suggesting that it is possible to increase the forested area to account for 78.8% and 79.2% of the country. The areas with the highest exposure to LUCC are on the Pacific Coast and the Peninsula of Yucatan (Fig 1, Fig. A.1, Fig. A.2, and Fig. A.3). In those regions, the tropical dry forests are in frontier with tropical evergreen and temperate ecosystems. In contrast, in the worst-case scenario, there are agricultural and livestock expansions in the Sierra Madre Occidental and Sierra Madre del Sur (Fig. A.2). These areas are mainly represented by temperate and cloud forests.

The exposure to climate change (CC) suggests an increment in temperature and, for the most part of the country, a reduction in precipitation. According to RCP2.6 and the four General Circulation Models, by 2050 73% of Mexico will show increases in annual temperature between 1.7^{o}C and 2.3^{o}C. Furthermore, 75% of the country is depicted experiencing increments between 2.0^{o} - 2.6^{o}C by 2050 and between 2.4^o - 3.2^{o}C by 2070, under the RCP4.5. By 2050, the RCP 8.5 projects increments between 3.0^{o}C and 3.8^{o}C in 73% of the country, and by 2070 there could be an increase of 3.6^{o}C to 4.6°C in 76% of Mexico. The largest increments are projected in small areas at the mountain chains which are dominated by temperate forest, and in different regions, as in the Northwest and Northeast of the country that are dominated by scrublands and deserts. In the worst-case scenario the most affected area is in the north where the states of Sonora and Chihuahua are in the Sierra Madre Occidental and North Altiplano (Fig. A.1, A.2 and A.4).

Precipitation shows great variability among the General Circulation Models projections. It is expected that Mexico would show a rise in precipitation >5% in 28%, 27% and 17% of the country, according to the RCP2.6, RCP4.5, and RCP8.5 respectively. These changes occur in the Central American mountain chain (Isthmus of Tehuantepec) and in the lower part of the East mountain chain (Sierra Madre Oriental). Contrastingly, by 2050 and 2070, 9% and 10% of the country would show a decrease in precipitation (>3%) under the BAU and the optimistic scenarios, particularly in the Central area of the Sierra Madre Oriental and the North-Gulf coastal plains (Fig. A.2 and A.5). Also, by 2070, a reduction in the precipitation is expected, >5%, in 12% and 13% of Mexico, and an increment >3% in 16% and 20% of the country, according to RCP2.6 and RCP4.5 respectively (Fig 1). The worst-case scenario shows decreases ≥5% in 37% and 68% of the country by 2050 and by 2070. The cumulative exposure of both threats, LUCC and CC, shows that by 2050 5%, 12% and 27% of Mexico would experience a score value >50 for the optimistic, BAU and worst-case scenarios respectively (Fig. A.5). The areas with the largest exposure to LUCC and CC are located around the Pacific coast where the tropical dry forest is distributed, and the Central Altiplano (or high plains) close to the Central Volcanic Belt (Fig. A.2), which is dominated by natural grasslands bordered with temperate forests and the Yucatan Peninsula.

III.2 Sensitivity

According to the IUCN (2017), Mexico has 256 species of endemic and critically endangered or endangered terrestrial vertebrates (56 mammals, 154 amphibians, 12 birds, and 34 reptiles) (Table A.4). Of these, amphibians are the most threatened vertebrates, with 62% of endemic amphibians considered critically endangered or endangered. In a similar manner, 39%, 12%, and 9% of the endemic mammals, birds, and reptiles, are endangered or critically endangered (Table 1). The dominant ecosystems constraining the endemic vertebrates are temperate forests, followed by scrublands, tropical dry forests, and natural grasslands. Interestingly, about 30% of the distribution of these species converged with disturbed regions such as in rain-fed-agriculture and pasturelands covers (Fig. 2).

The distribution of the threatened amphibians accounts for 3.3% of the country, while mammals, birds and reptiles in these categories represent 9.9%, 16.2%, and 28.7% of the country (Fig 1). Endemic and endangered or critically endangered amphibians are principally distributed over the southern coasts of the country (Pacific and Gulf of Mexico) (Fig. A.1 and Fig. A.6). This region is represented by tropical rainforests, temperate forests and cloud forests (Fig. A.2). The endemic and the endangered or critically endangered mammals are spread across the Baja California Peninsula, part of the Southern Pacific Coast and the Gulf of Mexico in the southern part of the State of Veracruz. In contrast, endemic endangered or critically endangered birds are located on the Sierra Madre Occidental and in the Central Volcanic Belt (Fig. A.2). These regions show the largest extension of temperate forests. Additionally, endemic and endangered or critically endangered reptiles are mainly restricted to the arid ecosystems such as scrublands and natural grasslands in the northern and eastern central part of Mexico (Fig A.2 and Fig. A.6).

The bird group exhibits the highest species density (446 species per km^2). Most of this richness is found in the south of Mexico, South Gulf Coastal Plain, Sierra Madre del Sur, and the Central American mountain chain (Fig. A.2 and A.6), which are characterized by tropical rainforest, cloud forest, and are within the transition to temperate forests. The mountain chains (Sierra Madre Oriental and Sierra Madre Occidental), dominated by temperate forest, turned out to be the most important areas in terms of endemic and threatened species. The mammal group shows the second highest species density (139 species per km^2), and is represented especially in the southeastern tropical rainforest in the Sierra Madre del Sur, and in the border with Central American mountain chain (Fig. A.2 and A.6). These areas with high levels of biological richness are close to ecotones between temperate, cloud and tropical rainforests. In terms of endemic and threatened species the more diverse areas are in temperate forests (Central Volcanic Belt, such as Pico de Orizaba and Cofre de Perote), and the tropical dry forests (Pacific Coast, particularly in the Chamela region; Fig. A.1, Fig. A.2 and A.6).

Reptiles are the third group in terms of species density. The maximum richness is 59 species per km^2 and these are located in two regions: a tropical rainforest in the Gulf of Mexico (Los Tuxtlas), and the scrublands in northern Mexico (Cañón de Santa Elena). Moreover, the richest areas dominated by endemic and threatened density of reptile species were found in the eastern scrublands (Sierra Madre Oriental mountain chain (Fig. A.2 and A.6). Finally, amphibians had the lowest species density with a maximum of 32 species per km^2. This richness was observed in the tropical evergreen forests in the Gulf of Mexico (Los Tuxtlas). Eight species is the maximum number of endemic and threatened amphibians registered in temperate forests (Central Volcanic Belt as Pico de Orizaba, Cofre de Perote and Sierra Madre del Sur), and cloud forests (State of Guerrero) (Fig. A.1 and A.6). However, it is important to highlight that Chamela and Los Tuxtlas have two of the most important ecological research stations in Mexico (Fig. A.1), which may bias these numbers.

Table 1. Number of vertebrate species classified as critically endangered or endangered vertebrates in Mexico**

	Amphibians	Mammals	Birds	Reptiles
Total	372	466	1040	691
Endemic	246	143	93	399
Critically endangered	91	26	7	3
Endangered	84	37	16	36
Endemic critically endangered	81	26	4	1
Endemic endangered	72	30	8	33

**The figures in the table were calculated for the continental land, including major islands and excluding small islands of Mexico. These data contrast with the latest BirdLife-International (2019) report which included 64 new species for Mexico, with a total of 118 endemic species

III.3 Adaptive capacity

The areas with less adaptive capacity (high conservation risk index) are in the Central Volcanic Belt and the Central Altiplano, the South Pacific coast, the northwest area in the Sonoran Desert, and the Sierra Madre Oriental (Fig 1 and Fig. A.2 and A.3). These areas overlap with the most important cities of the country and the highest populated areas. Moreover, 56%, 70%, and 72% of the Mexican municipalities, accordingly to the optimistic, BAU and worst-case scenarios, show high critical risk index (≥90) and low adaptive capacity. These areas are mainly located in scrublands, temperate and tropical dry forests, suggesting a need to increase the protected areas in these ecosystems to prevent deforestation.

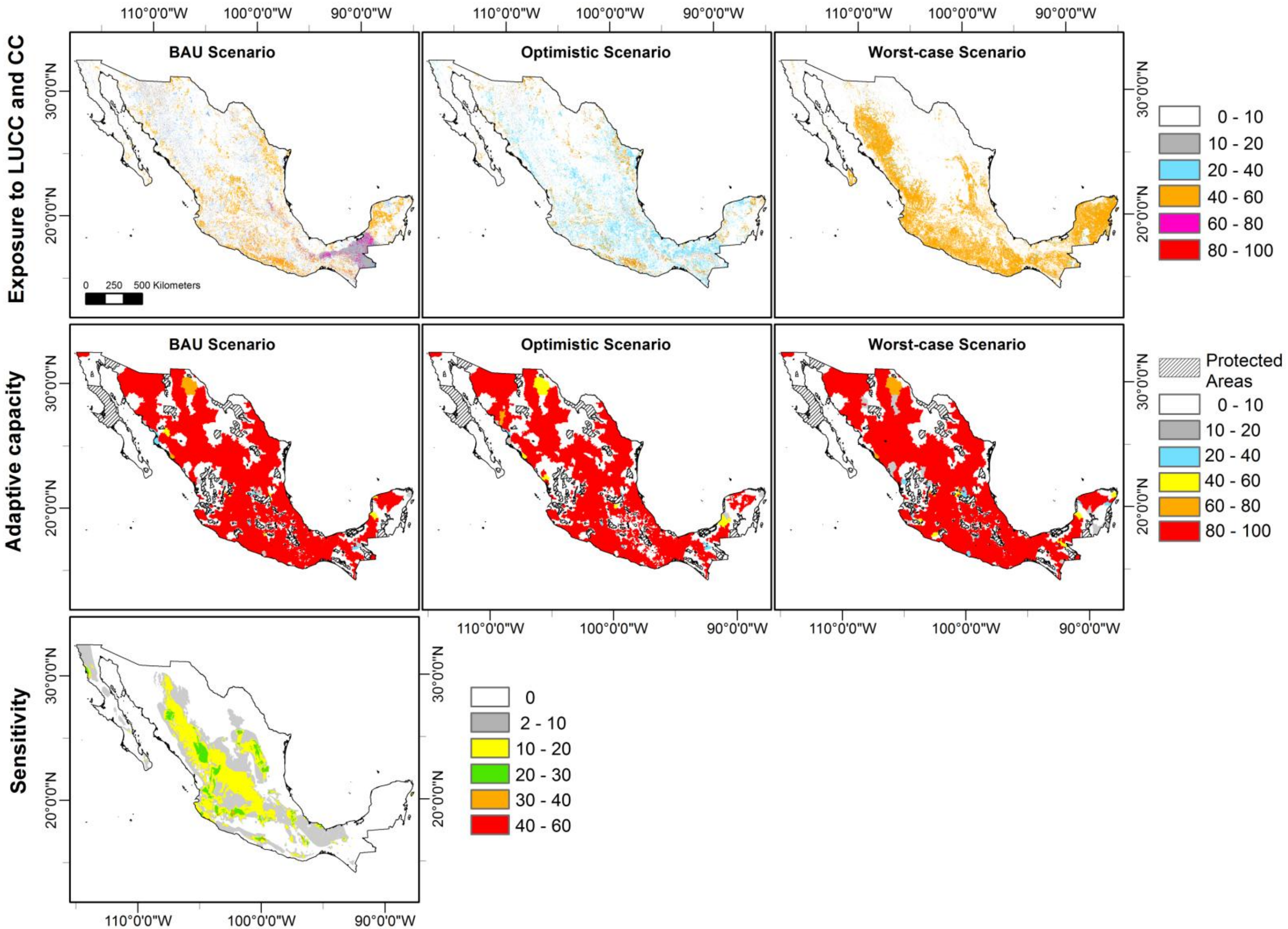

Fig 1. Exposure, adaptive capacity, and sensitivity by 2050 for the business-as-usual (BAU), optimistic and worst-case scenarios for Mexico. All the data are normalized between 0 and 100 (refer to methods). LUCC refers to land-use/cover-change and CC to climate change.

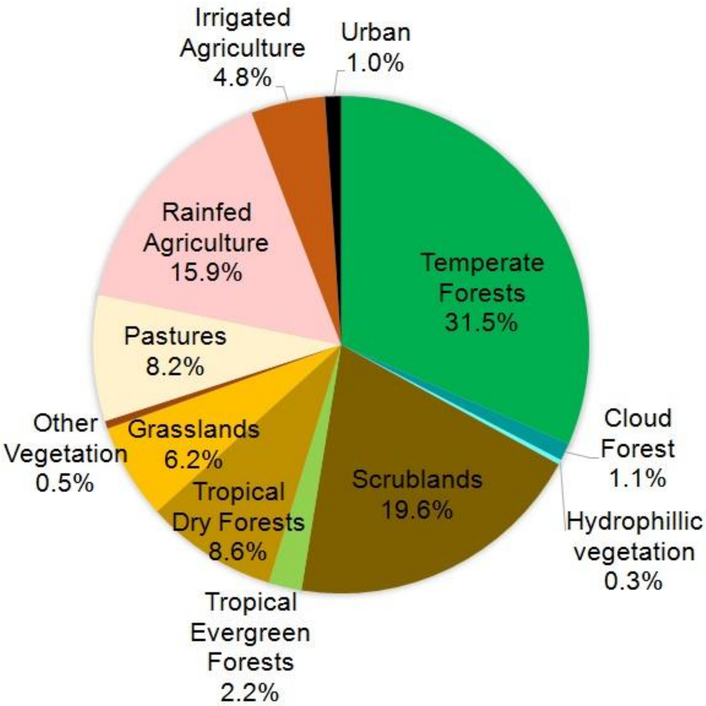

Fig 2. Endemic, critically endangered, and endangered species of vertebrates by land-use/cover in Mexico.

III.4 Vulnerability

The estimates of vulnerability range from very low (0) to high (80) and 42.6% of the country shows moderate to high vulnerability. By 2050, between 8.2%, 10.4% and 16.1% of Mexico shows a vulnerability index value ≥50, depending on which scenario is assumed (optimistic, BAU and worst-case). By 2070, these figures increase to 8.4%, 10.9% or 18.1% for each scenario respectively (Fig 3). There are 167 out of the 2,457 Mexican municipalities that reach the highest vulnerability scores (70) in the BAU scenario. In the worst-case scenario, the highest vulnerability value was 80 and four municipalities are in this category, while 452 score 70 in this index. Of those, seven municipalities represent 30.4% of the most vulnerable areas and 0.39% of the country's land. These municipalities are mainly in the state of Guerrero (Fig. A.1).

In Mexico, 3.5% and 6.7% of the pasture lands for cattle raising, and rainfed-agriculture match the most vulnerable areas for biodiversity conservation in the BAU scenario, while these figures increase to 5.4% and 8.9% in the worst-case scenario. From an ecosystem perspective, cloud forests, followed by tropical dry forests and natural grasslands are the most affected under the BAU and optimistic scenarios. Temperate forests are the most vulnerable ecosystems in the worst-case scenario, especially because of their high exposure to LUCC which can be reinforced with CC pressure. The most vulnerable portion of cloud forest is distributed along the Pacific Coast (states of Guerrero, Oaxaca, and Chiapas). The same pattern was found for the tropical dry forests and temperate forests in the states of Jalisco, Michoacán, Guerrero, and Oaxaca. In the case of natural grasslands, the most vulnerable areas are restricted to three regions (northeast of Jalisco, east of Durango and west of Zacatecas; Fig 3 and Fig. A.1).

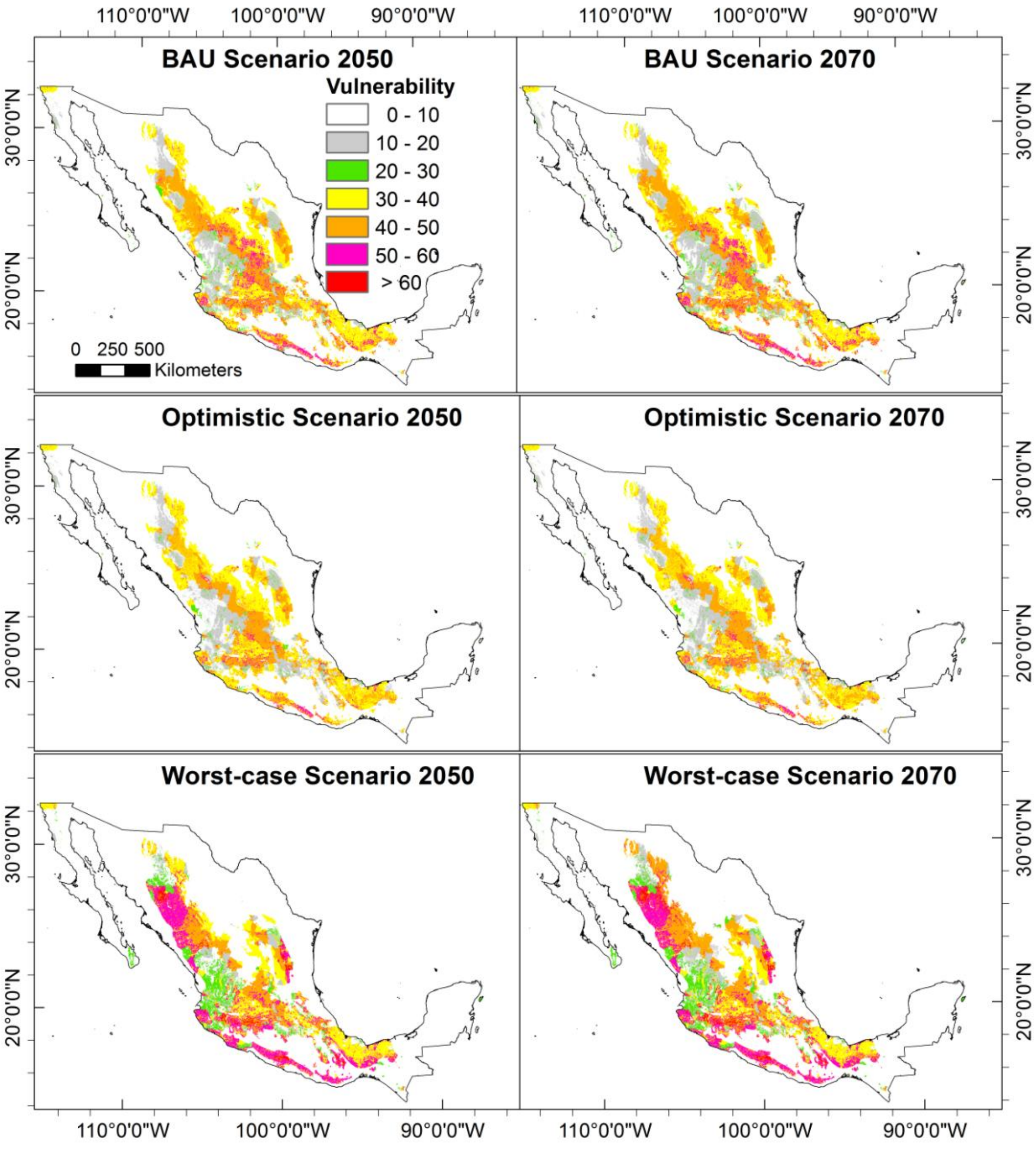

Fig 3. Vulnerability maps by 2050 and 2070 for the business-as-usual (BAU), optimistic and worst-case scenarios for Mexico.

IV. Discussion

Human activities, especially land-use/cover-change (LUCC), are causing a decline in global biodiversity (Newbold et al., 2015) which is reinforced by climate change (CC) (Oliver and

Morecroft, 2014). These processes increase the pressures of global, regional or local threats to the biodiversity. Therefore, it is necessary to develop innovative approximations to prioritize locations for biodiversity conservation (Brooks et al., 2006; Monsarrat et al., 2019) particularly under LUCC and CC scenarios to avoid the extinction of endemic species.

Our results show that under an optimistic scenario it is possible to experience a slight recovery of natural vegetation of 6.6% and 7.0% by 2050 and 2070 respectively. But to reach this goal there should be a combination of several factors that need to be reinforced, such as low or moderate population growth, which in turn is related to resources consumption (Riahi et al., 2017). In contrast, the BAU scenario shows a reduction of natural vegetation of 9.3% and 11.7% for the same time periods, mainly as a result of the agricultural expansion to satisfy the future national and international demands of crops and livestock. This highlights the importance of defining innovative local protection strategies to reduce the risk of species extinction. Moreover, it is relevant to promote management focused on a sustainable processes to improve agricultural practices to reduce the pressure on natural vegetation. Nevertheless, it is important to point out that future studies should evaluate not only the implications of agricultural intensification as an alternative, but also the inclusion of native varieties of crops and different management practices like agroforestry.

In recent years Mexico has expanded its protected areas in number and total area. However, they face important challenges to achieve effectiveness (Figueroa and Sánchez-Cordero, 2008; Watson et al., 2014). Mexico has 182 protected areas, of which 145 are terrestrial, representing 10.6% of the country. But more than half of these terrestrial protected areas are restricted to protect temperate forests and scrublands. While this may relate to the fact that Mexico is the country with the highest diversity of pines and oaks in the world (Rodríguez-Trejo and Myers, 2010), this does not reflect the real national needs for protection and/or conservation. Consequently, this study highlights the need to expand conservation practices towards other ecosystems that are underrepresented within the protected areas, such as tropical dry forests and natural grasslands, accounting for 8% and 5% respectively. Similar observations were previously made for Mexico and the globe (Linares-Palomino et al., 2011). Moreover, over different spatial scales it has been recognized that the Mexican tropical dry forest is at risk of high exposure to both LUCC (Corona et al., 2016; Mendoza-Ponce et al., 2018), and CC (Prieto-Torres et al., 2016). The same holds true for natural grasslands (Henwood, 2010; IUCN, 2014). However, none of the previous studies took into consideration the biodiversity of those ecosystems. Therefore, from an ecosystem perspective, there is a need to reinforce conservation management in three regions: 1) the south of the Mexican Pacific coast (tropical dry forests); (2) the Central Volcanic Belt (temperate forests); and (3) the natural grasslands bordering the eastern part of the Sierra Madre Occidental.

Exposure to LUCC and CC can be quantified in spatial and temporal dimensions. However, adaptive capacity and sensitivity are concepts that are challenging to characterize in an ecological context (Fortini and Schubert, 2017) and even more to be spatially explicit about. The adaptive capacity depends on ecosystems, communities, species, populations, individuals and genes (Hoffmann and Sgrò, 2011). At the ecosystem level, it has been shown that, in contrast to grasslands, forests and scrublands are influenced in terms of presence of species and by the size of the patches (Keinath et al., 2017). Moreover, at the species level, it is possible to find characteristics that allow high capacity, but at the same time, these traits confer a decrease in sensitivity (Williams et al., 2008). However, at the genetic level, fragmentation due to LUCC dynamics also affects evolutionary processes by modifying the flow of genes and reducing the introduction of novel genotypes into populations through hybridization (Hoffmann and Sgrò, 2011).

From a socio-ecological perspective, the ability to adapt to future challenges should include biophysical elements and different socioeconomic factors related to human decisions (Lindner et al., 2010). Consequently, finding indicators for assessing adaptive capacity based on socio-ecological traits is challenging, especially for large regions. In this context, the ratio between habitat conversion and habitat protection is a simple, helpful and informative metric of the adaptive capacity. This index assumes that areas where protection is higher than the anthropogenic conversion of land exert less pressure on the environment. However, there is the risk that these areas may be exporting their environmental pressures to other places (Lambin and Meyfroidt, 2011). In the Mexican context, almost half of the LUCC process is driven by the expansion of rainfed-agriculture, mainly related to internal consumption (Mendoza-Ponce et al., 2018). The adaptive capacity shows that more than 50% of Mexican municipalities have an ecological deficit, resulting in higher forest losses than are being protected. This suggests that most Mexican municipalities are challenged to protect their biodiversity with significant implications for potential species extinctions. Therefore, future land-management should take into consideration not only the protection of ecosystems, but also specific areas dominated by endemic and threatened species. And further studies should assess the potential effectiveness of conservation practices under different anthropogenic practices.

Sensitivity was conceptualized as a spatial characteristic that integrates endemicity and threat, on the basis that areas with more endemic and endangered species would be more affected by significant habitat loss and newer climate threats (Swab et al., 2012). However, assessing sensitivity as a spatial indicator cannot fully express the complexity of the ecological criteria, mainly due to the contrasting differences across the biological taxa (Williams et al., 2008). Species richness is an indicator to prioritize biodiversity conservation but it poses important challenges such as the large variability depending on the scale of analysis, taxonomic grouping, estimation methods, and the dynamic nature of species (Fleishman et al., 2006). Moreover, the specific traits of biological levels could perform differently under LUCC and CC (Brodie et al., 2012; Kara et al., 2017; Monsarrat et al., 2019; Paniw et al., 2019).

Finally, this study shows that there are clear limitations to the integration of spatial indicators for adaptive capacity and sensitivity for biodiversity assessment. However, until more data become available with a higher degree of detail, our results indicate that it is possible to prioritize areas for a feasible biodiversity conservation practice for the two most important threats. Moreover, the proposed framework is reproducible, transparent and flexible to adapt, and comparable across different ecosystems and regions.

V. Conclusions

This study proves that modelling is critical for biodiversity conservation by identifying future vulnerable areas and species in complex systems. The methodology presented here allows it to be replicable in other regions, which is fundamental for decision-making and land management. Moreover, (Q1) this study shows that the vulnerability and the irreplaceability framework is a useful alternative to identify areas to prioritize biodiversity conservation. This framework can be implemented over different spatial scales by the inclusion of direct threats to biodiversity and indirect drivers of change. Our study allows the reduction of global and national proposals of conservation for Mexico from 43% of the country to less than 19%. (Q2) Cloud forests and natural grasslands are highly vulnerable to land-use/cover-change and climate change in all periods, although temperate forests and tropical dry forests were shown to be strongly affected in some of the combinations of the historical periods. Besides, we highlight that seven municipalities out of the 2,456, represent 30.4% of the most vulnerable areas. This information can help prioritization of local monitoring actions of populations of threatened species. In this regard, we propose strategies to reduce the risk of extinction, such as: 1) defining new protected areas in regions that have critically endangered populations with small range distribution; 2) creation of biological corridors to allow genetic flow; 3) prioritization of the restoration of patches to ensure biodiversity conservation; 4) the design of studies and policies aiming at understanding and mitigation of local impacts of LUCC and CC; 5) preventing negative impacts of invasive species; and 6) the design of strategies for protecting the genetic variability of threatened populations.

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*BLINDED Revised Manuscript with NO changes marked (no author details)

Fig A.1. Mexican States. The numbers represent the location of physiographic and biogeographic regions.

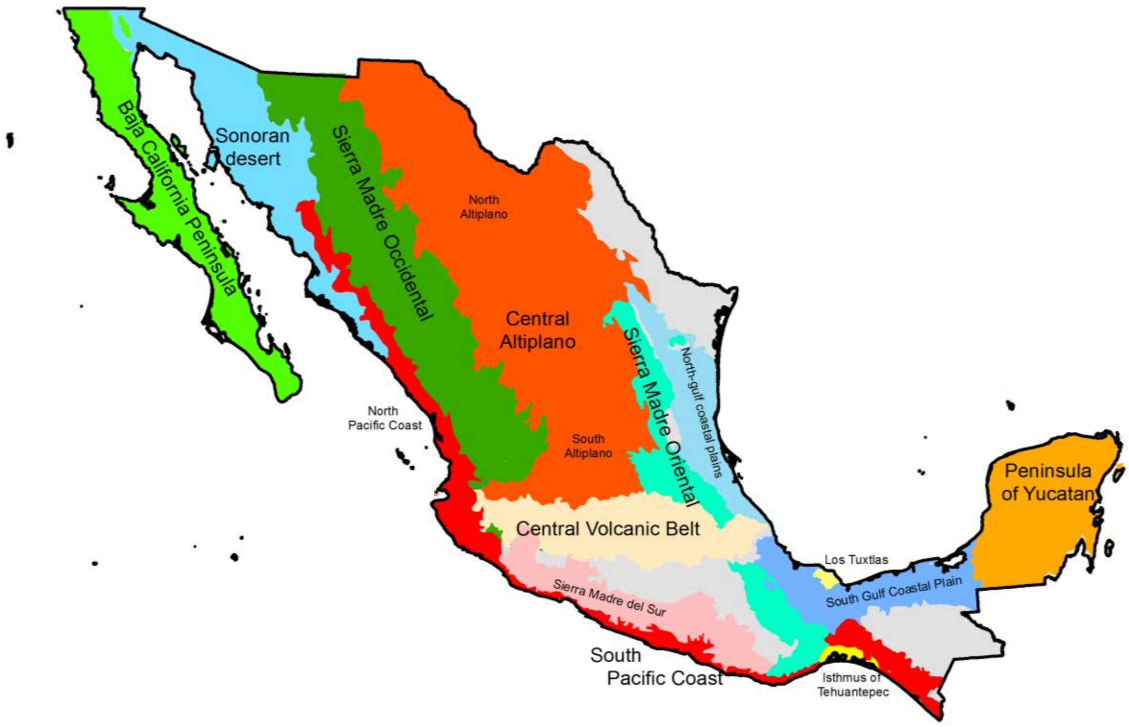

Fig A.2. Physiographic regions of Mexico reported in the manuscript.

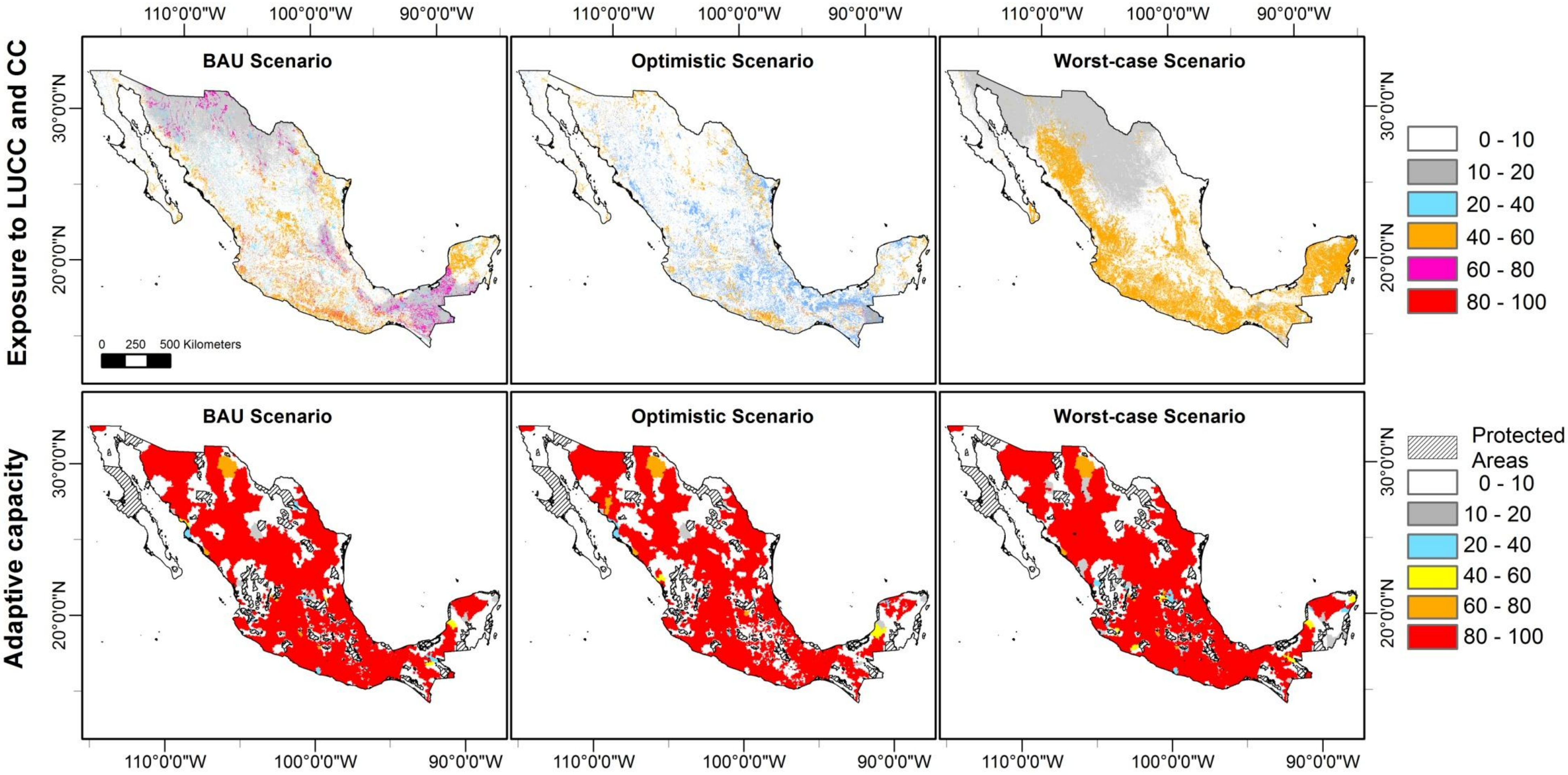

Fig. A.3. Exposure and adaptive capacity by 2070 for the business-as-usual (BAU), optimistic and worst-case scenarios for Mexico. All the data are normalized between 0 and 100 (see methods). LUCC refers to land-use/cover-change and CC to climate change.

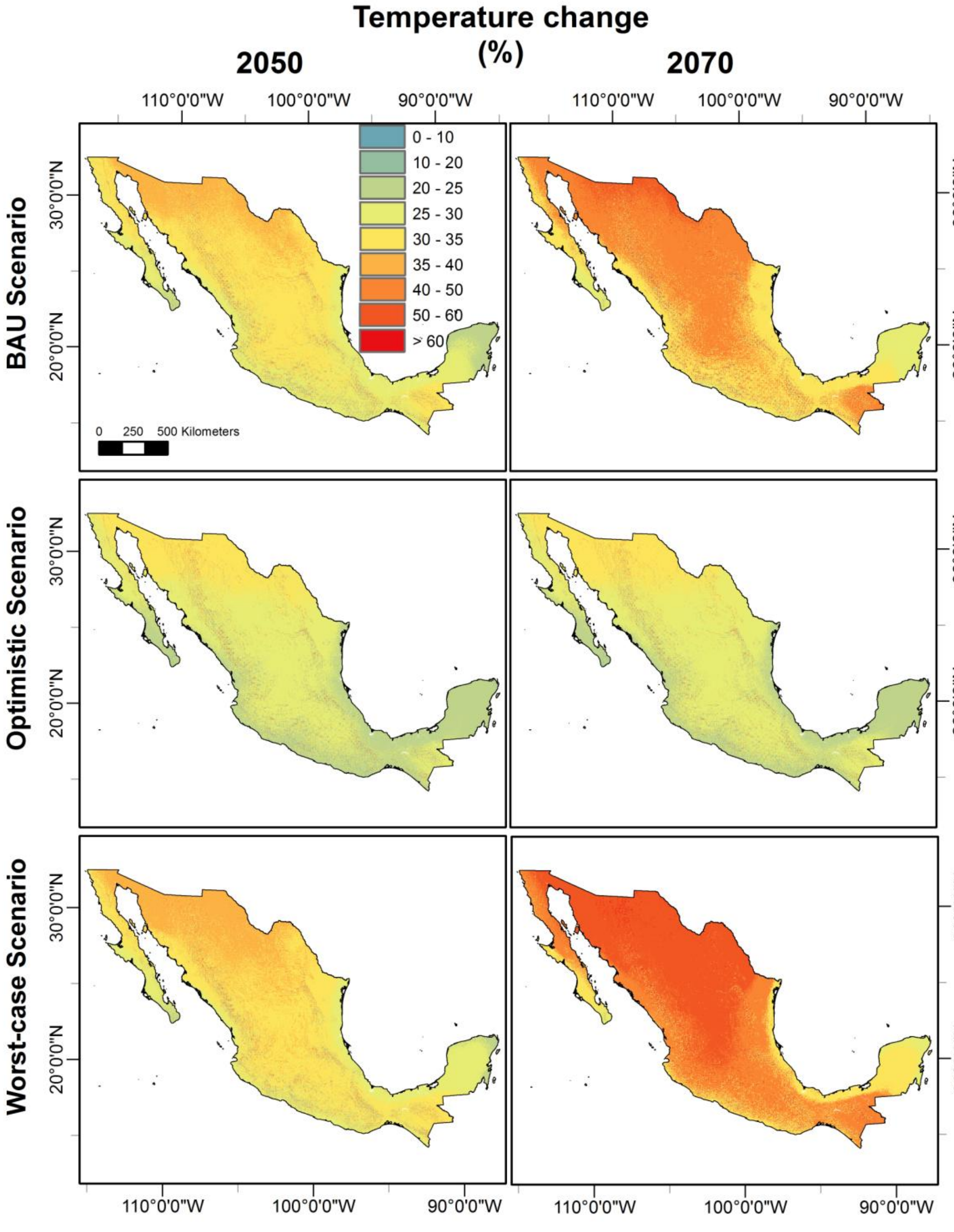

Fig. A.4. Change of mean annual temperature in percentage (%) for the 2050 and 2070 for the business-as-usual (BAU), optimistic and worst-case scenarios for Mexico.

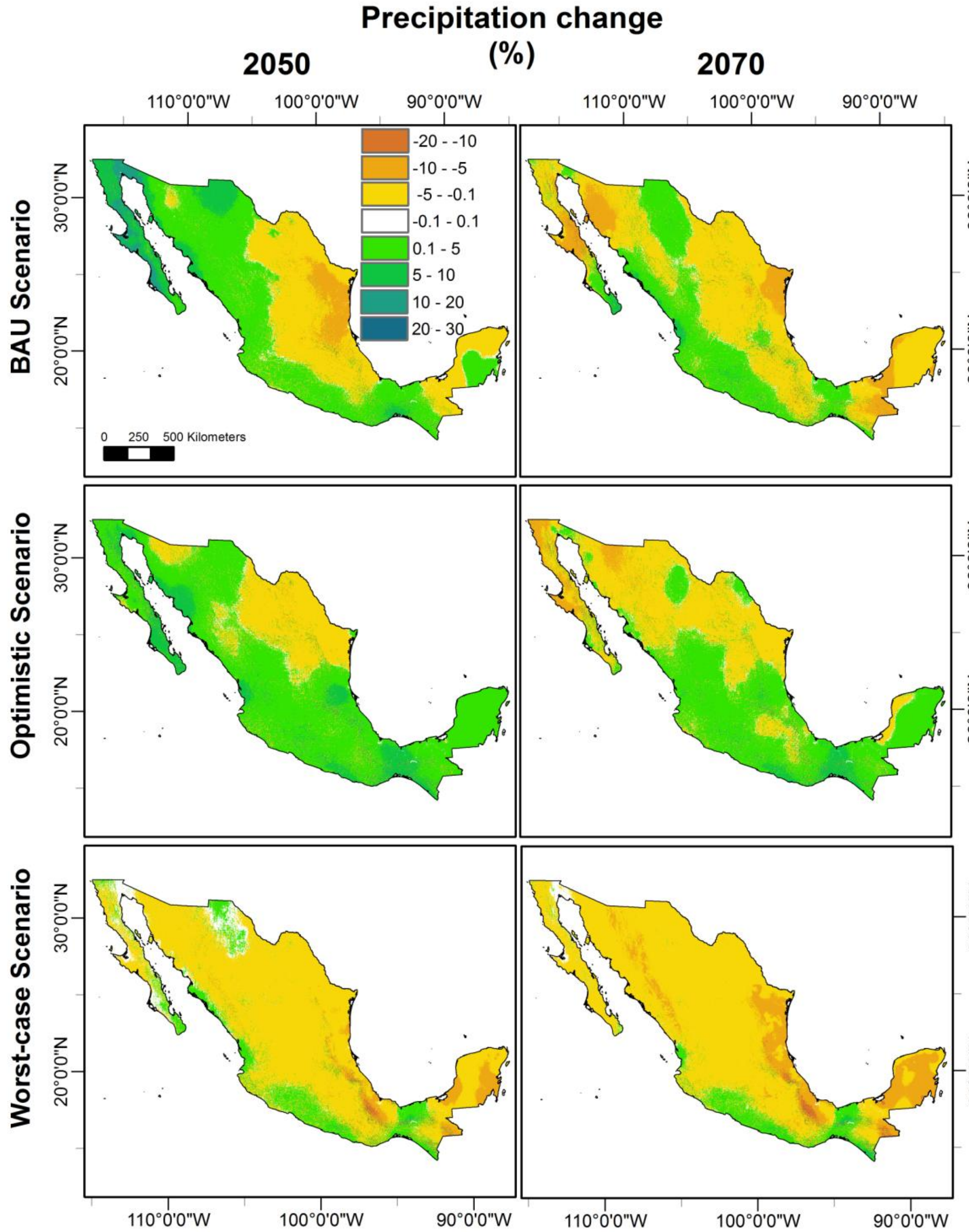

Fig. A.5. Change of annual precipitation in percentage (%) for the 2050 and 2070 for the business-as-usual (BAU), optimistic and worst-case scenarios for Mexico.

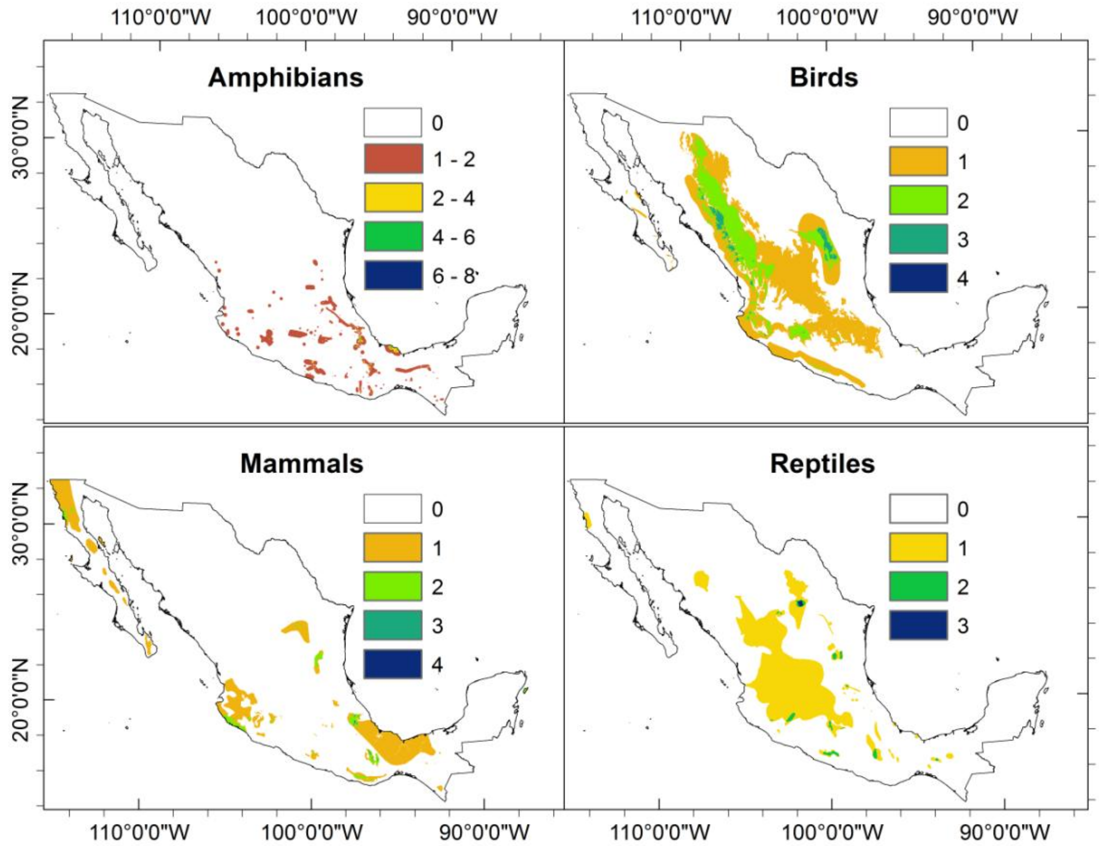

Fig. A.6. Number of species per vertebrate groups.

Table A.1. Explanatory variables used in the LUCC model.

Socioeconomic			Biophysical		
Variable and units	**Spatial resolution**	**Source**	**Variable and units**	**Spatial resolution**	**Source**
1. Population (number of people) 2. Population density (people km-^{2})	Municipality	(INEGI, 1980, 1985, 1990, 1995, 2000a, 2005, 2010a) (IIASA, 2016)	14. Digital Elevation Model (DEM) (masl)	60m	(INEGI, 2013)
3. GDP (billion US PP$2005 yr^{-1}) 4. GDP *per capita*	Municipality	(IIASA, 2016) (SNIM, 2005)	15. Slope (degrees)	60m	Derived from the DEM
5. Index of marginalization	Municipality	(CONAPO, 2010)	16. Distance to rivers (m)	1:**400,000**	(Maderey-R. and Torres-Ruata, 1990)
6. Volume of agricultural products (ton) 7. Volume of wood products (m^3) 8. Value of agricultural products (million Mexican pesos) 9. Value of wood products (million Mexican pesos)	Municipality	(INEGI, 2011)	17. Soil types	**1:250,000**	(INEGI, 2014a)
10. Distance to roads (m)	1:250,000	(SCT, 2008)	18. Annual Mean Temperature (BIO1) (^{o}C) 19. Temperature Seasonality (BIO4) (^{o}C) 20. Maximum Temperature of Warmest Month (BIO5) (^{o}C) 21. Temperature Annual Range (BIO7) (^{o}C) 22. Mean Temperature of Wettest Quarter (BIO8) (^{o}C) 23. Mean Temperature of Warmest Quarter (BIO10) (^{o}C) 24. Annual Precipitation (BIO12) (mm)	~1km^2	(Fick and Hijmans, 2017)
11. Distance to highways (m)	1:250,000	(INEGI, 2014b)			
12. Distance to localities and to urban areas (m)	1:250,000	(INEGI, 2000b, 2010b)			
13. Protected Areas and distance to PA (m)	1:50,000	(CONANP, 2015, 2016)			

Table A.2. Historical rates of change for Mexico.

T_0	T_1	A_0	A_1	Rates of change	
				$km^2\ yr^{-1}\ _{T0-T1}$	$\%\ yr^{-1}\ _{T0-T1}$
1985	1993	1,505,558	1,430,733	9,353	-0.64
1985	2002	1,505,558	1,401,709	6,109	-0.42
1985	2007	1,505,558	1,382,465	5,595	-0.39
1985	2011	1,505,558	1,374,869	5,026	-0.35
1993	2002	1,430,733	1,401,709	3,225	-0.23
**1993	2007	1,430,733	1,382,465	3,448	-0.24
1993	2011	1,430,733	1,374,869	3,104	-0.22
2002	2007	1,401,709	1,382,465	3,849	-0.28
2002	2011	1,401,709	1,374,869	2,982	-0.21
2007	2011	1,382,465	1,374,869	1,899	-0.14

T refers to the time step. ***A*** expresses the total area in km^2 for specific *T*. The rates of change are expressed in area and percentage on an annual basis for a specific time frame. **Highlights the selected period to model BAU scenario.

TableA.3. Annual rates of change *per* land use and land cover (% yr^{-1}). In colors are highlighted the lowest deforestation (gray) and the highest regeneration (green) rates. The optimistic scenario matrix was built from the lowest deforestation and highest regeneration rates. The worst-case scenario considers the highest rates of loss (orange) and the closest the mean of the regeneration rates (blue). There is no regeneration from irrigated agriculture nor urban covers. The national land use cover map from 2015 (INEGI)was used for validation.

	Temperate forests	Cloud forests	Hydrophilic	Scrublands	Tropical evergreen forests	Tropical dry forests	Natural grasslands	Other vegetation	Pasture	Rainfed agriculture
	Rates of vegetation loss								Rates of regeneration	
1985-1993	0.596	1.235	1.772	0.852	1.858	1.575	6.998	0.726	4.655	1.682
1985-2002	0.437	0.790	0.999	0.497	1.225	1.099	0.394	0.458	0.789	0.690
1985-2007	0.369	0.633	0.797	0.446	1.078	0.982	0.390	0.439	0.671	0.540
1985-2011	0.330	0.561	0.691	0.401	0.928	0.906	0.352	0.368	0.512	0.477
1993-2002	0.356	0.566	0.621	0.211	1.047	0.766	5.329	0.320	4.236	0.426
1993-2007	0.368	0.513	0.631	0.267	1.017	0.892	3.365	0.409	2.814	0.609
1993-2011	0.309	0.419	0.522	0.243	0.834	0.810	2.633	0.316	2.200	0.510
2002-2007	0.553	0.544	0.822	0.406	1.338	1.441	0.924	0.670	1.552	1.311
2002-2011	0.361	0.368	0.572	0.307	0.923	1.068	0.626	0.381	1.047	0.843
2007-2011	1.388	1.889	2.348	1.089	3.753	3.602	11.796	1.417	9.965	2.314

Table A.4. List of endemic and critically endangered or endangered terrestrial vertebrates in México.

Count	Amphibians	Birds	Mammals	Reptiles
1	*Ambystoma flavipiperatum*	*Xenospiza baileyi*	*Geomys tropicalis*	*Barisia herrerae*
2	*Craugastor omiltemanus*	*Zentrygon carrikeri*	*Habromys chinanteco*	*Barisia rudicollis*
3	*Craugastor polymniae*	*Campephilus imperialis*	*Habromys delicatulus*	*Chersodromus rubriventris*
4	*Craugastor pozo*	*Geothlypis beldingi*	*Habromys ixtlani*	*Crotalus pusillus*
5	*Ambystoma granulosum*	*Geothlypis speciosa*	*Habromys lepturus*	*Abronia chiszari*
6	*Craugastor silvicola*	*Amazona finschi*	*Habromys schmidlyi*	*Crotaphytus antiquus*
7	*Craugastor spatulatus*	*Hydrobates macrodactylus*	*Habromys simulatus*	*Ficimia hardyi*
8	*Craugastor uno*	*Lophornis brachylophus*	*Dipodomys gravipes*	*Gerrhonotus parvus*
9	*Craugastor vulcani*	*Rhynchopsitta pachyrhyncha*	*Lepus flavigularis*	*Abronia deppii*
10	*Cryptotriton alvarezdeltoroi*	*Rhynchopsitta terrisi*	*Megadontomys cryophilus*	*Lepidophyma lipetzi*
11	*Ambystoma leorae*	*Spizella wortheni*	*Megadontomys nelsoni*	*Anniella geronimensis*
12	*Duellmanohyla chamulae*	*Toxostoma guttatum*	*Megadontomys thomasi*	*Mesaspis juarezi*
13	*Ambystoma lermaense*		*Microtus oaxacensis*	*Mixcoatlus barbouri*
14	*Duellmanohyla ignicolor*		*Microtus umbrosus*	*Mixcoatlus melanurus*
15	*Ecnomiohyla echinata*		*Myotis peninsularis*	*Ophisaurus ceroni*
16	*Ecnomiohyla valancifer*		*Myotis planiceps*	*Abronia fuscolabialis*
17	*Eleutherodactylus dennisi*		*Nelsonia goldmani*	*Anolis breedlovei*
18	*Eleutherodactylus dilatus*		*Neotoma angustapalata*	*Rhadinaea marcellae*
19	*Eleutherodactylus dixoni*		*Neotoma bryanti*	*Rhadinaea montana*
20	*Eleutherodactylus grandis*		*Neotoma nelsoni*	*Abronia graminea*
21	*Ambystoma mexicanum*		*Orthogeomys lanius*	*Sceloporus chaneyi*
22	*Eleutherodactylus rufescens*		*Otospermophilus beecheyi*	*Sceloporus cyanostictus*
23	*Eleutherodactylus saxatilis*		*Pappogeomys bulleri*	*Sceloporus exsul*
24	*Eleutherodactylus syristes*		*Peromyscus bullatus*	*Anolis hobartsmithi*
25	*Ambystoma ordinarium*		*Peromyscus caniceps*	*Tantilla flavilineata*
26	*Exerodonta chimalapa*		*Peromyscus guardia*	*Tantilla shawi*

27	*Incilius cavifrons*	*Peromyscus interparietalis*	*Anolis pygmaeus*
28	*Incilius cristatus*	*Peromyscus mekisturus*	*Thamnophis melanogaster*
29	*Incilius gemmifer*	*Peromyscus melanocarpus*	*Thamnophis mendax*
30	*Incilius perplexus*	*Peromyscus melanurus*	*Trachemys taylori*
31	*Ambystoma taylori*	*Peromyscus ochraventer*	*Uma exsul*
32	*Incilius spiculatus*	*Peromyscus pseudocrinitus*	*Xenosaurus newmanorum*
33	*Isthmura gigantea*	*Peromyscus sejugis*	*Xenosaurus platyceps*
34	*Isthmura maxima*	*Peromyscus stephani*	*Abronia martindelcampoi*
35	*Isthmura naucampatepetl*	*Peromyscus winkelmanni*	
36	*Ixalotriton niger*	*Procyon pygmaeus*	
37	*Ixalotriton parvus*	*Reithrodontomys bakeri*	
38	*Lithobates chichicuahutla*	*Reithrodontomys spectabilis*	
39	*Lithobates dunni*	*Rheomys mexicanus*	
40	*Lithobates johni*	*Rhogeessa genowaysi*	
41	*Lithobates omiltemanus*	*Romerolagus diazi*	
42	*Lithobates pueblae*	*Sigmodon planifrons*	
43	*Lithobates tlaloci*	*Sorex sclateri*	
44	*Megastomatohyla mixe*	*Sorex stizodon*	
45	*Megastomatohyla mixomaculata*	*Sylvilagus insonus*	
46	*Megastomatohyla nubicola*	*Sylvilagus mansuetus*	
47	*Megastomatohyla pellita*	*Tamiasciurus mearnsi*	
48	*Parvimolge townsendi*	*Tylomys bullaris*	
49	*Plectrohyla arborescandens*	*Tylomys tumbalensis*	
50	*Plectrohyla calthula*	*Xenomys nelsoni*	
51	*Plectrohyla calvicollina*	*Xerospermophilus perotensis*	
52	*Plectrohyla celata*	*Zygogeomys trichopus*	
53	*Plectrohyla cembra*	*Heteromys spectabilis*	
54	*Plectrohyla charadricola*	*Cryptotis nelsoni*	

55	*Plectrohyla chryses*	*Cynomys mexicanus*
56	*Plectrohyla crassa*	*Dasyprocta mexicana*
57	*Plectrohyla cyanomma*	
58	*Plectrohyla cyclada*	
59	*Plectrohyla ephemera*	
60	*Plectrohyla hazelae*	
61	*Plectrohyla lacertosa*	
62	*Plectrohyla mykter*	
63	*Plectrohyla pachyderma*	
64	*Plectrohyla pentheter*	
65	*Plectrohyla psarosema*	
66	*Plectrohyla pycnochila*	
67	*Plectrohyla robertsorum*	
68	*Plectrohyla sabrina*	
69	*Plectrohyla siopela*	
70	*Plectrohyla thorectes*	
71	*Pseudoeurycea ahuitzotl*	
72	*Pseudoeurycea altamontana*	
73	*Pseudoeurycea anitae*	
74	*Pseudoeurycea aquatica*	
75	*Pseudoeurycea aurantia*	
76	*Pseudoeurycea conanti*	
77	*Pseudoeurycea firscheini*	
78	*Pseudoeurycea goebeli*	
79	*Pseudoeurycea juarezi*	
80	*Pseudoeurycea lineola*	
81	*Pseudoeurycea longicauda*	
82	*Pseudoeurycea lynchi*	
83	*Pseudoeurycea melanomolga*	

84 *Pseudoeurycea mystax*
85 *Pseudoeurycea nigromaculata*
86 *Pseudoeurycea obesa*
87 *Pseudoeurycea orchileucos*
88 *Pseudoeurycea orchimelas*
89 *Pseudoeurycea papenfussi*
90 *Pseudoeurycea robertsi*
91 *Pseudoeurycea ruficauda*
92 *Pseudoeurycea saltator*
93 *Pseudoeurycea smithi*
94 *Pseudoeurycea tenchalli*
95 *Pseudoeurycea teotepec*
96 *Pseudoeurycea tlahcuiloh*
97 *Pseudoeurycea tlilicxitl*
98 *Pseudoeurycea unguidentis*
99 *Pseudoeurycea werleri*
100 *Ptychohyla erythromma*
101 *Ptychohyla leonhardschultzei*
102 *Smilisca dentata*
103 *Thorius adelos*
104 *Thorius arboreus*
105 *Thorius aureus*
106 *Thorius boreas*
107 *Thorius dubitus*
108 *Thorius grandis*
109 *Thorius infernalis*
110 *Thorius insperatus*
111 *Thorius lunaris*
112 *Thorius magnipes*

113 *Thorius minutissimus*
114 *Thorius minydemus*
115 *Thorius munificus*
116 *Thorius narismagnus*
117 *Thorius narisovalis*
118 *Thorius omiltemi*
119 *Thorius papaloae*
120 *Thorius pennatulus*
121 *Thorius pulmonaris*
122 *Thorius schmidti*
123 *Thorius smithi*
124 *Thorius spilogaster*
125 *Thorius troglodytes*
126 *Aquiloeurycea praecellens*
127 *Aquiloeurycea quetzalanensis*
128 *Ambystoma altamirani*
129 *Bolitoglossa riletti*
130 *Ambystoma amblycephalum*
131 *Bolitoglossa veracrucis*
132 *Bolitoglossa zapoteca*
133 *Bromeliohyla dendroscarta*
134 *Charadrahyla altipotens*
135 *Charadrahyla chaneque*
136 *Charadrahyla trux*
137 *Ambystoma andersoni*
138 *Chiropterotriton arboreus*
139 *Chiropterotriton chiropterus*
140 *Chiropterotriton chondrostega*
141 *Chiropterotriton cracens*

142 *Chiropterotriton dimidiatus*
143 *Chiropterotriton lavae*
144 *Chiropterotriton magnipes*
145 *Chiropterotriton mosaueri*
146 *Chiropterotriton multidentatus*
147 *Ambystoma bombypellum*
148 *Chiropterotriton terrestris*
149 *Craugastor glaucus*
150 *Ambystoma dumerilii*
151 *Craugastor guerreroensis*
152 *Craugastor hobartsmithi*
153 *Craugastor megalotympanum*
154 *Craugastor montanus*

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Figure1

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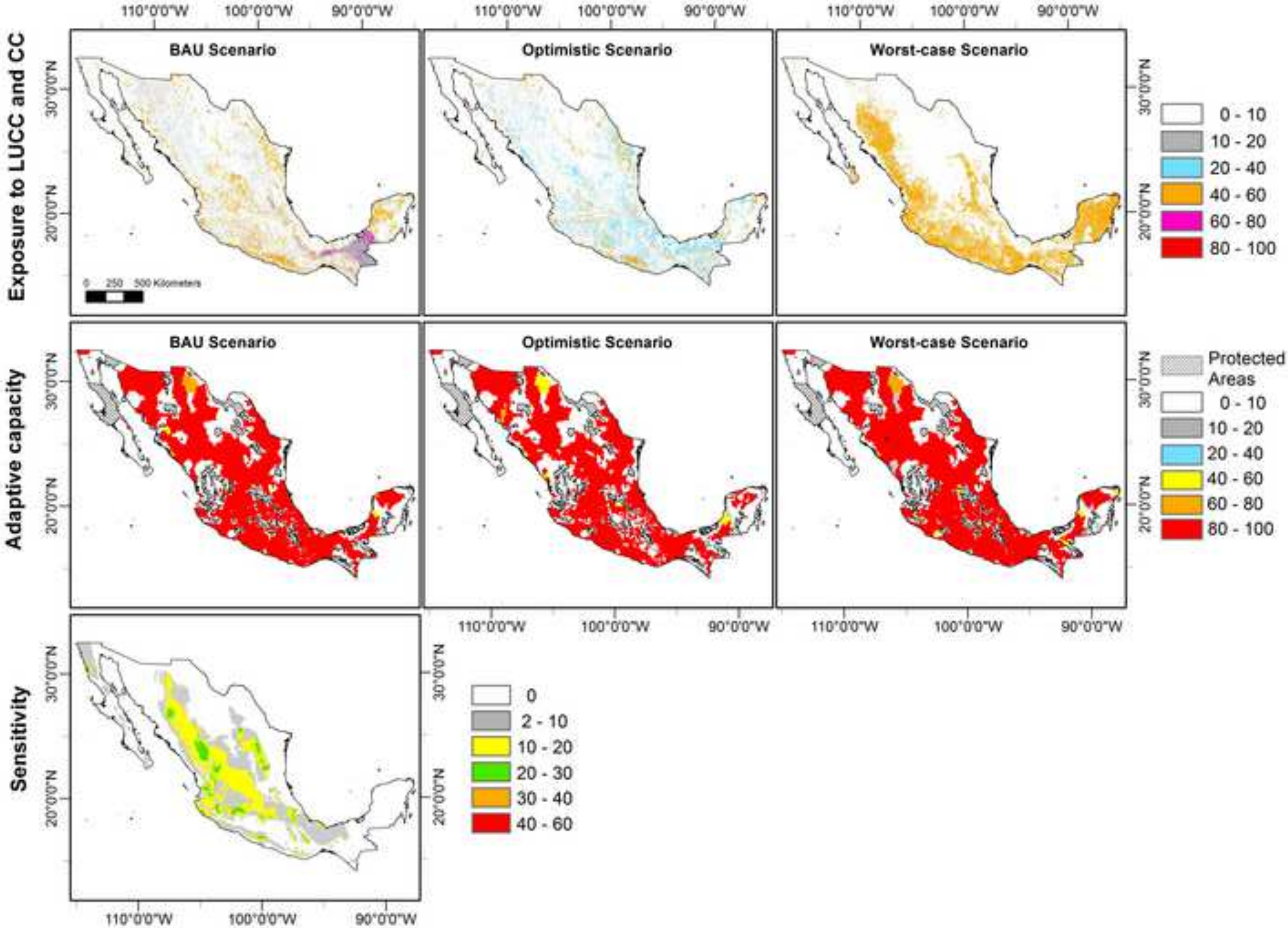

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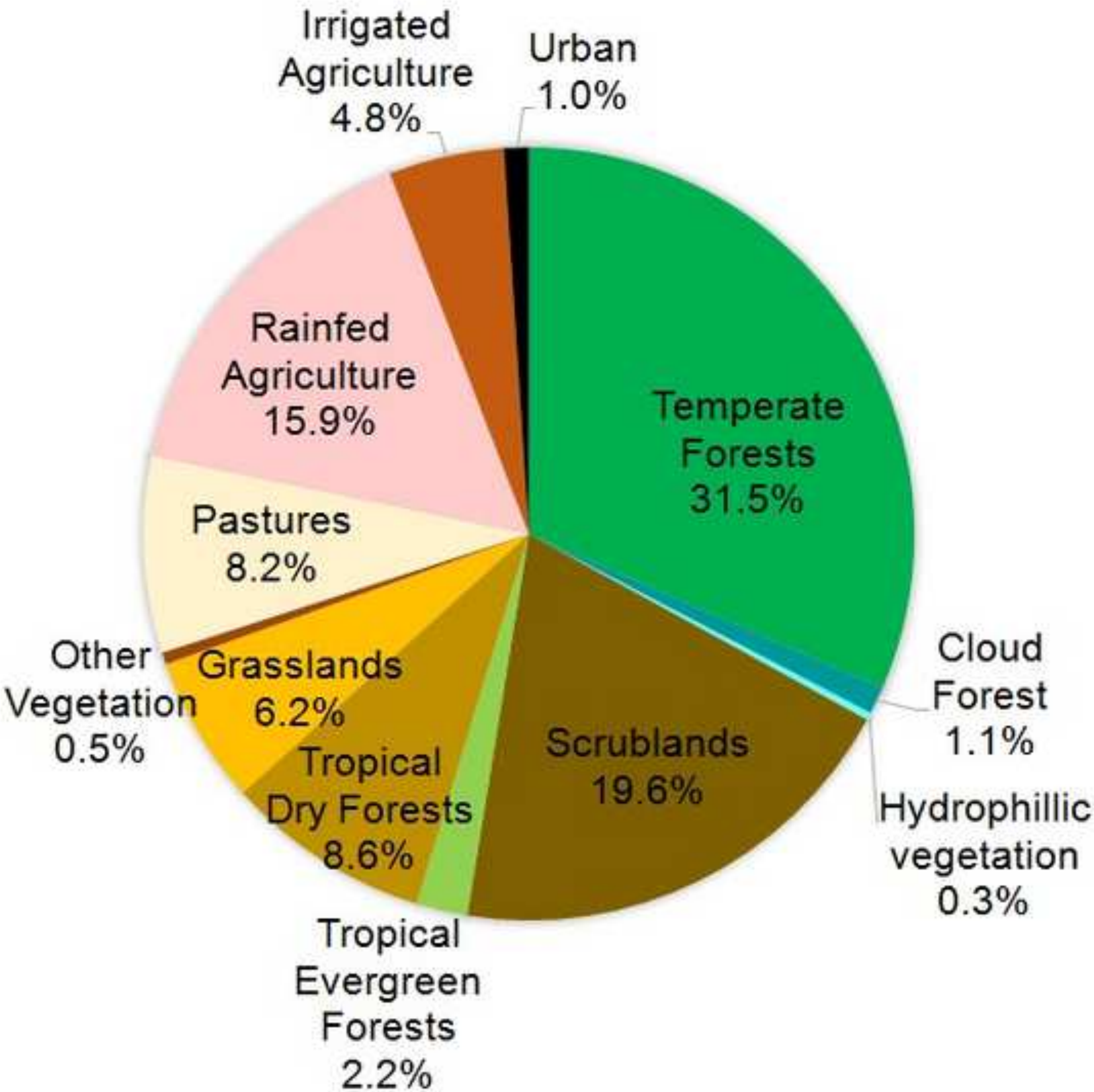

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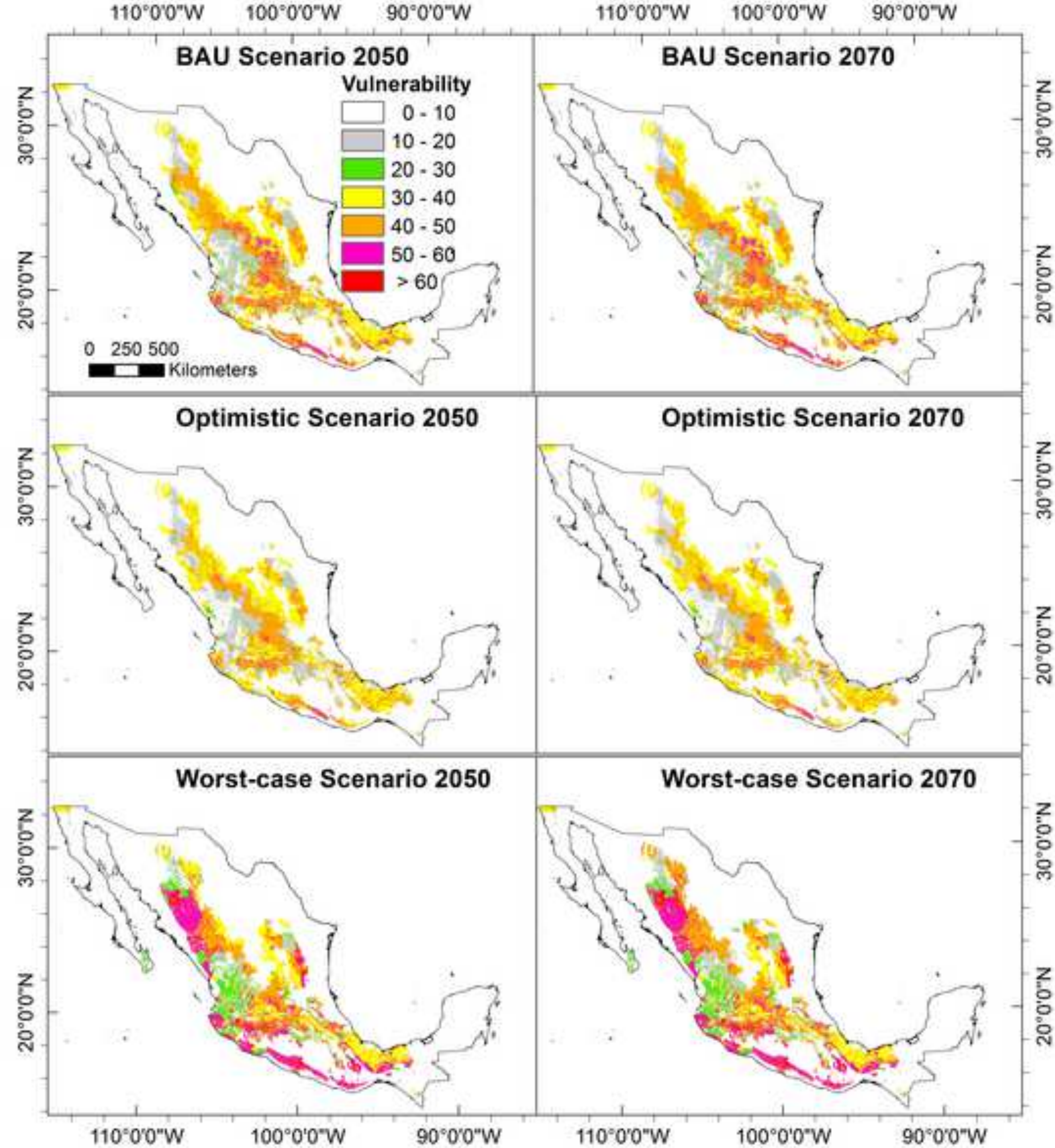

Highlights (for review)

- Global and national biodiversity studies suggest the need to preserve 45% of Mexico
- By 2050, 11.6%-16.1% of Mexico is vulnerable to LUCC and CC
- 30% of the most vulnerable areas are within 7 municipalities, 0.39% of Mexico