Validation and diffusion of the GLOBIO methodology in the Andean region

Authors
(in alphabetic order)

Carlos Alberto Arnillas[1]

Gustavo Galindo[2]

Manuel Peralvo[3, 4]

Carolina Tovar[1]

[1] Centro de Datos para la Conservación – Universidad Nacional Agraria La Molina, Perú

[2] Instituto Alexander von Humboldt, Colombia

[3] Fundación Ecociencia, Ecuador

[4] Seearth Consulting Group, Ecuador

September 2008

Table of contents

List of tables

List of figures

1 Introduction

Human activities have generated a gradual process of environmental degradation that lead to a global loss of biodiversity at a rate without precedents in recent history (Pimm *et al*. 1995). The loss of species is one of the most important manifestations of this degradation, and can be due to several causes. One of the main causes is the change of natural areas into land use, because it implies important transformations in the composition and structures of ecosystems (Liverman *et al*. 2004). Even when sectors are conserved in their natural state, wild populations inhabiting them could decrease due to isolation from other natural areas. In this way, the fragmentation process can lead to local extinctions, the smaller the area, the higher the risk (Hanski 1998).

Another biodiversity threat is the introduction of non native species. Generally this introduction has human purposes such as new agricultural production, plague control, among others. In other cases invasive species can arrive to a new place due to the access facilitation. Most of the time, changes in environmental conditions due to human activities, are responsible for these invasions. Invasive species may survive or not in the new site, but in case they survive, they even can be more successful than the local species, and eventually may even replace them.

Land use change and introduction of non native species are ways of affecting biodiversity but the extraction of resources is also an important topic. The most important forms of extraction are hunting, fishing, harvesting, and selective forest logging. These activities are often related to the expansion of road infrastructure, which facilitates the accessibility to local, regional and global markets of previously isolated areas.

Finally the processes associated to the global climate change are generating different impacts in biomes around the planet. These changes can be measured now as extreme, averages and seasonal variation of temperature as well as changes in precipitation, humidity, wind, among others. But these changes also influence existing climatic conditions in different ecosystems and are likely to modify the survival capacity of their original populations (APCI *et al.* 2008).

Evidently the causes of these changes are multiple and interactions between them exist. For instance, agriculture expansion responds to immediate causes (i. e. production dynamics such as increase in demand due to population growth) and/or underlying processes (technology, market access, institutional factors, consumption preferences) (Geist & Lambin 2002). In this context, it is necessary to have planning tools that allow synthesizing the effect of these processes on the remnant biodiversity for a given area. Similarly, it is also necessary to generate long term information and future possible trends for each process affecting biodiversity. Current and future assessment of biodiversity state would allow adopting proactive mitigation strategies, preventing impacts of factors that cause environmental degradation. Additionally, with this information it would be possible to minimize the environmental costs and to maximize the economic and social benefits of the strategies and policies applied.

Different methodological proposals have been developed to assess biodiversity state through systematic and relevant decision-making processes. For example, some proposals integrate indicators associated with human activities to estimate potential impact on natural ecosystems. In this sense, Sanderson *et al.* (2002) used spatially explicit data on population density, conversion of natural ecosystems, accessibility and infrastructure to generate an estimation of human footprint on a global scale. Similarly, Sala *et al*. (2000) identified land use, climate change, nitrogen deposition, establishment of alien species and the increase in atmospheric CO_2 as the main factors affecting biodiversity. Based on experts' opinion, these authors estimated potential impact of these factors on the biodiversity of different biomes for the year 2100. Other different approaches have used time series for monitoring populations. The aim was to estimate biodiversity state of different biomes (e.g. Loh *et al.* 2005), or conservation status of forest ecosystems using fragmentation indicators, patch size, edge length, among others (e.g. Kapos *et al*. 2000).

The present study describes the implementation of an alternative index developed by the Netherlands Environmental Assessment Agency (PBL, before MNP), together with UNEP-WCMC, UNEP-GRID-Arendal. This index estimates both, remaining biodiversity and contribution of different pressure factors to biodiversity loss. The developing of the index responds to the necessity of evaluating the overall objectives set by the Convention on Biological Diversity (CBD). This methodology is known as GLOBIO 3 and its development is centered around a major review of the literature published on the impact of various pressure factors (e.g. land use) on biodiversity, and the merger of GLOBIO 2 and the Natural Capital Index (Alkemade *et al*. 2006).

One of the interesting aspects of the proposed methodology is that it uses socio-environmental information. MSA (Mean Species Abundance) is a simple indicator of GLOBIO 3 that reflects the remaining biodiversity after human pressures. GLOBIO 3 considers five major pressure factors: land use change, fragmentation of natural ecosystems, road access, atmospheric nitrogen deposition and climate change. As mentioned before, it is possible to calculate the contribution of each factor to biodiversity loss. Given that MSA is an estimation of remaining biodiversity, it is independent of existing ecosystems. This turns it into a particularly useful indicator in ecologically diverse areas, such as those seen in the Andean countries. GLOBIO 3 was initially developed to work at 0.5 degrees resolution (approximately 50 km near the Ecuador). In the mean time GLOBIO 3 has improved the level of analysis for the MSA and it can be implemented at national scale, improving the resolution to 1 km (pixel size).

Part of the basic input of GLOBIO 3 is a land use map of the area of interest. In order to generate future scenarios of biodiversity state, GLOBIO 3 requires a “possible future” land use map. In order to build this future land use map it is necessary to use predictive tools to estimate the magnitude and spatial distribution of land use change. For the present study we used CLUE (Conversion of Land Use and its Effects; Verburg *et al*. 2002; Verburg & Veldkamp 2004), a modeling platform to determine the spatial distribution of the most likely future land uses in a study area. This tool uses series of predictions about the surface that will be required for each land use for a period of time. Afterwards CLUE makes a spatial allocation of this demand based on the most suitable areas for each land use class. The GLOBIO-CLUE methodological framework enables biodiversity assessment of current and future biodiversity state on a national scale. The impact of different policy options can be calculated for each selected scenario. For instance the impact of increasing agriculture in the next 10 years at a specific rate, the promotion of livestock through subsidies or the construction of a new road, are some of the possible scenarios that can be modeled. In this way, these tools could make politicians aware of the implications of their future decisions and how those impacts will be spatially distributed. This spatial component, crucial in mountain countries, is usually not included in the considerations and models used to assess the impact of projects.

This methodology is being applied in Southeast Asia as part of a Strategic Environmental Assessment (SEA). In this example the impact of the development of a large highway project in the Greater Mekong Subregion that connects the Chinese city of Kunming to Hanoi, Vietnam, crossing Laos, Thailand and Myanmar is investigated for its socio-economical benefits and environmental consequences. It is expected that this project will not only reduce highway connection time between two cities, but it will become a hub of economic development, as it goes through some of the poorest areas of the region. But at the same time, there is awareness that environmental impacts must be minimized to ensure the economic and social development in the region. That is why a strategic environmental assessment in that region is being implemented.

As well as in Southeast Asia, this approach has been implemented in several countries in the world to assess the potential impacts of different policy and global, regional and national scenarios. One of the major global applications of the methodology is for the Global Biodiversity Outlook 2 (Secretariat of the Convention on Biological Diversity 2006), which used the GLOBIO to assess the impact on biodiversity of different scenarios of economic development. At regional scale the methodology is among others used for EURURALIS 2.0 (Verburg *et al*. 2006), which used CLUE along with IMAGE and other models to identify possible changes in the rural sector in Europe.

This study is part of an initiative of the Netherlands Environmental Assessment Agency (PBL-MNP) that seeks to disseminate and validate the methodology GLOBIO as a planning tool at national level in various countries of the world. In South America, the methodology was applied in Colombia, Ecuador and Peru, as part of cooperation between institutions in each country. The deployment was carried out by the Instituto Alexander von Humboldt in Colombia, Fundación Ecociencia in Ecuador and the Centro de Datos para la Conservación from the Universidad Nacional Agraria La Molina, Peru. The inter-agency coordination has been under the International Biodiversity Project PBL-MNP.

In this context, the main objectives of the project are:

1. To assess biodiversity state at national and local level using the GLOBIO–CLUE methodology for the years 2000 and 2030 in Colombia, Ecuador, Peru and Venezuela.
2. To evaluate the GLOBIO-CLUE methodology as a tool to support planning processes that involve biodiversity conservation at national and local scales,
3. Disseminate the implementation and potential applications of the methodology to scientists and decision makers in the Andean countries.

The aims are: a) to promote both an analysis and discussion of the methodological advantages and disadvantages as well as conceptual issues associated with the methodology; and b) demonstrate the use of this methodology in planning processes at national and local scales.

One of the first steps during the implementation of the project was the inclusion of two partners to support the land use change studies in Venezuela and Bolivia. With these two countries, most part of the Northern and central Andes is covered by the study area. We contacted Fundacion Amigos de la Naturaleza in Bolivia and the Instituto de Ciencias Ambientales y Ecológicas at the University of Merida, Venezuela. We trained people in both institutes and currently they are completing the development of their own national study cases.

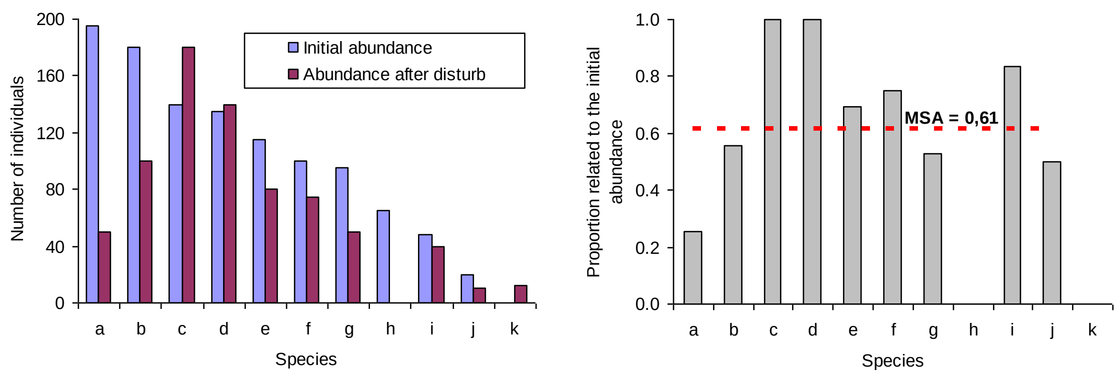
We presented the results of this first approximation to scientists of Peru and Ecuador, gathering important information for improving the model. Assistants to the workshop showed interest in this methodology and highlighted the importance of this tool for planning and management of future decisions. These case studies constitute the first step of the regional (South America) integration process for analyzing biodiversity and for offering more efficient tools to policy makers.

2 Methodological Framework

2.1 Estimating the state of biodiversity: GLOBIO 3

GLOBIO 3 uses the average abundance of species in a given area as an indicator for measuring biodiversity. This indicator is known as MSA (Mean Species Abundance). The fundamental assumption is that natural values of species abundance will be affected by human activities.. Figure 1a illustrates a hypothetical example of the original species abundance of 11 species, as well as the abundance after a disturbance or the introduction of some source of stress for the system. From this information, the percentage that represents the new abundance with respect to the original can be calculated, as shown in Figure 1b.

a. b.



In figure **a**, hypothetical data for a field study is shown to compare a sector with and without environmental impact or disturbance. The contribution of each species to the MSA is shown in figure **b**. To calculate the contribution of each specie the abundance is divided by the original abundance after the disturbance, without including the species that were not in the study area before the disturbance (in this case specie k). If in any specie the value proves to be greater than 1 (species c and d), the contribution is limited to 1 (this controls the effect of species that increase their abundance after the disturbance). The MSA is calculated by averaging the contributions of each species. (Adapted from Alkemade *et al.* 2006)

Figure 1 Hypothetical example of the MSA calculation, depending on the species abundance in an area

In Figure 1b the average of the ratio of all species is 0.61, a value that represents the average remaining abundance. Without impact, the average abundance would be 1, while values close to 0 indicate a noticeable decrease in abundance of some species and even disappearance of some of them. MSA only considers native species, new species after disturbance are not incorporated in the calculations. Furthermore, if the abundance of some species increases, the effect of the disturbance, it is assigned a ratio of 1.

2.2 Factors that affect biodiversity

The GLOBIO 3 model considers five factors causing biodiversity loss: land use, infrastructure, fragmentation, nitrogen deposition and climate change. Therefore there are five estimates of what would be the remnant biodiversity due to the impact of each factor (MSA_{LUC}, MSA_{INFRA}, MSA_{FRAG}, MSA_{NITR}, MSA_{CLIM}) for each cell in the study area. These values are then combined to obtain the remaining total biodiversity (MSA) using the following formula.

$$MSA_i = MSA_{USO\,i} MSA_{FRAG\,i} MSA_{INF\,i} MSA_{CC\,i} MSA_{N\,i} \quad (1)$$

Remaining biodiversity can be estimated at national level can be obtained by calculating the average MSA_{TOT} of all the pixels in the study area, as well as at regions or department levels.

2.2.1 Land use

Original biodiversity will vary, according to the degree of intervention in an area. Therefore, areas with selective extraction of some of their species will have higher MSA than areas where the original habitats have been replaced by agricultural crops. Alkemade *et al*. (2006) calculated MSA values (remaining biodiversity) for each type of land use, based on literature review. In this way, MSA values can be estimated from a land use map. Table 1 shows these values obtained from information compiled for 2618 species (680 plants, 1200 invertebrates and 730 vertebrates).

Land Use	Description	MSA_{LUC}
Primary vegetation	Forest and other natural vegetation with little or none human influence	1.0
Grass	Grass and natural shrubs where domestic cattle could have partially replaced native species of ruminants.	1.0
Forest slightly disturbed	Primary forests with limited use (i.e. hunting, selective logging, harvesting of non-timber products). Forest structure remains intact.	0.7
Secondary Forest	Forest succession in deforested areas.	0.5
Agroforestry	Agricultural production where the original forest (or planted trees) has been retained to provide shade or protection against the wind.	0.5
Forest Plantations	Planted trees, predominantly homogenous monospecific systems for timber production. The species can be exotic or native.	0.2
Perennial crops	Planted trees to produce fruit, coffee, cocoa, and so on. The operation means that the soil is left untreated for long periods of time.	0.2
Artificial Grass	Forests converted to pasture for cattle grazing.	0.1
Urban Areas	Areas with high density of artificial structures (eg. Cities, suburban areas, roads, airports, etc.).	0.05
Agricultural Areas		
Extensive agriculture	Agricultural areas where the use of fertilizers and pesticides is limited. The production is predominantly for subsistence.	0.3
Commercial intensive agriculture	Dryland agricultural areas, with high use of fertilizers and pesticides. The production is predominantly commercial.	0.1
Fully managed irrigated agriculture	Irrigated agricultural areas, intensively managed. High levels of fertilizers and pesticides. The production is predominantly commercial.	0.05

Source: Adapted from Alkemade *et al.* 2006

Table 1 MSA_{LUC} for different land use and land cover: a) General land use and land cover, b) Agricultural sub-classes.

2.2.2 Infrastructure

The presence of roads that interconnect towns and cities has different impacts on biodiversity. When a road is new, the main impact is the destruction of natural areas in its surroundings, establishing new areas for agriculture and / or livestock. The presence of a road already established, depending on the time of construction, can support a colonization process that is going to decline over time, as space is occupied.

In general, the construction of roads alters the original habitat bringing traffic and noise that causes displacement of species away from the road. The accessibility to new areas also generates greater utilization of resources, such as hunting of wildlife or the extraction of useful species (e.g. wood or game). Another effect on biodiversity refers to the road becoming a crossing barrier for some species. In some ecosystems this open space creates an alteration of microclimates for small species that make them go away (edge effect). Although roads are partially responsible of habitat fragmentation, the impact of fragmentation is analyzed independently as a separate factor.

Biodiversity loss due to infrastructure only considers area with natural vegetation. Areas with human activity such as agricultural areas have a greater impact because of the factor of land use, so the infrastructure is not considered a factor in those areas. The impact is measured in terms of distance to roads and assumes that the proximity to them will render a smaller MSA value. It also considers a different impact of the infrastructure for the different types of biome. The effect of this pressure factor is calculated as:

$$MSA_{INF} = \alpha * \ln\left(\frac{0.001*(dist+10)}{\left(1+\left(0.000001*\beta*(0.0221*pop+0.373)\right)\right)^{(year-2000)}}\right)+\delta \quad (2)$$

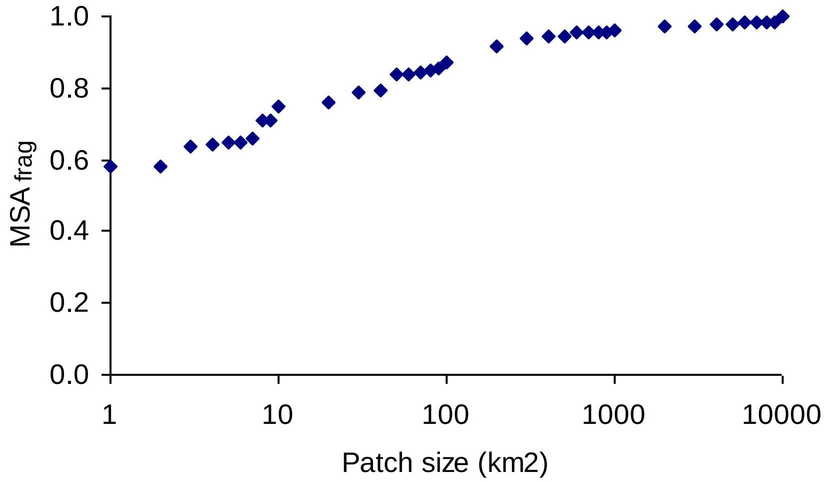
Where α, β and δ are specific parameters for the types of land use and land cover defined in table 1, *dist* represents the distance in meters to the infrastructure in question (e.g. roads), *pop* is the population density in a given site (in persons per Km^2), and year is the year for which the MSA is estimated.

2.2.3 Fragmentation

It is known that species have a minimum requirement area for supporting a viable population. The presence of roads, areas with farming or other human use causes fragmentation of natural areas into smaller patches, affecting the viability of the species. The main effect of fragmentation is that populations are divided into isolated patches without connection, with the consequent reduction in the availability of resources and competition for them in a smaller area (Hanski 1998). The MSA associated with fragmentation takes into account the patch size of natural vegetation in which the unit of analysis is located, and its effect on the remnant biodiversity. MSA values are assigned by size ranges, patches between 0 and 1 Km^2 have a value of 0.55 and the following values are shown in figure 2.

For the present study (Andean countries) we considered that the boundaries between structurally different ecosystems also generate fragmentation. For example, most of forest species can not use resources in grassland ecosystems, therefore, boundary between grasslands and forest causes fragmentation. For this purpose we considered the next categories: forest, grassland-schurbland, dessert and glaciers.

MSA values due to fragmentation are calculated only for areas with natural vegetation. Areas with human activities remain with a MSA_{frag} of 1 (which when multiplied does not affect the other values), as the fragmentation itself does not generate any biodiversity loss in these habitats.



Source: Van Rooij 2007

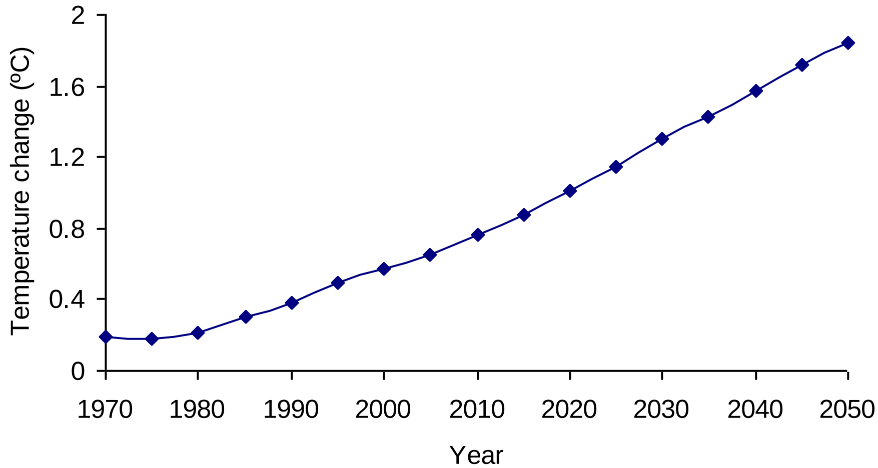
Figure 2 MSAfrag values for different natural areas of different patch size

2.2.4 Nitrogen deposition

This factor considers the effect of the accumulation of nitrogen due to the use of fertilizers. It is believed that there is an effect when the capacity of nitrogen deposition exceeds a critical value, at which biodiversity is affected. This threshold is different for each type of ecosystem. If the value is below this limit, there will be no significant impact on biodiversity. For this case study there was no reliable information to South America, and this factor was excluded from the analysis.

2.2.5 Climate Change

The effect of climate change on remaining biodiversity is analyzed from the logic of habitat variation. Given that temperature (see figure 3) and local patterns of precipitation will change, this will affect the ranges of species distribution. This produces the generation of three types of area: areas where it is expected that the species or biomes may disappear, areas that the species will invade their habitat because it was displaced, and the areas where the species or biomes remain biomes (stable area). Therefore, remaining biodiversity is measured as the ratio that represents the stable area over the original area.



Source: Van Rooij 2007

Figure 3 Temperature increase compared to the year 1900 (OECD, base scenario)

Future biomes distribution has been modeled according to change in climate. A proxy of its effect has been developed based on a linear change of temperature and a sensitivity value for each biome (slope, see table 2). The equation is as follows:

$$MSA_{CC} = 1 - Slope * \Delta Temperature$$

Biome	Sensibility (ºC^{-1})	MSA_{cc} 2000 ΔTºC = 0,569	MSA_{cc} 2030 ΔTºC = 1,298
Shrubs	0,129	0,9266	0,8326
Natural Grasslands and steppes	0,098	0,9442	0,8728
Desert	0,036	0,9795	0,9533
Tropical Forest	0,034	0,9807	0,9559

Source: Alkemade *et al.* 2006

Table 2 Sensibility Value and MSACLIMATE for different biomes for years 2000 and 2030

2.2.6 Integrating the pieces: From the map of land uses to the MSA

As it is shown, each of these procedures allows approximating the effect of each factor from one or more maps. The main inputs are maps of land use, roads and original biomes (i.e., the distribution of biomes in the absence of the human impact). Based on these maps, and knowing the year the map of land use, it is possible to calculate the MSA expected for each pixel in the study area by applying the equation 1.

To calculate MSA for future years, it is necessary to identify the major projects of new roads in the study area and generate land use maps for these future years.

2.3 Changes in land use: The CLUE model

The initial step to determine the state of biodiversity by 2030 is to generate scenarios of potential land use and land cover for that year. To generate these scenarios were used CLUE (Conversion of land use and its effects), a methodological framework developed at the University of Wageningen (Verburg *et al.* 2002). In this methodology, the problem of evaluating the land use changes is divided in two parts. The first part is to estimate the area needed for each type of land use in the coming years, which sets the "demand" expected of each of these types of land use. The second part, is to assign a land use class to each landscape unit (pixel) following a set of rules, so that the total number of pixels assigned to a category of land use lies with the demand and that the pixels assigned to a given category are those that satisfy the best conditions according suitability maps.

Pixel allocation for future years follows some rules: 1) The land policies which imply that a pixel can not change from year to year (for example, if one assumes that protected areas are completely effective in controlling deforestation). 2) That the future use is consistent with prior use. For example, it is unlikely to have agriculture in sectors previously used for mining. These characteristics are defined in a matrix of transition that defines valid paths for change of use and land cover. 3) The inertia or elasticity of use, where is more likely that a pixel where there are urban uses continue under this type of usage. 4) The probability that a type of land use develops in a given pixel, regardless of the type of use the pixel previously had. The latter may include items that are considered to be static, such as height or the slope of the site, or dynamic, such as the construction of a road already planned or the contagious effect that occurs around agricultural sectors. The difference between these two dynamic factors is that while the first one is external to the model, the second is a product of the simulation. Based on available information we constructed land demand, matrix of changes, elasticity values, and suitability maps. Each of them will be resembled on the following sections.

2.3.1 Distribution Rules: Matrix of changes, elasticity and use suitability maps

The matrix of changes is a schematic representation of the possible changes between the types of land use. For example, a livestock sector can become a mining industry from one time to another, but the inverse change is not possible. To ensure consistency between models, a standard matrix was defined for all the study areas with minor variations. These variants seek to recognize the differences between the systems of land use and land cover of the different countries modeled.

The elasticity is a measure of how easy is for a land unit to pass from one class to another. For example, it is easier for an agricultural pixel to remain as an agricultural pixel. The classes of land use totally elastic are those in which the probability of occurrence of a year is not affected because the previous year has had the same use. The classes completely inelastic (more inertia) are those which once established it is very unlikely to change. Among the less elastic land use classes are: mining, urban and areas where significant investments in infrastructure has been done. Extensive agriculture, intensive agriculture and livestock were assigned intermediate levels of elasticity, depending on the characteristics of each one.

Suitability maps were constructed for each land use class based on climatic, topographical, of accessibility and restriction variables (Verburg *et al.* 2002). For this purpose, we used step backwards logistic regression

The variables used to make these predictions were:

Climatic variables: Annual Mean Temperature, Annual Total precipitation, annual ombrothermic index and ombrothermic index for the driest trimester (Rivas-Martínez 2005).

Topographic variables: Elevation, slope, total curvature, terrain convergence index, exposure topographic index (smoothed and non-smoothed).

Accessibility variables: Access time to market (based on Jarvis *et al.* 2006)

Legal protection system: Natural Protected Areas

The complete list of used variables and their description can be found in 6.1.

To make predictions minimizing the problems of spatial correlation of observations, it was chosen to do a random or systematic sampling of the points in the study area, guaranteeing a minimum distance between points. Finally, ROC curves were constructed for evaluating suitability maps.

One of the key assumptions for this model building is that the spatial rules do not change over time (static model). In the case of the measurement of how appropriate is a pixel to a class of use, e.g. the suitability maps, the algorithm assumes that the difference in the probability between two pixels will remain constant over time. This difference between two pixels can vary due to the elasticity or when a dynamic layer is incorporated. However, even in this case, the values of the coefficients of the regression do not change. In practical terms, the only thing that changes with time is the set of pixels that may belong to a particular class and the intercept of the regression, which is the value that is adjusted throughout the time to ensure that the demand is satisfied.

2.3.2 Demand

Land use demand is the amount of area required for each land use class per year. Land demand between years 2000 and 2030 was constructed using available databases at national or local level to document the trends of recent years. Besides, several international studies where consulted to obtain a joint vision of the future land use demand of the region in the global context (MNP 2006, Bruinsma 2003, Raskin & Kemp-Benedict 2002, FAO & OECD 2008). Unfortunately, none of these studies had projections per country but for Latin America. After reviewed them, it was chosen to use the Third Global Environmental Outlook by Raskin & Kemp-Benedict (2002). This document presents projections for scenarios of *market forces* and *political reform*, consistent with scenarios A1 and B1, respectively, of the IPCC, and to projections made by FAO for the years 2015 and 2030 (Bruinsma 2003). All these figures were used as a guide, being later adjusted for the current characteristics of each study area, and where information was available, with the time trend of recent years.

2.3.3 Pixel Allocation Model

After all the information is gathered (land use demand and suitability maps), CLUE assigns the pixels following an iterative algorithm which is summarized below (a description more complete can be found in Verburg *et al.* 2002).

A. For the first year of the model, the probability functions and the demand for each land use class are determined. Then the next steps follow:

   1. First, the cells in the study area that may change are determined. The cells that are considered part of a protected area or can not vary for any other reason are excluded from future calculations.

   2. For each cell *i* the probability for each land use ($TPROP_{i,U}$) is calculated, according to:

$$TPROP_{i,U} = P_{i,U} + ELAS_U + ITER_U$$

      where $P_{i,U}$ is the probability of the U class in the cell i (taken from the model of probabilities), $ELAS_U$ may be zero (if the cell in the previous year was not in the class U, that is if the option of change in use is evaluated) or the elasticity of the U class (if the value of cell in the previous year was in fact from the U class, that is if the option of continued use is evaluated), and $ITER_U$ is the iteration variable that adjusts for each U class.

3. An initial allocation of pixels with a homogeneous $ITER_U$ value for each class is made, assigning to each *i* cell the type of use with the highest $TPROP_{i,U}$ value.

4. The total number of cells assigned to each land use class is counted. The area associated with each land use is then compared with the requirements of land use (demand). If the area allocated to a particular use is lower than the required, the $ITER_U$ parameter of that use is increased. If the allocated area is higher, the parameter is diminished.

B. Steps 2, 3 and 4 are repeated until the demand is correctly allocated (within certain preset ranges of precision). When this happens, the land use map is saved and continues with next year, repeating the same steps.

In the Madre de Dios study case, the CLUE model could not be run, for that reason it was developed an allocation algorithm resembling the CLUE process (details in the study case).

3 Main results from the study cases

3.1 Colombia

3.1.1 Introduction

From a historical viewpoint Colombia's economy is based on agriculture. Gradually there was a shift and the construction, mining, commerce, industrial, transport and financial sectors have gained more importance (DANE 2008). During the last decade, Colombian economy has been based on the open markets policies and activities with an average annual increase in GDP during the last 5 years of more than 4% and an increase in consumption especially in consumer durables. Policies have been centered toward the implementation of free trade treaties as a way to incorporate the country in a global economy.

Based on that policy, governments have supported the construction and actualization of the transportation network, proposing important highways, maritime and river ports and other nationwide infrastructure projects.

Foreign investment is increasing, thanks to a macroeconomic stability, increased security perception and policies that stimulate it. In 2007 it represented 27% of the countries GDP (DANE 2007), the commerce and mining sectors have received a lot of foreign capital, especially in the later for petroleum exploration and coal extraction.

Maybe as a direct result of an extended armed conflict, there has been an increase in large estate patterns. In addition increased concentration of rural land ownership and livestock grazing has been extended, occupying most of the countries rural frontier (Balcazar 1998).

The progressive liberalization of the economy has lead to an intense structural shift in the agriculture sector. Transitory crops that were commonly subsidized (e.g. rice, sorghum and cotton) have been in crisis while extensive and intensive livestock grazing, and permanent crops have increased. Biofuel crops have been stimulated by benefits from credits and commercial policies, given their apparent advantages in the domestic (and international) markets. These crops have been developed by large scale organized enterprises. On the other hand, coffee, the most important export product during the last century and pillar of a smallholding rural economy, has decreased in area and in production (DANE 2007), because of its low prices in international markets and the growing opportunities for more profitable economic activities. Illegal crops have had a shifting area variation during the last decade (UNODC 2008). Even though an aggressive eradication campaign has been implemented, these crops continue play an important part in the rural economy for the more remote areas of the country.

The ministry of the Environment has increased its functions towards handling the housing and regional development activities of the country. The environmental sector, with the exception of the national parks office that has increased its budget historically, has been negatively affected with this change. It has rebounded the ministries capability to handle and evaluate effectively the impact on biodiversity and conservation caused by the increase of productive projects.

The research institutes of the Ministry of the environment, with the support of the European Economic Community (EEC), are making a big step towards an integrated spatial support system, worked together to produce a Colombian ecosystem map at regional scale for the year 2000 (IDEAM et al. 2007). The results of this map were the bases of the land cover data used in this project. The CLUE-GLOBIO methodology seemed adequate to support decision-making in economic projects and their impact on the state of biodiversity. Spatially constructed scenario based models that link land use with socioeconomic and demographic activities and impacts are the natural development for the use of this tool as an environmental support system.

3.1.2 Methodology

3.1.2.1 Study Area

The study area comprises the continental portion of Colombia. San Andres and Providencia; the Colombian islands in the Caribbean, were not taken into account because of the regional scale of the analysis.

3.1.2.2 Actual land use / land cover map

The land use /land cover map was derived from the Colombian Continental and Marine Ecosystem Map (IDEAM et al. 2007), an initiative of the research institutes of the country and with the economic support of the European community. The baseline information for the land cover/ land use component of this map were LANDSAT ETM images from 2001-2003 and other supplementary detailed thematic cartography. The LUCC legend was based on level 2 CORINE land cover standards and the final product was presented at a 1:500.000 scale.

The 23 classes from the LUCC legend of this map were reclassified to the MSA_{LUC} categories to finally distinguish 12 different classes. Five of these classes are natural or semi natural (primary forests, natural grass and shrublands, natural bare, rock and snow, natural inland water and secondary forests) and five are for agriculture uses (extensive agriculture, transitory/annual agriculture, perennials and biofuels, man-made pastures and forest plantations). Artificial man made surfaces is represented by the class Eroded and build up areas. Finally, wetlands and water bodies were classified as natural inland waters or artificial water bodies (table 3). Afterwards, the map was converted to a 1km² raster and projected to the sinusoidal parameters.

Land use land cover classes	Area (ha)
Natural forests	61 060 700
Plantations	160 800
Secondary forests	8 151 700
Extensive agriculture	4 962 200
Transitory/annual agriculture	1 057 400
Perennials/ biofuels	3 308 800
Natural grass and shrublands	14 524 100
Man made pastures	17 292 500
Natural bare, rock and snow	24 500
Natural inland water	2 590 600
Artificial water bodies	66 600
Eroded and built up areas	512 700
Total	113 712 600

Table 3 Area for each Colombian Land use/land cover class

3.1.2.3 Parameters and Decision rules for the calculation of the allocation of land use change

The quantitative changes in land cover and land use need to be spatially distributed. In order to accomplish this task, CLUE uses an algorithm based on: a) the dynamic simulation of the competition between the national level demands for each land use class and their local preferences for locations (suitability), b) the competitive strength of each class (spatial stability) and c) the restrictions of change. These parameters and decision rules have to be adjusted to the specific conditions of the country.

Elasticity and transition matrix

Elasticity is an indicator of the spatial and temporal stability of the land use/land cover classes (Verburg et al. 1999) and relates to how difficult a land Use/land cover class can move in space and time. The highest conversion costs (more spatial stability) was given to *build up areas*, *water bodies* and *natural rocks*. Natural forest was assigned with a value of 0,9 because it was taken into account that slight reforestation can exist in some areas of the country (Armenteras & Rodriguez 2007). G*rasslands* and *shrublands* were also assigned with 0.9. The more dynamic land use is *Man made pastures* that can be transformed to almost any other land use and can appear in any part of the country and was assigned an elasticity value of *0.1*. All the other land use classes are in the intermediate elasticity range of *0.3*-*0.6* (table 4).

The transition matrix is another decision rule build to determine which land use conversions are possible or not on a year to year basis. Natural forests, grasslands and shrublands can change to almost any land use, but no land use can change to these natural classes in the 30 year temporal scale of the analysis.

LUUC	Elasticity	Land use Conversion matrix											
		(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Natural forests (0)	0.9	+	+	+	+	+	+		+				
Plantations (1)	0.6		+	+			+		+				
Secundary forests (2)	0.3		+	+	+	+	+		+			+	+
Extensive agriculture (3)	0.3		+	+	+	+	+		+				+
Transitory/anual agriculture (4)	0.5		+	+	+	+	+		+			+	+
Perennials/ biofuels (5)	0.6		+	+	+	+	+		+			+	+
Natural grass and shrublands (6)	0.9		+	+	+	+	+	+	+	+			+
Man made pastures (7)	0.1		+	+	+	+	+		+				+
Natural bare, rock and snow (8)	1									+			
Natural inland water (9)	1										+		
Artificial water bodies (10)	1											+	
Eroded and built up areas (11)	1												+

+ in the conversión matrix means that a row LUCC (0-11) can change to a column LUCC

Table 4 Elasticity and conversion matrix for the land use/ land cover classes of Colombia

Demand

Projections of land use for year 2030 were extrapolated from the baseline land use and land cover of 2000 and a 35 year series (1970-2005) of the *statistical Annuary for Latin America and the caribbean* (Cepal 2006). Colombian agriculture information of this publication was based on the Statistical Database of the Food and Agriculture Organization of the United Nations (FAOSTAT) and from the annual statistics of the National Statistical Department of the country (DANE). The information was verified and for some land uses, it was complemented with statistics from DANE and of the Department of Agronomic studies (SAC). Two future scenarios were considered: Market forces and Policy Reforms, based on the Raskin & Kemp-Benedict (2002) scenarios.

Suitability

Kok and Veldkamp (2001) highlight the importance of separating uniform units based on agro ecological zones for doing land use pattern analysis. The suitability of each land use for each pixel depends on its specific land use dynamics and its location distinctiveness. Considering the variability of these dynamics within the country, and as counterpart, the regional scale of the analysis, five regions were distinguished for Colombia (Figure 4). These regions are similar to the ones proposed by Wassenaar et al. (2007) in their projection of land use for tropical Latin America.

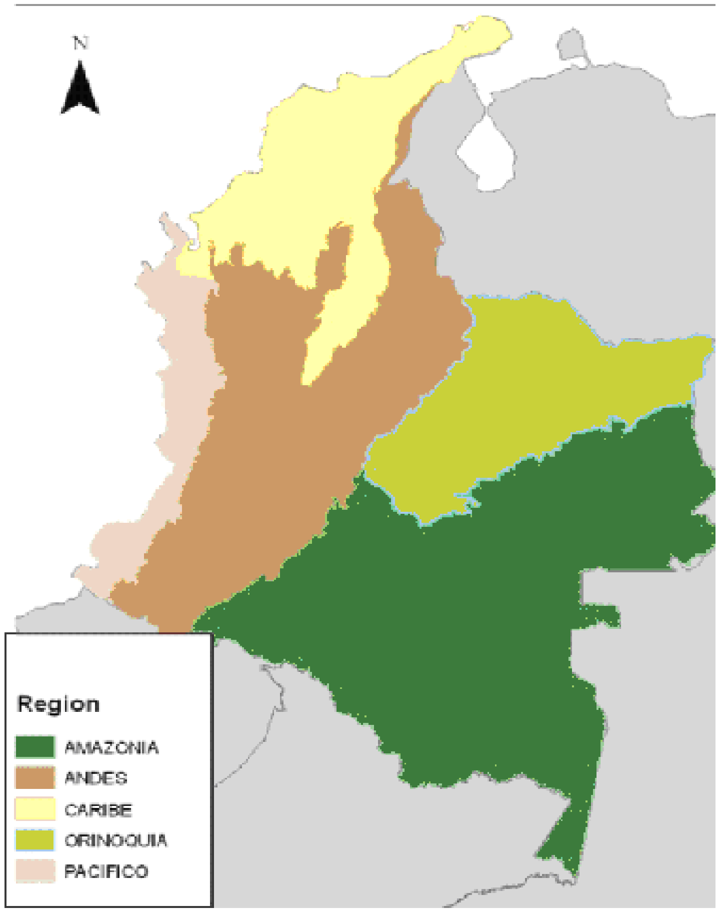


Figure 4 Natural and land use regions distinguished for Colombia

Each region has different biogeographical characteristics and land use dynamics that influence its potential land use suitability (table 5). An unbalanced sample of 20% of the country's total 1km pixels with a separation distance of 2000 m was selected using the *Hawth's Analysis Tools v. 3.27* extension for *ArcGIS.* The selected pixels were assigned to the correspondent region to analyze the distribution of the selected static location factors with the distribution of the selected samples and determine the relations between the different land uses and their location characteristics.

Region	Description
Caribbean	The most common natural land cover classes are forest mangroves, tropical dry forests, dry shrublands and especially natural inland waters, but all the forests and shrublands are highly fragmented. This region is bathed by the alluvial valley of the Magdalena river and delimited by the Caribbean ocean and the mountains of the Andes. As the more relevant land use and socioeconomic activities, the Caribbean has cattle raising activities in large state tenancy patterns even though there is an expansion of mining and biofuel crops.
Andean	The typical natural land cover classes are: Sub-andean forests and Andean cloud forests beneath the 500 m in three biogeographically and anthopogenically differentiated "cordilleras" and above the 3000 m Paramos persist. Also, in climatically azonal conditions below the 2000 m dry shrublands can be found as remnant patches. In the Andean region is concentrated 70% of the Colombian population and most of the country's GDP, giving large pressures over biodiversity and natural land cover and have caused high levels of fragmentation and biodiversity loss. There is also high variability in the land uses and their dynamics within the Andes.
Pacific	The more common natural land covers are tropical humid forests and forest mangroves all with high levels of endemism. They are located in the eastern slope of the Andes below 500 m and adjacent to the Pacific Ocean. Climatically, this region is characterized by high levels of precipitation and humidity. Socioeconomically, the region is characterized by high levels of poverty and the presence of indigenous and afro-descendant communities. There is a high variety of land uses in the region.
Orinoquia	Tropical gallery forests and savannas below 500 m in the Orinoco basin. Most of the population is concentrated in the piedmont part of the region where there is also an expansion of agriculture and petroleum activities. The eastern savannas are characterized by extensive cattle raising activities. This region is believed to be the next "colonization frontier" of the country due to the high impact projects that are being planned.
Amazonia	Continuous Tropical humid forests below 500 m in the Amazon and Orinoco basins. Socioeconomically and demographically, the region is characterized by low population densities and a gradual expansion of colonization frontiers associated with petroleum activities or illegal crops production and transportation. Subsistence agriculture sometimes related with traditional practices can also be found along rivers.

Table 5 Description of the regions used for the regressions in Colombia

Fifteen static location factors were selected for this analysis as the variables that influence the presence of each land use. Most of them are biophysical and derived from an interpolated 1 km² *SRTM* DEM (elevation, slope, terrain form index, terrain ruggedness index, terrain convergence index, topographic exposure index, topographic relative moisture index, relative slope position and total curvature index). Four climatic factors were incorporated in the analysis: the annual average temperature and the annual total precipitation were taken from the *Worldclim v 1.4* databases (Hijmans et al. 2005), the ombrothermic index and the ombrothermic index of the drier quarter were derived from this data. The detailed description of each of these variables is found on Annex I.

The location of the national protected Areas for the year 2007 was used as a variable that can influence the presence of the different land uses. As a proxy for socioeconomic and demographic activities, a pixel based accessibility model was incorporated (Jarvis et al. 2006).

The baseline information for the cost-distance model was:

- Level 1-3 road network from the Geographical Institute Agustin Codazzi (IGAC) 2007 1:500 000 cartography.
- Navigable river network derived from the Geographical Institute Agustin Codazzi (IGAC) 2007 1:500 000 cartography.

- Populated centers of more than 1000 inhabitants derived from the Geographical Institute Agustin Codazzi (IGAC) 1:500 000 cartographic information and DANE 2005 census data.
- DEM data. 90 m. SRTM interpolated to a 100 m grid.
- Maritime ports obtained from the Geographical Institute Agustin Codazzi (IGAC) 2007 1:500 000 cartography.
- Water bodies. IDEAM et al. (2007) Ecosystem Map.

The final result is a 1 km² surface in which each pixel has travel times (hours) to the populated and commercial centers. The travel times are based on the friction to cross each pixel given the different types of roads and navigation networks and the friction derived from topographic characteristics associated with each pixel.

Logistic regressions were used for each land use and in the five regions, to establish the relations between land uses and the location factors. Using the selected samples, the regressions were done using *SPSS v. 15.0* software, considering 50 interactions and a *0.1* cut value criteria for exclusion or inclusion of the variables. The fitted model was selected with the Backward (LR) selection method. For some regions some location factors were excluded of the analysis because of the probability of the Wald statistics. For the land use *plantations* there were few pixels in each of the regions, and this small sample caused some bias in the preliminary results, therefore the location dynamics of this land use were left constant in the final result. The same was done with the LUUC classes *Natural bare, rock and snow, Natural inland water, Artificial water bodies and Eroded and built up areas*.

The significant statistical relations between location factors and each land use were used in the software CLUE to build the suitability surfaces for each case.

Future land use land cover Map

The suitability maps, combined with the decision rules of elasticity, the conversion matrix and the quantitative estimates of the land use demand for the two scenarios (Market Forces and Policy Reforms), were used to project the LUUC location of change for the year 2030 using the software CLUE (Verburg et al. 2002).

3.1.2.4 Biodiversity State for the years 2000 and 2030

Biodiversity state for the two years was evaluated using the GLOBIO Methodology (Alkemade *et al*. 2006). The results of *CLUE* were used as the base land use/cover information for year 2030. The road network from the Geographical Institute Agustin Codazzi (IGAC) 2007 1:500 000 cartography, converted to a 100 m grid, was used to establish the effects of fragmentation and infrastructure over biodiversity. The biome map used is a a sub product of the Colombian ecosystem map (IDEAM et al. 2007) and was reclassified to the following 7 categories of the MSA biomes: Tropical forests, grasslands, desert and xeric shrublands, xeric shrublands, mangroves, lakes, and rock & ice. This biome map was used to evaluate the effect of climate change, infrastructure and fragmentation over biodiversity.

Land use and land use intensity was also evaluated using a population density surface, this layer was constructed based on urban and rural census information (DANE 2005) and IGAC 1:500 000 political boundaries information. Nitrogen deposition was not evaluated as a potential factor of change. Finally, the GLOBIO model was run in Arcview using the script modified in this project.

3.1.3 Results and discussion

3.1.3.1 Land use/ Land cover Change

Land Use/ Land cover change was modeled using CLUE software. The inputs were the results of the logistic regressions, the suitability maps and the projected national land use demands.

Regressions and Suitability Maps

The coefficients of the selected variables of the 35 resultant logistic regressions (one per land use /land cover class for each region) were used to build the *logit* models. Suitability maps were constructed using equations based on the final coefficients of the logistic regression.

There is a wide variety of factors that explain land use change for Tropical Latin America (Wassenaar *et al.* 2007). The results of the logistic regressions confirm this; there is a considerable amount of variation across the different regions. Most of the resultant logistic regressions models select more than 5 variables and most of them have different location factors. On the other hand, it seems that a slight difference and variation in the resultant coefficients of the selected factors for one land use on two different regions can have notorious effects in the allocation of the land use in the clue model. In this regard, more sensibility analysis that takes this into account should be done when modeling land use change in *CLUE* using regions.

Accessibility, the only location factor related with socioeconomic conditions, is the variable that appears more often in the results. Do socioeconomic factors explain more the location of the different land uses than biophysical and climatic ones in Colombia? Given the relative importance of this variable in explaining the location of the different land uses, more socioeconomic factors should be included in posterior analysis to answer this question. Among the climatic variables, temperature and precipitation are also often selected with the backward stepwise procedure to explain the distribution of some of the land uses.

Table 6 shows the relation between the independent variables and two of the seven land uses modeled using *logit*. In these two classes, the location of the National protected areas was not statistically significant in explaining their presence or absence.

	Intensive agriculture	Intensive agriculture	Intensive agriculture	Intensive agriculture	Intensive agriculture	Man made pastures	Man made pastures	Man made pastures	Man made pastures	Man made pastures	Natural grass and shrublands	Natural grass and shrublands	Natural grass and shrublands	Natural grass and shrublands	Natural grass and shrublands	Perennials biofuels	Perennials biofuels	Perennials biofuels	Perennials biofuels	Perennials biofuels
Variables	Amazonia	Andes	Caribe	Llanos Orientales	Pacífico	Amazonia	Andes	Caribe	Llanos Orientales	Pacífico	Amazonia	Andes	Caribe	Llanos Orientales	Pacífico	Amazonia	Andes	Caribe	Llanos Orientales	Pacífico
Intercept	- (***)	- (***)	- (***)	+ (***)	- (***)	+ (***)	- (***)	- (***)		- (***)	- (***)	- (***)	- (*)	+ (***)	- (***)	+ (***)	- (***)	- (***)	- (***)	- (**)
protected areas											- (***)	+ (***)	- (***)	- (***)	- (***)					
Elevation	+ (***)	+ (***)	+ (***)	- (***)	- (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	- (***)	+ (***)	+ (***)
Slope		+ (**)		- (***)	+ (***)	- (***)	- (***)	- (***)	+ (**)		- (***)	- (***)	- (***)		+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (**)
Terrain shape index		+ (**)	- (***)		- (***)	+ (**)	+ (***)	+ (***)	+ (***)		- (**)	+ (***)		+ (**)			- (***)			
Terrain ruggedness index		+ (***)				- (***)		- (***)	- (***)			- (***)	- (***)	- (***)	+ (***)	- (***)	- (***)		- (***)	- (**)
Topographic relative moisture index		+ (***)				- (***)		+ (***)						- (***)				+ (***)		
Total curvature		+ (***)										+ (***)					+ (***)			
Terrain convergence index		- (***)	+ (***)	- (***)	+ (***)	- (***)	- (***)	- (***)	+ (***)		+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	+ (***)	
Topographic exposure index	- (***)	- (***)	- (***)	+ (***)		- (***)	- (***)	- (***)	- (***)		- (***)		- (***)	+ (***)	- (***)	- (***)	- (***)	+ (***)		- (**)
Relative slope position					- (***)	- (***)	- (***)	+ (***)			- (**)	+ (***)	+ (***)				- (***)	+ (***)		
Time to market	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (**)	+ (***)	+ (***)		+ (***)	- (***)	- (***)	- (***)	- (***)	- (***)
Yearly average temperature	+ (**)	+ (***)	+ (**)	- (***)	+ (***)	- (***)	+ (***)	+ (***)	- (***)	+ (***)	+ (***)	- (***)	- (***)	+ (***)	+ (***)	- (***)	+ (***)	- (***)	+ (***)	+ (*)
Yearly Annual precipitation	+ (**)	+ (***)	+ (***)	- (***)	+ (***)	- (***)	- (***)	+ (***)	+ (***)	+ (***)	- (***)	+ (***)	- (***)	- (***)	- (***)	+ (***)	+ (***)		+ (***)	+ (***)
Ombrothermic index		- (***)	- (***)	+ (***)	- (***)	+ (***)		- (***)	- (***)			- (***)	- (***)	- (***)		- (***)	- (***)	+ (***)	- (***)	
Ombrothermic index of the 2(3) driest months	- (**)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)		+ (***)	+ (***)		- (***)	- (***)	- (***)		- (***)

	Secundary forests	Secundary forests	Secundary forests	Secundary forests	Secundary forests	Transitory anual agriculture	Transitory anual agriculture	Transitory anual agriculture	Transitory anual agriculture	Transitory anual agriculture	Forests	Forests	Forests	Forests	Forests
Variables	Amazonia	Andes	Caribe	Llanos Orientales	Pacífico	Amazonia	Andes	Caribe	Llanos Orientales	Pacífico	Amazonia	Andes	Caribe	Llanos Orientales	Pacífico
Intercept	- (***)	- (***)	- (***)	- (***)	+ (***)	+	- (***)	- (***)	- (***)	+ (***)	+ (***)	- (**)	+ (***)	- (***)	+ (***)
protected areas											+ (***)	+ (***)	+ (***)	+ (***)	+ (***)
Elevation	+ (***)	- (***)	+ (***)		- (***)	-	+ (***)	+ (***)	+ (***)	+ (***)	- (***)	- (***)	- (***)	- (***)	- (***)
Slope	+ (***)	- (***)				-	+ (***)	+ (***)	- (***)	- (***)	+ (***)			+ (***)	+ (***)
Terrain shape index		+ (***)			- (***)	-	- (***)				+ (***)		+ (**)		
Terrain ruggedness index		+ (***)	+ (***)	+ (***)	- (**)	-		- (***)	- (***)	- (***)	- (***)	+ (***)	+ (***)	- (**)	+ (***)
Topographic relative moisture index		+ (***)	+ (***)	- (**)		-		+ (**)			+ (***)	+ (***)	+ (***)	+ (***)	
Total curvature							- (***)								
Terrain convergence index		- (***)	- (***)			- (*)	+ (***)	+ (***)	- (***)	- (**)	- (***)	- (***)	- (***)	- (***)	- (***)
Topographic exposure index	- (***)	- (***)	- (***)			-	+ (***)	+ (***)	+ (**)		+ (***)				+ (**)
Relative slope position	- (***)	+ (***)	+ (***)	- (***)	- (***)	-		+ (***)			+ (***)	+ (***)		+ (***)	+ (***)
Time to market	- (***)	- (***)	- (***)	- (***)	- (***)	-	- (***)	- (***)	- (***)	- (***)	+ (***)	+ (***)	- (***)	+ (***)	+ (***)
Yearly average temperature	+ (***)	+ (***)	+ (***)	+ (***)	- (***)	-	+ (***)		+ (***)	- (***)	- (***)	+ (***)	- (***)	- (***)	+ (***)
Yearly Annual precipitation		+ (***)	+ (***)	- (**)	- (***)	-	+ (***)			+ (***)	+ (***)	+ (***)	+ (***)	- (***)	+ (***)
Ombrothermic index	+ (***)	- (***)	- (***)	+ (***)	+ (***)	+	- (***)		+ (***)	- (***)	+ (***)	+ (***)	+ (***)	+ (***)	- (***)
Ombrothermic index of the 2(3) driest months	- (***)	- (***)	- (***)	- (***)	+ (***)	-	+ (***)	- (***)	- (***)	- (***)	+ (***)	+ (***)	+ (***)	- (***)	

Table 6 Coefficients (β) of the logit regressions that explain the relationships between the independent location variables and the land use classes Extensive Agriculture and Man made Pastures in the 5 regions defined for Colombia.

Notes: Signs for each cell indicates positive relationship (+) or negative (-), asterisks indicate significant degree, (***) < 0,001, (**) < 0,01.

Suitability maps for each land use/cover were built based on the results of the logit models describing the probability of location for each class (Figure 5). As a highlighted result, the suitability map for *Natural Forests* had high values in almost all the country (even in the Caribbean where the predominant current land use is *Man made pastures*), and with the exception of the Orinoco region where forest exist as linear strips in the places where edaphic and hydrological conditions are appropriate and the 1 km² scale resolution is not useful to model these characteristics.

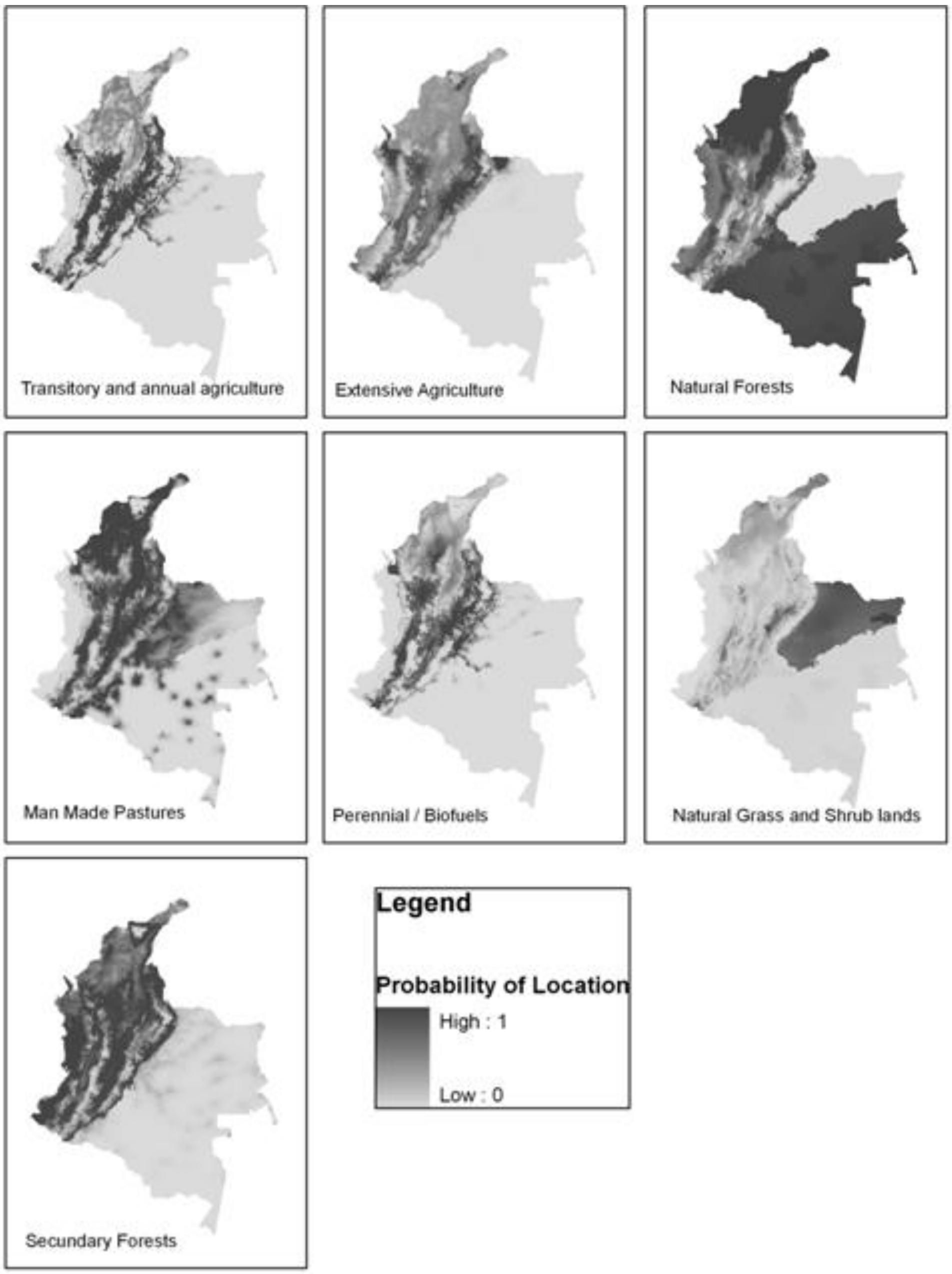


Figure 5 Suitability Maps for the analyzed Colombian land use types

Demand

Markets first Scenario

In this scenario it has been assumed that Colombia is under a *market first* economic policy during the last years and the tendencies will be maintained until the year 2030. After the first years of the 90's the country opened towards a global economy where economic forces rule the markets with a minimal government control. A rapid and maintained economic growth has prevailed but, on the other hand, market forces have echoed in significant losses of the traditional agriculture products that can not compete with globalized markets. High environmental degradation has been caused due to an uncontrolled growth.

Census driven information about the tendencies for each of the agriculture land use classes was collected from CEPAL (2006), where there is a 45 year information series for the country. Using this database, the tendency for *Transitory and annual crops* was derived from summing up for each year the areas of the following crops: rice, sorghum, sugar cane, wheat, cotton, soy and irrigated crops. *Man made pastures* and *Permanent and Biofuel crops* information was gathered directly from de CEPAL database. Information for the *Extensive agriculture* was collected from DANE (2006) that has a 25 year series. (Figure 6).

The slope of the linear regression for each of these land use class and their area in the year 2000 (obtained from the land use map), were used to project the tendencies up to the year 2030.

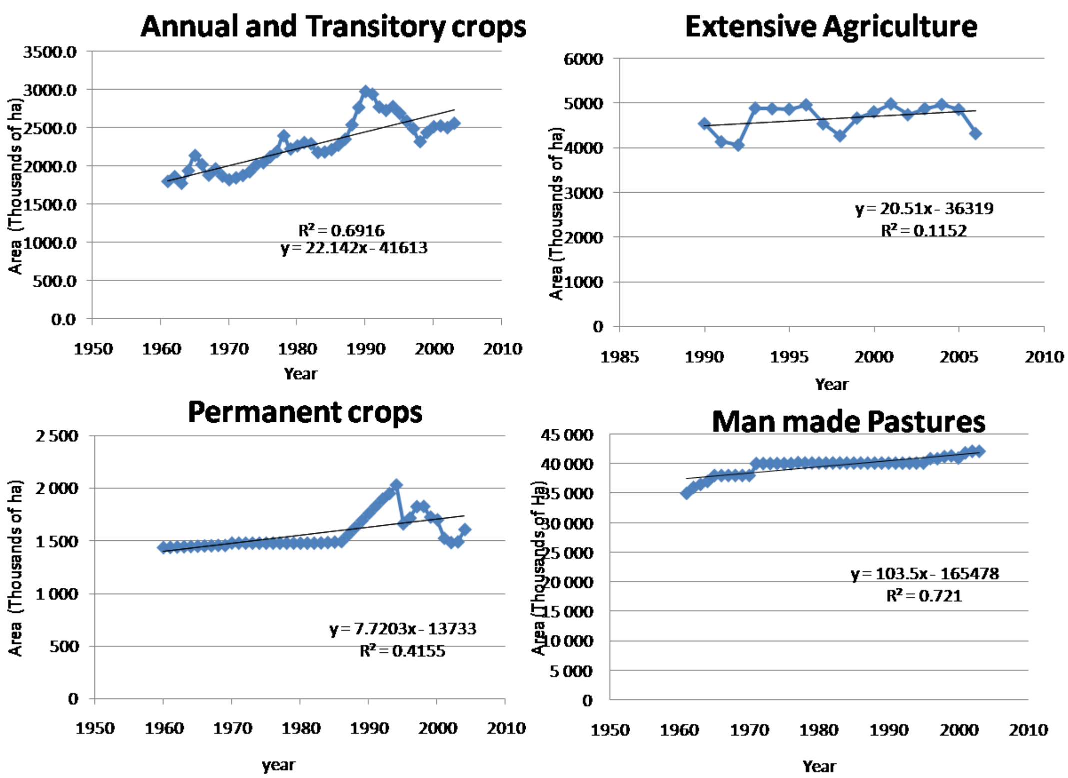


Figure 6 Extension of the different agricultural land uses in Colombia from 1960-2005

According to CEPAL (2006) the annual media variation of the *natural forest* area for Colombia is *-0.1* and the annual media variation for *plantations* is *5.8*. These rates of loss and gain were used to project their area up to the year 2030. There is no information about the *natural grass and shrublands* annual rates of variation, therefore we assumed that they have the same loss rates as the countries natural forests. *Secondary forest area for each year* was derived from the subtraction of the area of all the other projected land use types. By doing this it is expected that this land use class will diminish in area during the 30 year period of the analysis.

Policy Reform Scenario

The policy reform scenario proposed by Raskin & Kemp-Benedict (2002) considers structural changes that would promote or inhibit certain land use classes after a growing consciousness of the importance of environmental and social well being. Sustainable development policies will be proposed that will diminish the deforestation rates and land use degradation. In this scenario global awareness is the factor that helps to slow down the speed of land use change and degradation.

The scenarios predict an increase of agriculture in the policy reform scenario and a reduction of the Man made pastures areas in comparison to the market forces scenario. The following assumptions were taken into account to build the policy reform demand scenario:

- The *Natural forest* and *Natural grass and shrublands* area in the year 2030 will be the same as the area of this same class for the year 2015.
- *Man made Pastures* would be reduced to half the area of *market forces* scenario for the year 2015. From that year onwards, the reduction would be 4 times less than in the market forces scenario.
- *Plantations* would have the same predicted behavior than in the market forces scenario until the year 2015. Afterwards they have a 1.5 yearly increase.
- The three agriculture land uses are triplicated with respect to the *Market forces* scenario until the year 2015. Afterwards they have and increase with respect to that scenario of 0.1.

In general, for both scenarios, the land use with higher national demand with respect to what exists now is *Plantations*. The land use types *Natural forests*, *Secondary forests* and *Natural grass and shrub lands* are the only ones that would decrease in area from 2000-2030. In the *policy reform* scenario *Man made Pastures* would have an area reduction with respect to the market forces scenario, but in the latter there would be less agriculture areas (Figure 7).

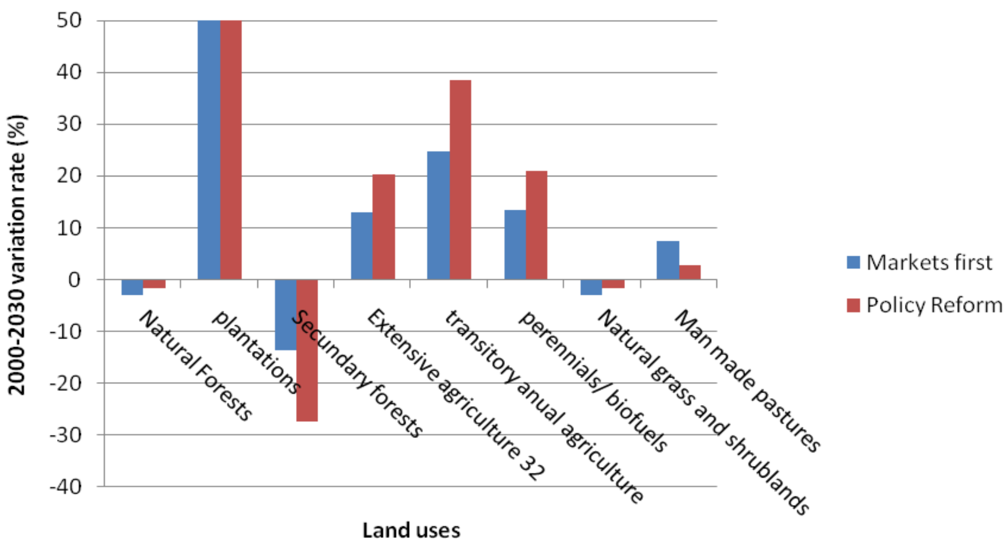


Figure 7 Rate of variation (2000-2030) for the different Colombian land use types.

Land use Maps for the years 2000 and 2030

The more transformed Colombian regions for the year 2000 are the Andean and the Caribbean ones (Figure 8). Even though, the first has large natural forest patches in the eastern and western piedmonts and the latter has remnants of dry forests, large extensions of natural wetlands and the naturally conserved “Sierra Nevada de Santa Marta”. The Orinoco and the Amazon maintain a highly pristine condition and most of the land use classes are concentrated in the piedmont areas.

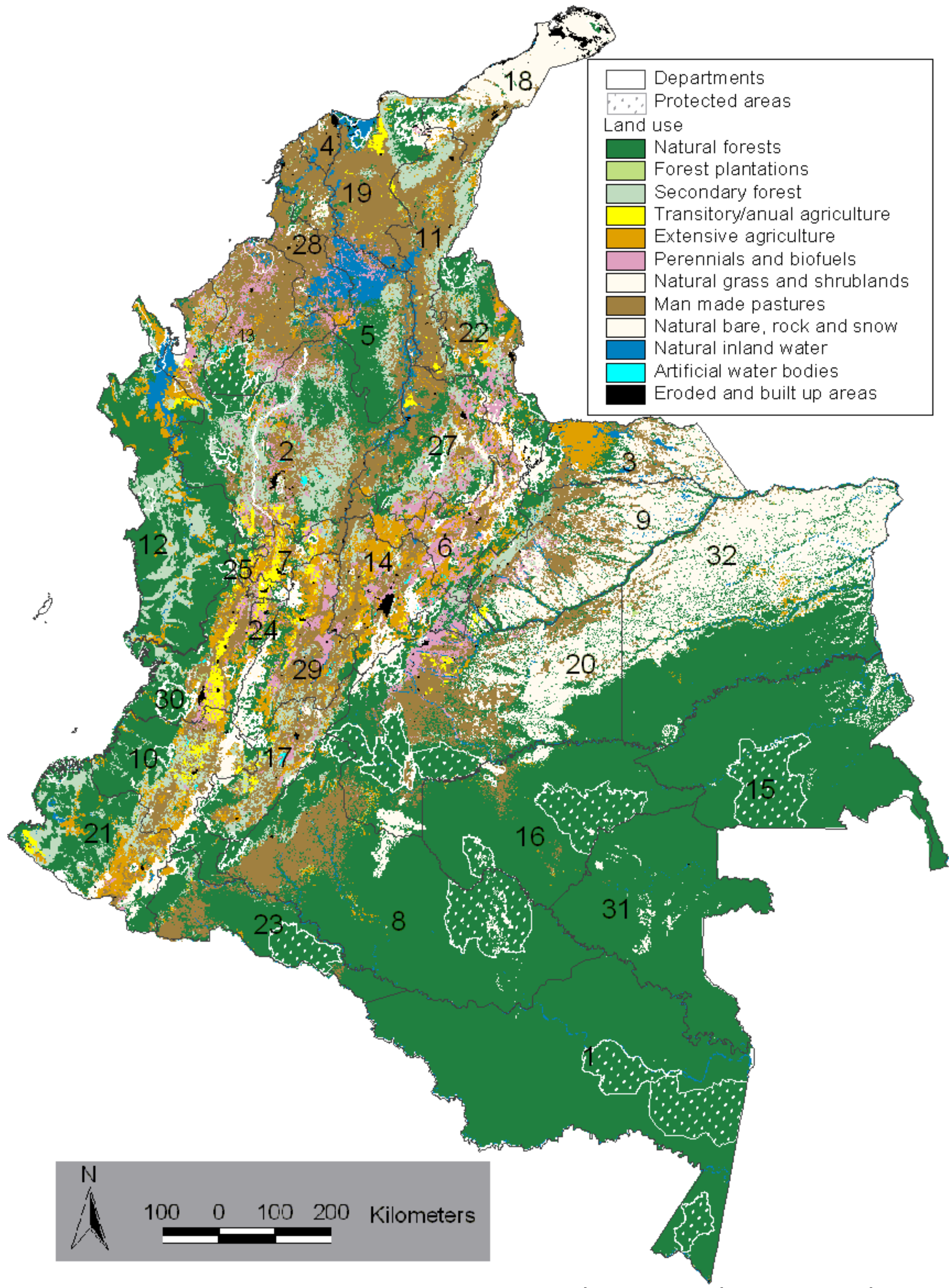
Agriculture is predicted not to be suitable in the Amazon, with the exception of some areas with pastures in the piedmont. This can be explained by the allocation considerations of CLUE. Pixels of one land use class are allocated in areas near to preexistent pixels of this land use class. Given the pristine condition of this region for the baseline year, the allocation of the changed pixels tends to concentrate in the piedmont areas where is located the current agriculture is located. Nevertheless this could not always be the case, given the percolated dynamics of fragmentation associated with illegal crop production in the Colombian Amazon (Armenteras & Villa 2006).

The forest and savannas of the piedmont in the Orinoco basin are predicted to be transformed to agricultural areas by 2030 for both scenarios. The difference between scenarios is the velocity of those changes.

Demand for *Market forces* scenario projected an increase of *Permanent crops* and *Biofuels* for the next years. The result of the model allocated those increases in the Caribbean, near the Chocó region and specially, in the Orinoco piedmont on behalf of the gallery and tropical forests that actually exist there. Natural grasslands were converted to *Man made Pastures* in the Orinoco piedmont for the two scenarios, but as in the case of the land use allocation in the Amazon, there is uncertainty in the models effectiveness to predict the allocation of change for this land use for the eastern part of the region, where conditions are very pristine and there were no agriculture land uses in the baseline year.

Logit model was not effective to predict plantations, due to its small area on the baseline year in comparison to the whole study area. However, plantations have a high yearly rate of gain in the proposed national land use demands. Using only the demand, elasticity and conversion matrix decision rules; this land use is predicted to expand in the Amazonic piedmont of Putumayo, frontier with Ecuador.

For the two scenarios and for the year 2030, land cover change would be concentrated in the Caribbean and the Orinoco regions, where natural land covers are expected to be replaced by the four agriculture classes (Figure 9).



Departments: 1. Amazonas, 2. Antioquia, 3. Arauca, 4. Atlántico, 5. Bolívar, 6. Boyacá, 7. Caldas, 8. Caquetá, 9. Casanare, 10. Cauca, 11. Cesar, 12. Chocó, 13. Córdoba, 14. Cundinamarca, 15. Guainía, 16. Guaviare, 17. Huila, 18. La Guajira, 19. Magdalena, 20. Meta, 21. Nariño, 22. Norte Santander, 23. Putumayo, 24. Quindío, 25. Risaralda, 27. Santander, 28. Sucre, 29. Tolima, 30. Valle del Cauca, 31. Vaupés, 32. Vichada

Figure 8 Land Use Land Cover Map of Colombia for the year 2000

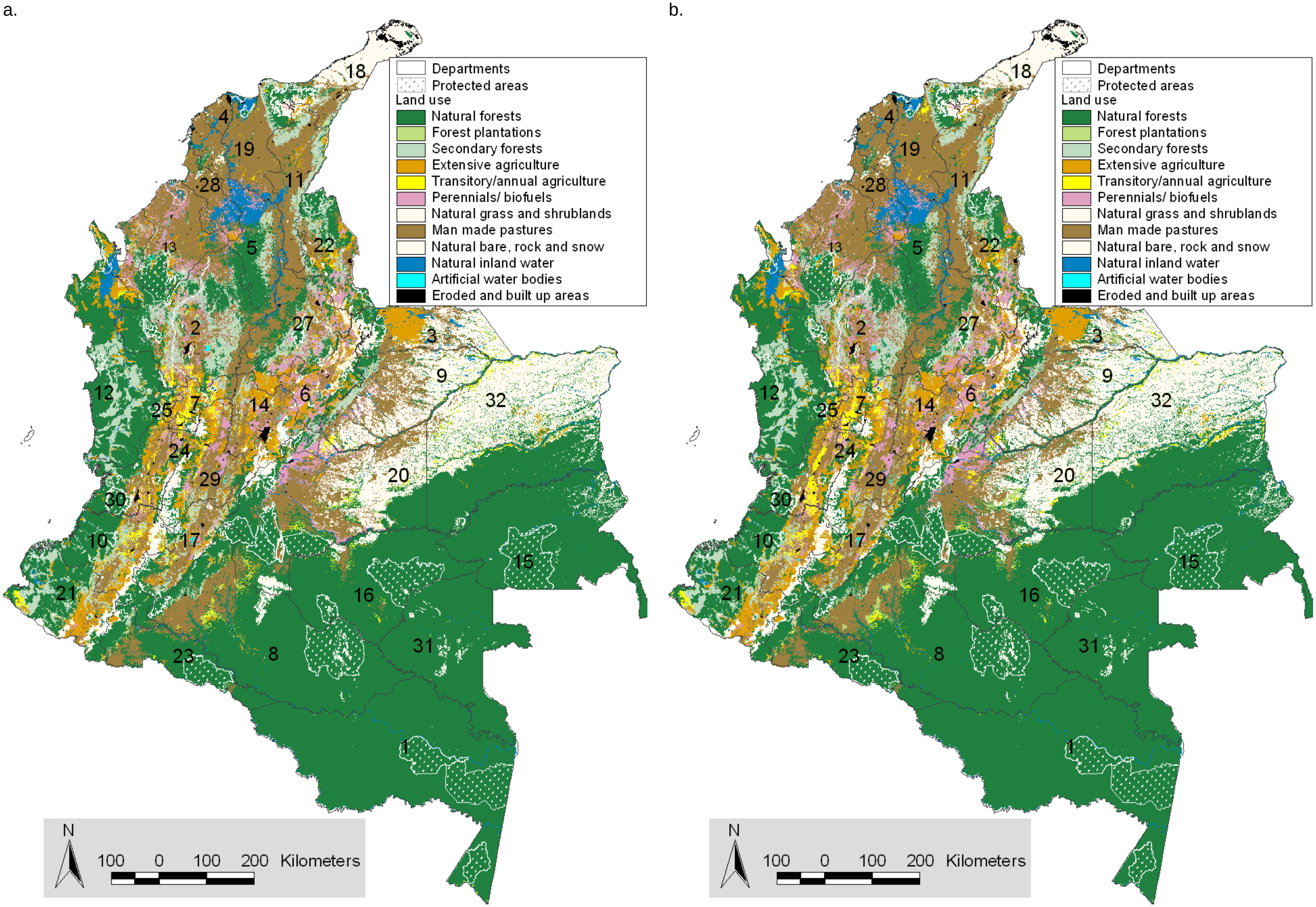


Figure 9 Land Cover/ Land use maps for the year 2030 for Colombia with the two modeled scenarios: Markets Forces (a) and Policy Reform (b).

3.1.3.2 Biodiversity Changes

Biodiversity Changes were evaluated by the results and the subproducts of the GLOBIO methodology.

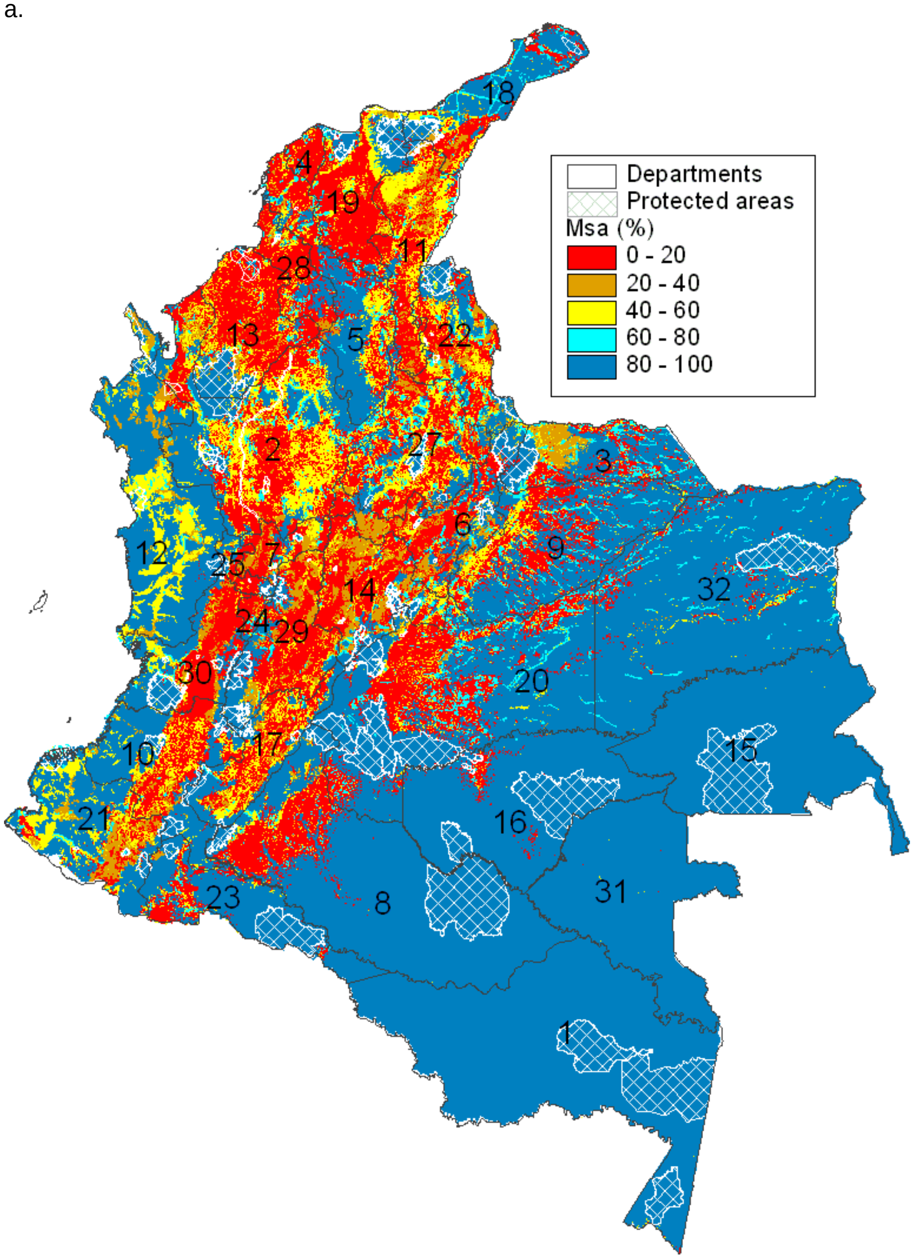
Even though Nitrogen deposition was not taken into account for this analysis and its effect could reduce even more the total MSA values due to its effect on the eastern savannas of the Orinoco, the remnant biodiversity for Colombia for the year 2000 is 70.3%, which is just below the world average according to Alkamade et al. (2006). Colombia is a Biodiversity Hotspot with 10% of the global species biodiversity and the meaning of this MSA result should be revised using other auxiliary information and its interpretation should be done taking into account the high levels of biodiversity of the country in relation with its relative area. MSA for fragmentation is just 1.8%, and climate change and infrastructure have also low values for the index in the year 2000. The driving factor that is affecting more the MSA loss is land use change (25.4%), this value is 6.4% higher than the global average and this factor alone is the one that is contributing to the low MSA result.

MSA values are low in the Andean and Caribbean region, where most of the Colombian population is concentrated in a long history of landscape transformation and where a variety of land uses interact. Even though, the Andean region is one of the 25 world biodiversity hotspots (Myers 1998) with unique endemisms and diversity centers (Davis et *al.* 1997). The Caribbean region is characterized by its wetland diversity, nevertheless GLOBIO is a terrestrial model and does not evaluate effectively the diversity loss for this ecosystems that have a large extension in the region.

The Amazon, the Orinoco and the Pacific regions have high MSA values for the year 2000, for there are zones where logging activities associated with colonization processes have transformed the natural forest to secondary ones diminishing the MSA index. (Figure 10a).

Amazonas, Vaupes, Guainía and Guaviare are all amazonic Departments and they have the highest remnant biodiversity values of the country. In contrast, Atlántico and Cesar; both located in the Caribbean region, have the lowest biodiversity remnant values and the reduction of their MSA index is due mostly by land use change. Arauca and Casanare are located in the Orinoco and they are the departments where the contribution to MSA loss is due to more driving factors different from land use (Figure 10b).

a.



b.

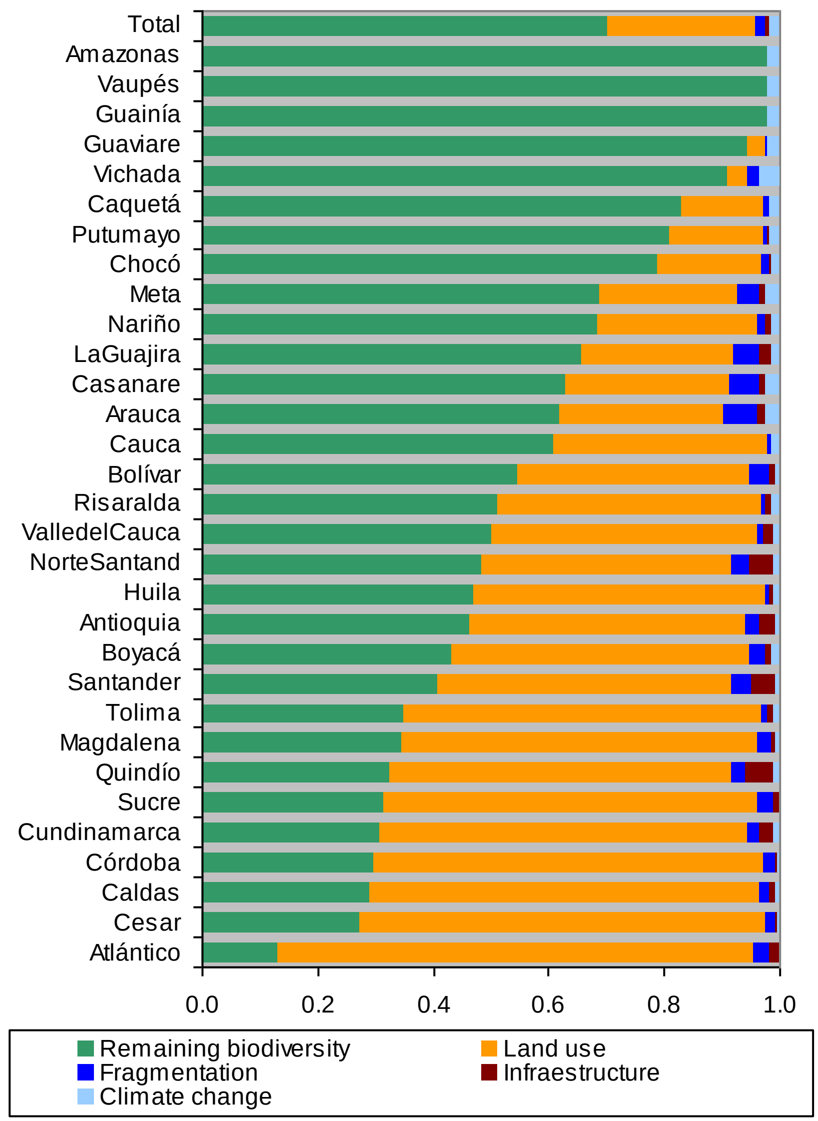


Figure 10 MSA Map for Colombia and contribution of each factor to biodiversity loss in each Department for the year 2000

There is a difference of 0.6% between the MSA results for the *market forces* and the *policy reform* scenarios. This slight difference is due to the higher contribution of land use to the loss of MSA in the first scenario. Climate change is expected to double its contribution to the total MSA at national level for the year 2030 (Figure 11).

The road and population density information was incorporated into the GLOBIO model statically, assuming that there will be no change until the year 2030. In the future, this information should be incorporated to the model dynamically to highlight the impacts of infraestructure projects over biodiversity and Land use.

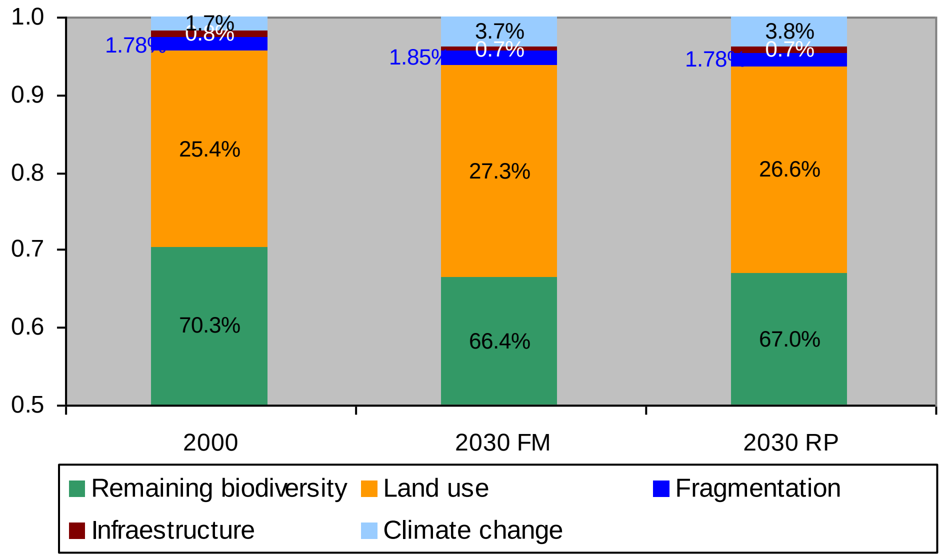


Figure 11 Remnant Biodiversity and loss caused by different driving factors for the year 2000 and for Market forces and Policy reform scenarios for the year 2030.

The regions that account for more MSA loss in the 2030 scenarios are the Caribbean and the Orinoco, where the land use changes were allocated as a result of the CLUE model. The Amazon and Pacific regions have small decreases in MSA while there is some reforestation in the eastern and western slopes of the Andes (Figure 12).

The same tendencies that were observed in the MSA 2000 map are found in the Market forces and P**olicy reform** scenarios for 2030. The Amazon Departments continue to have the highest amount of remnant biodiversity and the Atlántico and Cesar the least. For the Departments of Casanare, Vichada, Arauca and Meta, located in the Orinoco region, there is an increase in the contribution of Climate change in the total biodiversity loss (Figure 13).

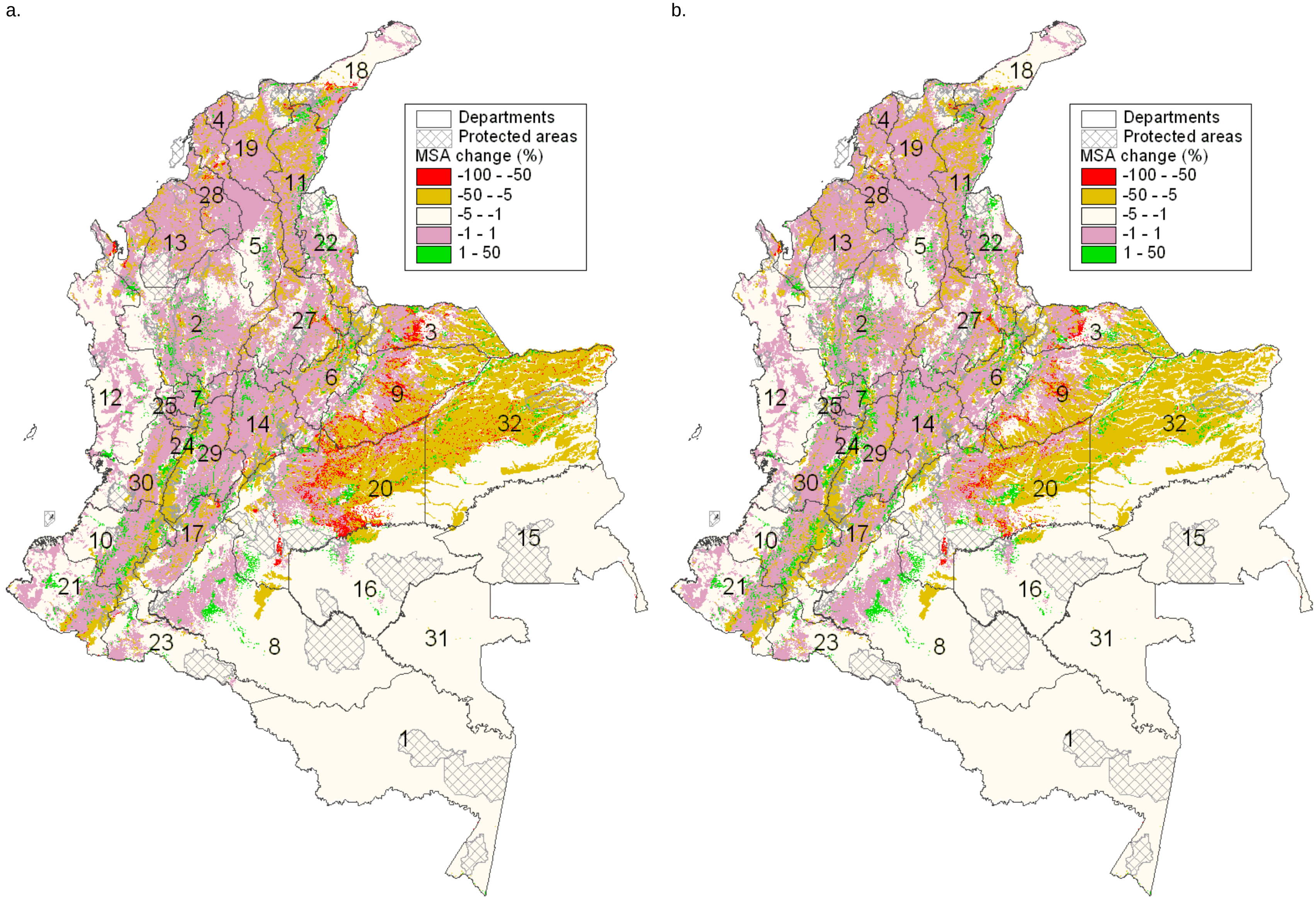


Figure 12 MSA Change Maps in Colombia for the year 2030 with the market forces (a) and policy reform (b) scenarios

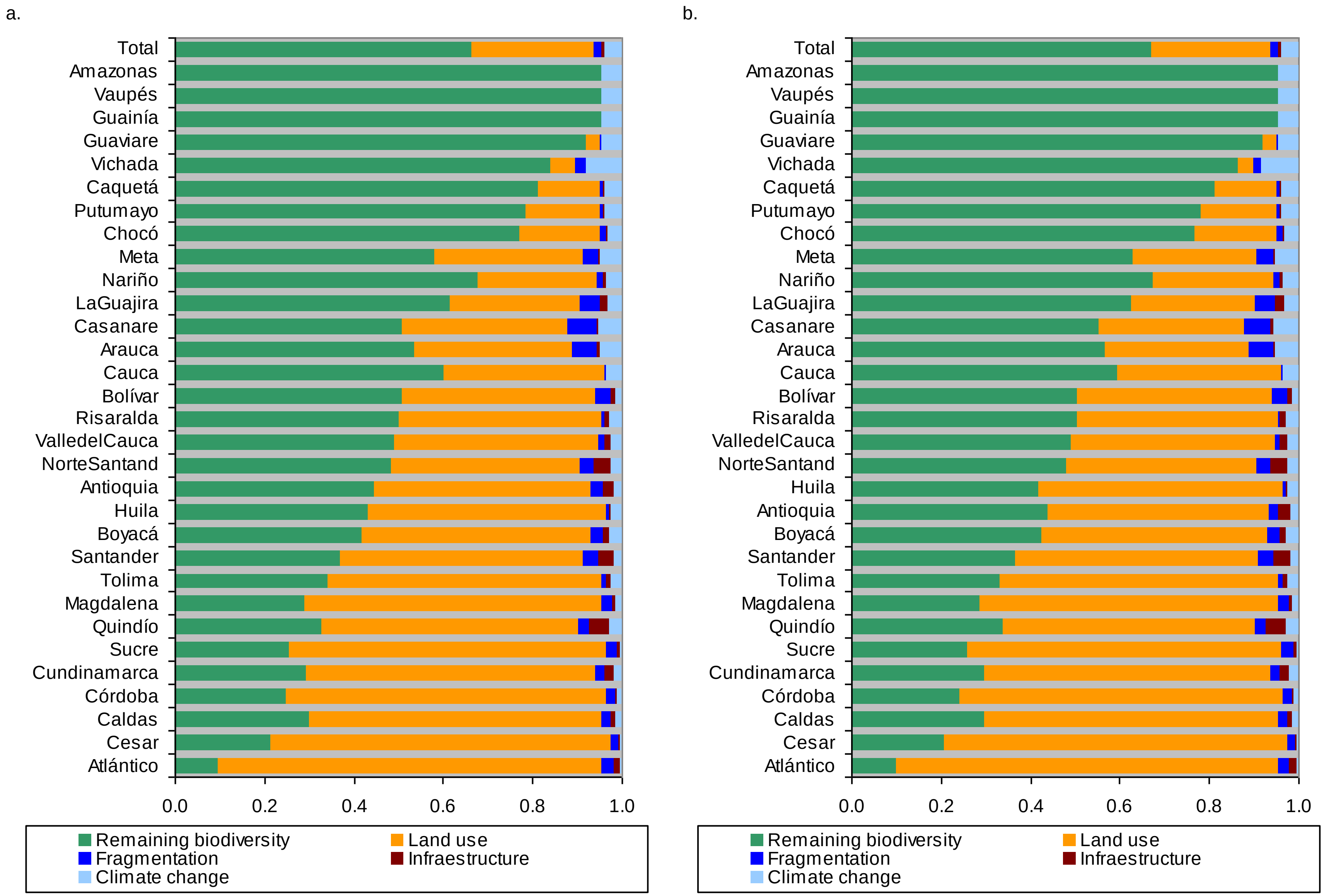


Figure 13 MSA Map for Colombia and contribution of each factor to biodiversity loss in each Department for the year 2000 with the MF (a) and PR (b) scenarios.

3.1.4 Conclusions

To use a national standardized land use and cover map with a regional level CORINE legend proved to be very useful for the modeling needs and for the adequate results of the project. A multi-temporal land cover change analysis is needed as a validation tool. One of the more important characteristics of the hybrid model is its capacity to integrate different socioeconomic and biophysical information with land cover and demand characteristics. Even though there is detailed socioeconomic statistical information in the country, it was not used due to the regional characteristics of the project, but this information at the local level could be used to give feedback to the GLOBIO-CLUE model. Socioeconomic and Land cover scenario analysis at the regional and national level was the baseline information that is needed to do more concrete predictions of land cover change.

The regions where there is more reduction in MSA given the Markets First and Policy Reform scenarios are the Orinoquian and the Caribbean regions. Mining industry and big transportation projects are concentrated there; also, in these regions livestock grazing is more extended and many of the bio-fuel and permanent crops are been harvested at the cost of savannas, gallery and dry forests.

Also, in the Orinoquian region of the country is where there is less representation in the national system of protected areas. Recommendations, actions and policies that increase its protection and promote sustainable productive systems should be highlighted. The Caribbean region has had a long process of land transformation that goes way behind to pre-hispanic times and actually, many of the natural ecosystems that exist are remnants of the dry and humid forests that originally existed. Each of these natural patches maintains high levels of biodiversity. The Orinoquian region has remained more natural, but it is the actual colonization frontier of the country.

Taking into account some of the uncertainties of the models, the regions that remain more pristine in the 2030 scenarios are the Pacific and Amazonian regions, but the Andes is where the scenario models predict more areas to increase its MSA. Due to the variability in temporal and historical spatial dynamics of land use in the region and its dynamics of land tenure, results should be handled with care and its analysis should receive feedback from other models at different scales and with different driving factors.

For Colombia, the driver of change that causes the highest reduction in MSA is Land Cover (25.4 % in 2000 to 27.3 % in the MF scenario). How this predictive change affects the natural ecosystem composition and pattern and how this is related with its functioning should be topics for posterior analysis. Climate Change is projected to have a low and more rapid effect in the Orinoquian region, and in sub-xerophitic shrublands of the Andes and the Caribbean. Even though, the effect of climate change in the biodiversity of the Andean region has to be evaluated more adequately due to the uncertainties of the global climatic circulation models in areas of high climatic variability like in the Andes, and the high number of restricted range species with a short environmental range that live there.

Colombia has a total reduction in MSA of 3.9% and 3.3% in the MF and PR scenarios. The model does not take into account the importance of hotspots and the relative importance in maintaining high levels of biodiversity in these areas. How this reduction affects the biodiversity should be taken into account if an evaluation of the reduction in biodiversity loss for the year 2010 is to be done.

In the applied model the transportation network is assumed to remain the same during the 30 year analysis period. But there are high levels of uncertainty in this assumption given the political context of the country. However, to incorporate a new road transportation network in the model is easy and the results could be used as a way to draw attention of the impact of new transportation projects on biodiversity to decision makers.

There are many other sources of uncertainty in the model, for instance the quality of the available spatial data is limited and we are assuming that we have the correct climatic and land cover data and that the environmental variables and the logistic statistic models detect and control correctly (using spatial extrapolation) the relations and limits of the different land uses. Also, with this methodology it is assumed that the weight for each MSA sub index is the same. In this sense, other alternatives that consider the different weights between the sub indexes could be considered for the estimation of the MSA (e.g. Saisana *et al.* 2005)

Different policies and managements may influence the rate of land use change; these results should be shown to decision makers with effective communication skills as a way to turn the tendencies and as a tool to take better decisions related with proposed infrastructure, biofuel and mining sector projects. The MSA model has, as one of its more typical applications, its communication possibilities to both scientists and decision makers and this should be boosted up.

3.2 Ecuador

3.2.1 Introduction

Continental Ecuador has an area of approximately 248 100 km^2. It has been estimated that this country, with the approximate size of the state of Nevada, harbors between 5 and 10% of the global biodiversity (measured as species number). However, in spite that 17% of the area of Ecuador falls inside the national system of protected areas (SNAP), it has been found that much of this country's biodiversity still faces important threats from anthropogenic activities. For example, a recent study estimates that the average of remnant distributions for birds and plants in the Andean region is 52%, while it would be 42% for the Coast. In the same study, it is estimated that the average level of representation inside the SNAP of a set of bird and plant species selected as proxies of the conservation status of biodiversity is 49 and 86% respectively in the highlands. In the coast, the average representation of bird species inside the SNAP is only 11%, while for plants this level is 14%. These figures reflect important challenges in the future for the persistence of Ecuador's biodiversity.

The high levels of environmental heterogeneity in Ecuador are mirrored by the diversity of productive systems and the heterogeneity of its social and natural landscapes. Historically, the coastal region has experienced the development of highly intensive productive systems linked to international markets. The roots of this process are the existence in the region of fertile soils and a seasonally dry weather, especially in the southern portion of the Coast (Murphy & Lugo 1995). In parallel, the second half of the past century witnessed an important process of migrations to the cities and the areas dedicated to the production of agricultural goods for international markets. As a consequence, the landscapes in the central and southern portions of the Coast are dominated by crops such as banana plantations, rice and sugar cane. In contrast, the moister region in the north of the Coast has less intensive agriculture and the most important land use systems are associated with the extraction of tropical hardwoods by a complex set of actors that include smallholders, wood exporting companies, and middlemen (Sierra & Stallings 1998; Sierra 2001).

The Ecuadorian Andes have experienced long term processes of human use that pre-date the Spanish conquest (Denevan 1992). The colonial era marked an important process of accumulation of land ownership, where the most productive lands located at the bottom of the inter-Andean valleys were allocated to large operations, while the less attractive lands located at higher elevations were used by smallholders, mostly of indigenous origin. The land reform processes that took place at the end of the 1960s and beginning of 1970s had limited impacts and the described patterns of land ownership still prevail in important areas of the Ecuadorian Andes (Caviedes & Knapp 1995). In this context, the conversion of ecosystems in the Ecuadorian Andes to agricultural uses has been widespread. The active agricultural frontier is situated near the Páramo ecosystems, where the main agricultural systems correspond to complex associations of annual crops operated by smallholders, or extensive uses of the territory related to cattle grazing.

The Amazon region of Ecuador has experienced the most recent process of intensification of human intervention in relation to the Coast and the Andes. In the second half of the past century, the coverage of road infrastructure in this region was expanded, in a process associated with the beginning of oil exploration and exploitation activities. Given the conditions of high demand for suitable land in the Andean region, the process started an important period of migration to the Amazon region in the 1970s (Walsh et al. 2002). The main environmental changes resulting from these processes has been the deforestation and fragmentation of tropical forests, especially in the northern part of this region, associated with cattle ranching and industrial mono-crops (e.g. oil palm) (Sierra 2000). The southern part of this region remained more isolated, and in this area mixed-economy agricultural systems dominate.

3.2.2 Methodology

The implementation of the GLOBIO3 methodology in Ecuador allowed the assessment of the general state of biodiversity conservation for the year 2000. In addition, scenarios of the MSA indicator were created for the year 2030. Figure 14 depicts the general methodological strategy used in the generation of the scenarios.

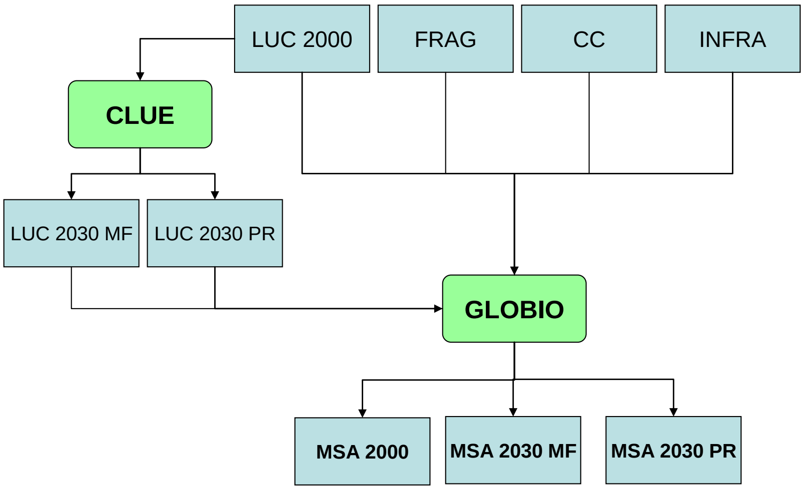


Figure 14 Methodological framework used to asses the biodiversity state for year 2000 and for market forces (MF) and policy reform (PR) scenarios for year 2030

In the methodological framework presented in figure 14, the main driver of pressure projected to the year 2030 is land use and land cover. Other pressure factors that also change for the year 2030 are fragmentation (resulting from LUCC) and climate. Below the implementation of the CLUE is presented for the generation of land use and land cover scenarios for the year 2030. Afterwards the generation of pressure factors and the total MSA calculation are described.

The final activity in the implementation of the methodology GLOBIO3 - CLUE was the socialization of the main results to different audiences in order to receive comments and suggestions to the methodology and results. Two workshops were held for discussion, the first aimed at a group of researchers in the field of conservation and biodiversity management, and the second aimed at a group of decision makers in areas related to environmental planning.

3.2.2.1 Implementation of CLUE in Ecuador

Soils and land cover data sources

The base information used in the generation of the land use scenarios is the Map of land cover and land use for the year 2000 generated by the PROMSA project for Ecuador (MAG-IICA-CLIRSEN 2002). This map was generated using a combination of digital classification and visual interpretation accompanied by a process of extensive field validation. This map depicts six main natural and anthropogenic land use and land cover classes: 1) forest vegetation, 2) pastures, 3) crops (monocrops and associations), 4) water bodies, 5) eroded areas and 6) other (e.g. glaciers). In addition, the map implements a cartographic representation that depicts both pure classes (e.g. 100% banana plantations) and associations with different levels of dominance (e.g. 70% agroforestry – 30% pastures, 50% forest – 50% pastures). The map contains 32 pure classes and 172 associations.

The map was visually edited using as a reference a set of ASTER images for the period 2000 – 2001. The edition process included the spatial redefinition o the boundaries of some polygons and / or the change of attributes in other cases. Finally, with the purpose of adapting the map to the requirements of the MSA indicators, the original classes in the land use and land cover map were reclassified using the thematic definition attached to the MSA_{LUC} classes (table 1). The resulting classes are listed in table 7. The field "Modeled land use" indicates which land use and land cover classes were used in the regression modeling stage (Section 4.1). The classes of bare soil, water bodies and urban areas were assumed constant for the modeled period. The natural vegetation classes decrease as a result of the increment in area of the modeled land uses. Therefore, no models were estimated for these classes. The reclassified land use map was transformed to a raster format at a resolution of 1 km^2 using a nearest neighbor assignation.

Class	Abbreviation	Area (km2)	%	Land use modeled
Primary forest	BP	118 133	47.61	No
Forest Plantations	PF	182	0.07	No
Fully managed irrigated agriculture	AT	8 119	3.27	Si
Commercial intensive agriculture	AI	16 877	6.80	Si
Perennial crops and bio-fuels	CP	17 733	7.15	Si
Shrublands and grasslands	PN	38 120	15.36	No
Artificial Grass	PP	43 879	17.69	Si
Bare soil / Rocks / glaciers	SD	1 035	0.42	No
Lakes	AN	1 744	0.70	No
Reservoirs	AA	342	0.14	No
Eroded land / urban areas	AE	1 949	0.79	No
	TOTAL	248 113		

Table 7 Reclassified land use classes from the PROMSA land use and land cover map

Transition rules

The present implementation of CLUE did not include restrictions on land use change due to spatial policies. In its place, protected areas were included as a variable in the generation of models of land use and land cover (See page 44). The logic behind this methodological strategy is that many protected areas in Ecuador contain areas dedicated to anthropogenic uses. It was therefore decided to estimate the effect of the existence of the protected areas rather than take a very restrictive policy (e.g. not consider deforestation processes within protected areas).

The parameters of elasticity considered for the land uses included in CLUE are found in table 8. The values of stability used confer greater stability to the natural vegetation classes. Similarly, the land use classes were sorted according to their value of elasticity, giving it greater facility in ascending order to pasture, intensive agriculture, technified agriculture, perennial crops and forest plantations.

Class	Elasticity	BP	PF	AT	AI	CP	PN	PP
Primary forest	1.0	+	+	+	+	+	-	+
Forest Plantations	0.9	-	+	+	-	+	-	-
Fully managed irrigated agriculture	0.7	-	+	+	+	-	-	+
Commercial intensive agriculture	0.5	-	+	+	+	+	-	+
Perennial crops and biofuels	0.8	-	+	-	-	+	-	-
Shrublands and grasslands	1.0	-	+	-	+	-	+	+
Artificial Grass	0.0	-	+	+	+	+	-	+

Notes: The signs (+) and (-) indicate that the transition from the current use (column) to the future use (row) is permitted or not, respectively. The classes bare soil, natural and artificial water bodies, eroded areas and urban areas were not projected in the scenarios (i.e. maintain a constant area).

Table 8 Transition matrix and elasticity parameters used in the implementation of CLUE

Demand

Two scenarios of future demand for land use and land cover were generated for year 2030. These scenarios are based on the information generated by Raskin and Kemp - Benedict (2002) at South America's level for the Third Review of the Status of the Global Biodiversity Outlook (GEO-3). In that study, two possible estimates of growth in land use were generated based on narratives for four possible future scenarios. We used the narratives and data for the "Market Forces" (MF) and "Political Reform" (PR) scenarios to create two land use scenarios for year 2030.

Distribution Models

Empirical models were implemented to estimate the "preference" or suitability across the landscape for the technified agriculture, intensive agriculture, crops and perennial grasses land uses (table 7). The dependent variable was a binary map with value 1 for every occurrence of the above land uses and 0 for the remaining classes. The independent variables used in the models were:

Topographic variables: elevation, slope, planiform curvature, relative slope position, terrain convergence index, terrain ruggedness index, topographic relative moisture index, topographic exposure index, terrain shape index.

Climatic variables: yearly annual precipitation, ombrothermic index, ombrothermic index of the 2 driest months, thermicity index

Accesibility variables: time to market

Legal protection system: natural protected areas

Soil variables: soil depth, soil drainage class, soil fertility. (Source: Mapa de Suelos del Ecuador, scale 1: 1'000 000)

Description of the topographic, climatic, accessibility and legal protection system variables are shown in 6.1.

To avoid potential problems of multicollinearity introduced by the topographical variables, exploratory analyses were conducted to select a subset of independent variables with lower correlation among them. To this end, a factor analysis was made to generate a matrix of rotated components (Principal Component Analysis, with Varimax rotation). The analysis of the components allowed identifying variables that potentially would be contributing with the same information (ie variables correlated). The variables used for models are listed in table *10*.

To include regional differences in terms of biophysical and socio-economic dynamics associated with different types of land use, empirical models were constructed for six sub-regions within continental Ecuador. The sub - regions were defined on the basis of general biophysical differences as historical criteria that are considered to have influenced and influence the productive dynamics observed in the present (figure 15).

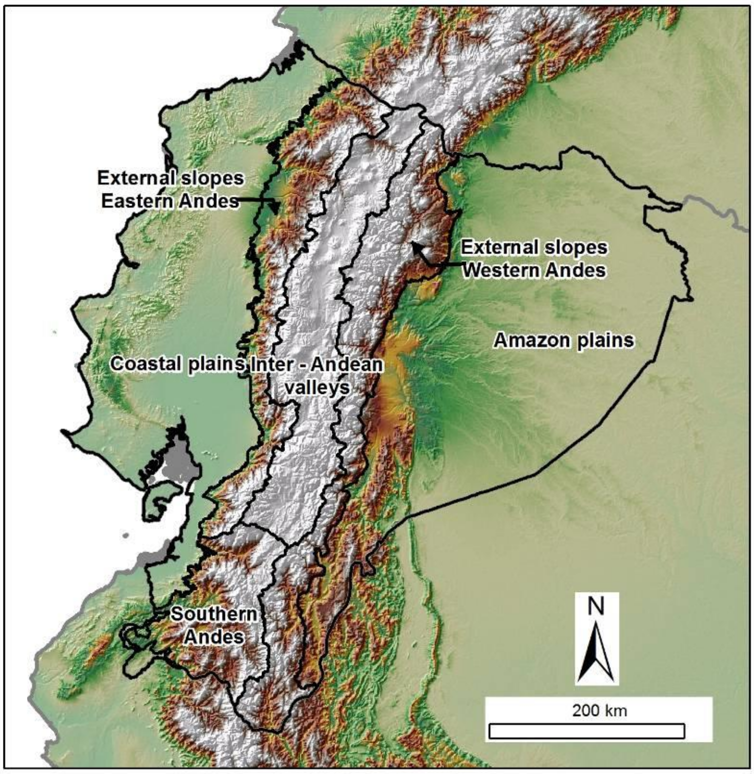


Figure 15 Sub regions defined in continental Ecuador for modeling land use

Samples of pixels to calibrate the models were created using the utility FileConvert V 2.0 which is part of the CLUE platform (Verburg 2005). This tool allows creating a random sample of observations to estimate the coefficients of logistic regression for each land use to be modeled. To generate the samples a selection of 10% of the area of Ecuador (i.e. ~ 24,800 points) for each land use modeled was defined. Additionally, a minimum distance between each observation of at least 2 pixels (i.e. 2 km) was used to control as far as possible the autocorrelation between observations. Finally, the observations in the sample so obtained were classified by sub-region (figure 15). The regressions were estimated for each sub-region for the land uses that were considered would have a more dynamic change in the modeled period (table 9). Additionally, certain uses had very marginal areas in some sub-regions and did not appear represented in the sample.

Class	Coast	South Andes	Andes west side	Inter-andean valleys	Andes east side	Amazon
Fully managed irrigated agriculture	745	12	33	14	0	0
Commercial intensive agriculture	389	200	193	799	16	61
Perennial crops and biofuels	1064	60	379	40	72	166
Artificial Grass	2186	261	315	404	215	1049

Note: The gray highlighted results in the table were modeled.

Table 9 Land uses modeled by sub-region. The cell values correspond to the size of the sample for use/sub-region.

The models for each land use were generated using a Backward stepwise selection method with probabilities of 0.01 and 0.02 for entry and exit, respectively. The resulting models were evaluated using the AUC index, which measures the area under the ROC curve (Receiver Operating Characteristics). The calculations were made using SPSS V. 15.

3.2.2.2 MSA values calculation for the continental Ecuador

The values of the MSA were calculated for the continental Ecuador at year 2000 and for the two land use scenarios (MF, PR) at year 2030 (figure 14). The calculation was made using the factors described in Eq. 1 with the exception of the atmospheric nitrogen deposition factor. This is because the data source of nitrogen deposition has a too low resolution (50 km) in relation to the data for the other factors considered (1 km) and that the estimates included in GLOBIO 3 were made for ecosystems that are not found in South America.

The generation of MSA_{LUC} was made on the basis of the values presented in table 1 for the classes represented on the maps of land use and land cover for the years 2000 and 2030 (table 7). The impact of the infrastructure was calculated using Eq. 2 for the years 2000 and 2030. The data source for population density was a map created for the evaluation of conservation priorities in Ecuador (Cuesta et al. 2007). Similarly, the MSA_{FRAG} was calculated for the three land use maps (2000 and two scenarios at year 2030). For this factor it was considered both the fragmentation generated by human activities and the fragmentation between natural ecosystems (e.g. between grasslands and forests). The MSA_{CC} was calculated on the basis of the data of temperature rise to year 2030 estimated in the base scenario of the OECD for the biomes reflected in table 2. Finally, the final MSA was obtained for the four factors mentioned for the year 2000 and for the two scenarios at year 2030.

3.2.3 Results and discussion

3.2.3.1 Land use and land cover scenarios for 2030

Land use distribution models

The results of logistic regression models for each sub-region defined in Ecuador are presented in table 10. In general, the AUC values obtained suggest that the models differentiate properly biophysical and socioeconomic conditions influencing the spatial location of different land use types. The models for perennial crops and irrigated agriculture show the highest values of AUC, which suggests that the spatial distribution of these uses responds adequately to the selected variables. In contrast, the models for man-made pastures have lower values for this measure of quality. This may be due to the greater diversity present in this kind of land use, representing both modern technology systems to managed pastures (e.g. for dairy production) and less intensive systems. The exception to this pattern occurs in the Amazon, where livestock systems tend to have greater uniformity in terms of handling and response to factors of spatial location.

There are some general patterns resulting from the influence of the variables used on the land use distribution modeling (table *10*). For example, in cases where the variable that represents the National System of Protected Areas (SNAP) has a significant influence on the land use type, this variable, consistently inhibits the probability of occurrence of these uses. This empirical verification of the influence of protected areas allows obtaining more robust projections of future LUCC, under the assumption that the management of protected areas is maintained in the modeled period. Another factor which consistently decreases land use type probability of occurrence is greater distance to markets (d_hours). This pattern is consistent with results of other studies regarding the effect of transportation costs on the occurrence of various land use types (Walker 2004).

Other variables have more complex patterns which vary by sub-region. For example, while the probability of occurrence of perennial crops increases with altitude for the Coast and Amazon regions, it decreases in the eastern slopes of the Andes. In a similar way, higher values of slope influence negatively the probability of occurrence of irrigated crops, but not perennial crops in the coast. These higher values of slope also increase probability of perennial crops for eastern slopes of the Andes and Amazon regions. This may be because the management of perennial crops is not significatively affected by steep slopes and other agricultural uses. In sum, the models reflect specificity on different combinations of variables for the different regions of the country.

	Fully managed irrigated agriculture	Commercial intensive agriculture				Perennial crops and biofuels				Artificial Grass					
	Coast	**Coast**	**South Andes**	**Andes west side**	**Interandean valleys**	**Coast**	**South Andes**	**Andes east side**	**Amazonia**	**Coast**	**South Andes**	**Andes west side**	**Interandean valleys**	**Andes east side**	**Amazonia**
elev	- (***)		+ (***)			+ (***)		- (***)	+ (***)		- (***)	+ (***)			+ (***)
io_d2	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)		+ (***)	- (***)	+ (***)	- (***)		- (***)	- (*)
prectot	+ (***)		- (***)	- (***)		+ (***)	+ (***)		- (***)	+ (***)	+ (***)		+ (***)	+ (***)	+ (***)
slope	- (***)		+ (***)		- (**)	+ (***)		+ (***)	+ (**)	+ (***)	+ (*)	- (**)			- (***)
total_c													- (**)		
trmi		+ (*)	+ (**)	+ (*)					+ (*)						+ (***)
tscales									- (**)	- (***)			- (***)	- (***)	- (***)
d_hours	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (**)	- (***)		- (***)	- (***)	- (***)	- (***)	- (***)
s_dren_1	- (***)	+			+ (***)					+ (***)				-	
s_dren_2	- (***)	+ (***)			+ (***)				-	+ (***)				- (*)	
s_dren_3	- (***)	+			+ (***)				-	+ (***)				- (***)	
s_dren_4	- (***)	+			+ (***)				- (**)	+ (***)				- (***)	
s_fert_1		+	- (**)		- (***)				- (***)	-				+	- (***)
s_fert_2		-	- (***)		- (***)				- (**)	- (***)				+	- (***)
s_fert_3		- (*)	- (*)		- (***)				+	-				+ (*)	- (***)
s_fert_4															
s_prof_1	+ (***)	-			+ (**)				+ (**)	- (***)					+
s_prof_2	-	+			+ (***)				+ (**)	+					+ (***)
s_prof_3	- (***)	-			+ (**)				+ (***)	+					+ (***)
s_prof_4															+
snap	- (***)				- (**)		- (**)	- (**)		- (***)			- (***)		- (***)
AUC	0.900	0.696	0.815	0.779	0.846	0.799	0.876	0.880	0.960	0.658	0.715	0.727	0.689	0.853	0.856

Notes: In each cell it is specified the positive (+) or negative (-) influence of the variable on the probability of occurrence for each land use. The level of significance is specified by the number of stars (***) <0.001; (**) <0.01 (*) <0.05. The variables used are elevation (elev), ombrothermic index of the two driest months (io_d2), average annual precipitation (prectot), topographic slope (slope), total curvature (total_c), topographic index of relative humidity (trmi), landscape roughness index (tscales) distance in hours to the nearest market (d_hours), four kinds of soil drainage (s_dren), four kinds of soil fertility (s_fert), four kinds of soil depth (s_prof), and areas belonging to the national system of protected areas (snap) (See 6.1).

Table 10 Results of the logistic regression models for land uses by sub-regions

Demand

The market forces scenario considers that the trends observed in recent decades will continue in the future. In this scenario, economic development and processes related to the preservation of the environment are managed mainly through market mechanisms. The liberalization of economies continues and eventually the developing countries converge to the models and institutional development of the industrialized countries. In contrast, the political reform scenario considers that social and environmental sustainability objectives are achieved through policies at different levels of organization. This scenario considers that the market is not the most effective mechanism for maintaining common beings supply (e.g. natural capital) and gives more emphasis to proactive mechanisms of governance (Raskin & Kemp-Benedict 2002).

These two scenarios are associated with future estimates for a set of indicators related to the environment, the economy, energy use, environmental pressures, among others. To generate the estimated demand for land use and land cover for the year 2030, the projections Raskin & Kemp - Benedict (2002) were used as a base for the indicators of land use and land cover (table 11).

Class	Area ($x10^6$ ha)					Δ 2000 - 2032 (%)	
	1995	2015		2032			
		MF	*PR*	*MF*	*PR*	*MF*	*PR*
Urban areas	17.5	17.5	17.5	35.0	17.5		
Cropland	105.1	122.6	157.7	122.6	157.7	7.7	38.5
Artificial grassland	508.1	613.2	560.6	683.3	595.7	29.5	12.9
Primary forest	928.6	823.4	876.0	718.3	841.0		
Forest plantation	0.0	0.0	0.0	17.5	17.5		
Others	192.7	175.2	140.2	175.2	122.6		

Source: Raskin & Kemp-Benedict 2002

Table 11 Land use and land cover variation estimates for South America at year 2032

To build the estimated of land use and land cover change for the classes described in table 7 some modifications regarding the original proposal of Raskin & Kemp-Benedict (2002) were implemented:

- A linear growth trend up to year 2030 was assumed for the agricultural land and planted grass classes. This was considered more appropriate to be implemented in Ecuador in comparison to the trend specified in the Raskin & Kemp-Benedict (2002) scenarios where the agricultural land class grows until the year 2015 and thereafter maintains its extension until 2030 in both scenarios.
- To calculate the growth rate for the period 2000 - 2030, first, the average of the two scenarios for each type of land use and land cover estimated for 2000 was calculated using the trend from 1995 to 2015 (table 11). Later the growth of the agricultural lands and planted grass classes was calculated as the difference between the values of 2030 and 2000 divided for the area estimated for 2000.
- In the PR scenario, the growth rate for the agricultural area in the period 2000 - 2030 is 38.5%. It was considered that this value was too high for Ecuador and that it can represent the expansion of agricultural areas in some regions of Brazil as a result of the rising demand for bio-fuels. For this scenario an agricultural lands growth of 20.2% was assumed, as estimated by Bruinsma (2003) for Latin America and the Caribbean.
- The growth rates defined for the agricultural lands and planted grass classes were imputed to land use of the reclassified map (table 7). For example, for the MF scenario the growth rate of 7.7% was assigned to the classes "Tech agriculture", "intensive agriculture" and "perennial crops and biofuels."
- Finally, the decline of the natural vegetation classes (primary forest and natural pastures and shrublands) was calculated as the difference between the total area of the country and the growth of the anthropic use classes.

The demand scenarios implemented are reflected in table 12. As it is shown, the main difference between the scenarios is the higher growth in agricultural classes and the lower growth of the planted grass class in PR in relation to MF scenarios.

Class	2000 (%)	MF		PR	
		2030 (%)	Δ (%)	2030 (%)	Δ (%)
Primary forest	47.6	42.7	-10.4	43.3	-9.1
Forest Plantations	0.1	0.1	0.0	0.1	0.0
Fully managed irrigated agriculture	3.3	3.5	7.7	3.9	20.2
Commercial intensive agriculture	6.8	7.3	7.7	8.2	20.2
Perennial crops and biofuels	7.1	7.7	7.7	8.6	20.2
Shrublands and grasslands	15.4	13.8	-10.4	14.0	-9.1
Artificial Grass	17.7	22.9	29.5	20.0	12.9
Bare soil / Rocks / glaciers	0.4	0.4	0.0	0.4	0.0
Lakes	0.7	0.7	0.0	0.7	0.0
Reservoirs	0.1	0.1	0.0	0.1	0.0
Eroded land / urban areas	0.8	0.8	0.0	0.8	0.0

Table 12 Demand scenarios for continental Ecuador to year 2030. The values of exchange correspond to the percentage of the 2000 – 2030 variation in relation to the area of each class in 2000.

Spatial patterns of LUCC

The land use and land cover map for year 2000 and the two scenarios generated for year 2030 are shown in figure 16.

Table 13 presents the results for the four provinces that would experience the most significant changes in these two trajectories. The table shows both absolute conversion values and the percentage of loss in relation to the original area of natural ecosystems in year 2000.

a. Deforestation

Transformed surface				**Transformed rate** Related to forest and shrubland at year 2000			
Market forces		Policy reform		Market forces		Policy reform	
Province	*Km²*	*Province*	*km²*	*Province*	*%*	*Province*	*%*
ESMERALDAS	2670.0	ESMERALDAS	1982.0	MANABI	56.0	LOS RIOS	65.1
MANABI	2225.0	MANABI	1900.0	LOS RIOS	52.4	EL ORO	51.5
SUCUMBIOS	1256.0	PASTAZA	1027.0	EL ORO	48.3	MANABI	47.9
PASTAZA	1211.0	SUCUMBIOS	930.0	SANTA ELENA	48.0	BOLIVAR	32.3

b. Grassland conversion

Transformed surface				**Transformed rate**			
Market forces		Policy reform		Market forces		Policy reform	
Province	*km²*	*Province*	*km²*	*Province*	*%*	*Province*	*%*
GUAYAS	980.0	GUAYAS	619.0	LOS RIOS	74.4	LOS RIOS	70.7
MANABI	692.0	CHIMBORAZO	464.0	MANABI	38.7	MANABI	25.2
CHIMBORAZO	329.0	MANABI	450.0	GUAYAS	34.2	IMBABURA	22.4
IMBABURA	282.0	IMBABURA	304.0	IMBABURA	20.8	GUAYAS	21.6

Table 13 Deforestation and ecosystem conversion trends in the most affected provinces according to the scenarios for year 2030 (market forces and policy reform

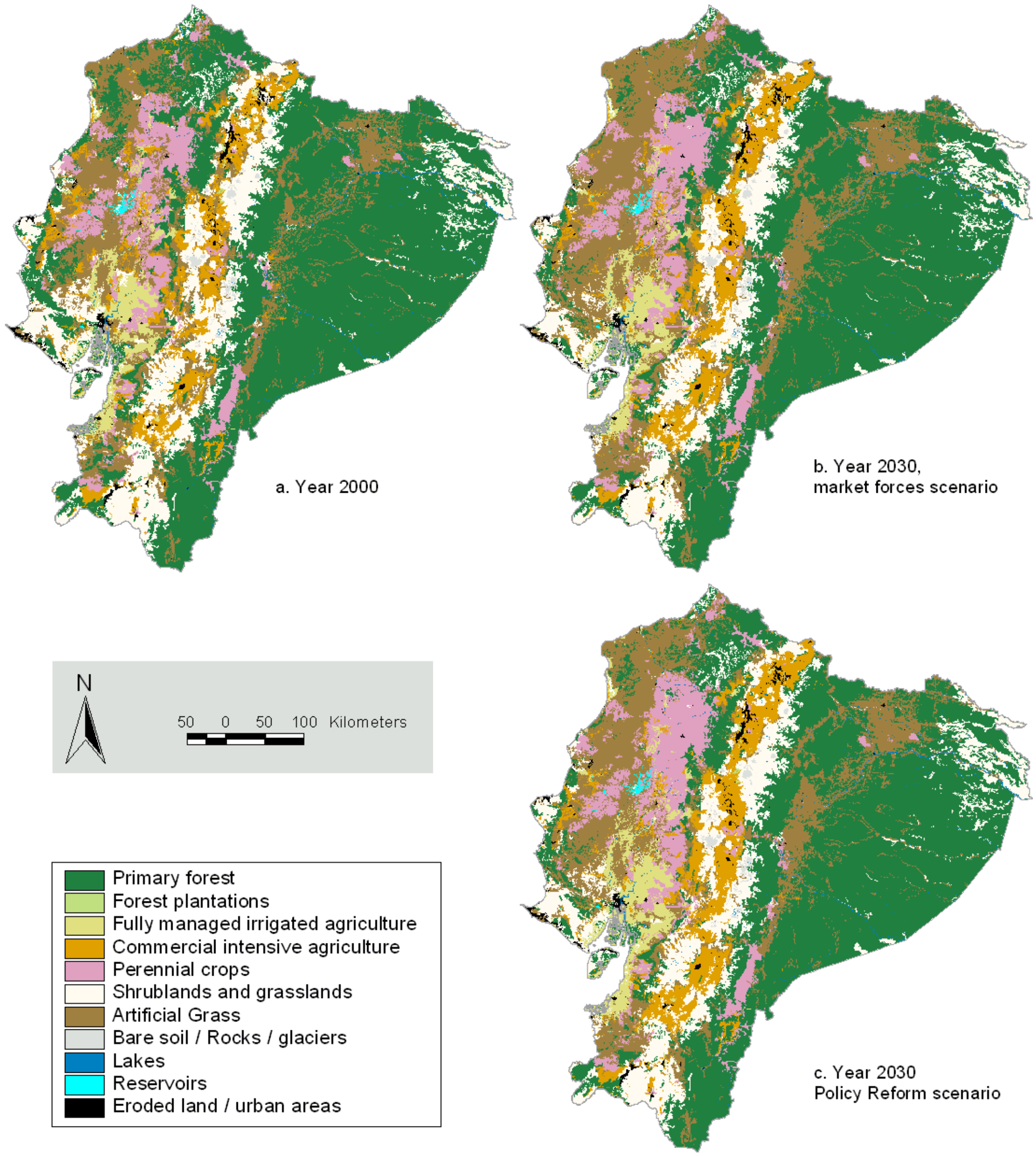


Figure 16 Spatial patterns of land use and land cover change at year 2000 and two scenarios generated in CLUE for the year 2030.

For both scenarios, the highest values of deforestation would be located in two coastal provinces (Manabi and Esmeraldas) followed by two provinces in the Amazon region (Pastaza and Sucumbios). However, analyzing the percentage of loss of forest cover in respect to the forest area in 2000, the most affected provinces will be Manabí, Los Ríos, El Oro, Santa Elena and Bolívar (table 13). This is because the provinces on the coast have suffered historically high levels of intervention and therefore forest cover at the beginning of the modeling period is lower in relation to other provinces (e.g. in the Ecuadorian Amazon). The provinces with higher conversion of grassland and shrubland ecosystems in absolute terms are Guayas, Manabi, Chimborazo and Imbabura. In percentage terms for this conversion trajectory the most affected provinces would be Los Rios, Manabi, Guayas and Imbabura.

Generally speaking, it can be seen that the province that would experience major conversions in their natural ecosystems (forest and grassland) is Manabi. For all provinces, the PR scenario assigns lower absolute values of deforestation than the MF scenario. In all the cases, the most important transition is forests to planted grasses followed by forest to perennial crops. The analysis of potential loss of natural ecosystems by absolute value and percentage would allow assigning priorities for differentiated intervention. For example, if the interest is to preserve areas of scarce natural ecosystems in the various provinces, the most appropriate indicator is the percentage of loss.

An important factor that can not be inferred directly from the presented results is which specific ecosystem(s) would be under different levels of threat. For example, in table 13b, the conversion of grassland and shrubland ecosystems is mainly due to the loss of deciduous forest areas in the coast provinces, while representing loss of moorland areas in the highland provinces. A similar distinction can be done to the trajectories of deforestation, which represent an aggregate loss of both montane forest and lowland forests.

3.2.3.2 Scenarios of biodiversity state in Ecuador

Spatial patterns of the remaining MSA at year 2000 can be seen in figure 18. The map shows areas with low remaining biodiversity corresponding to the areas of intensive human use on the coast, inter – Andean valleys, and the deforestation fronts in western Amazonia. In contrast, areas with high remaining biodiversity can be observed in the Amazon, the east side of the Andes and the northern coast. In general, there is correspondence between protected areas with areas of high biodiversity remnant (i.e. high MSA), and the existence of significant gaps in protection in the provinces of Pastaza, Morona Santiago and the north of Esmeraldas and Carchi. In the central-south coast, the most important areas of remaining biodiversity are forests associated with the Cordillera Chongón - Colonche in the provinces of Manabí, Santa Elena and Guayas.

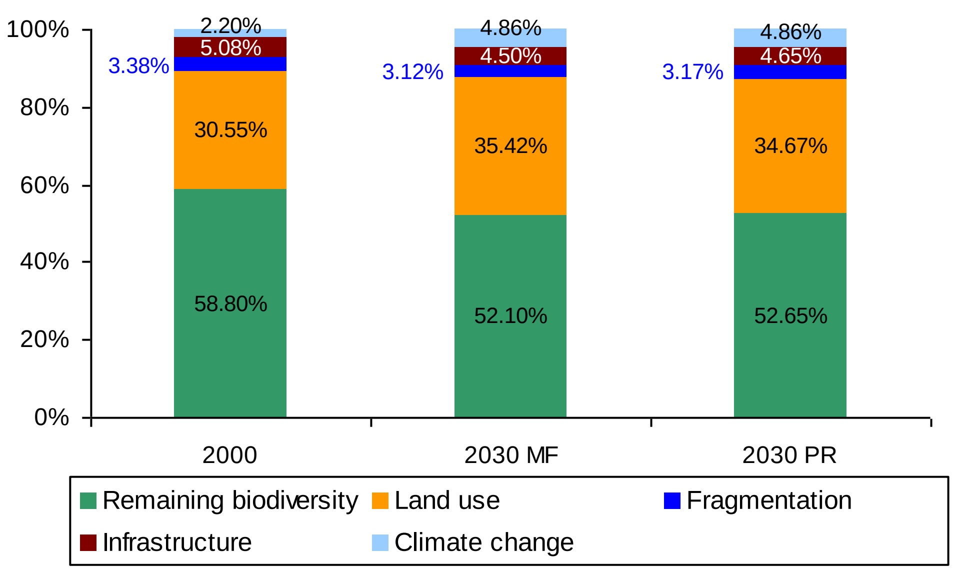
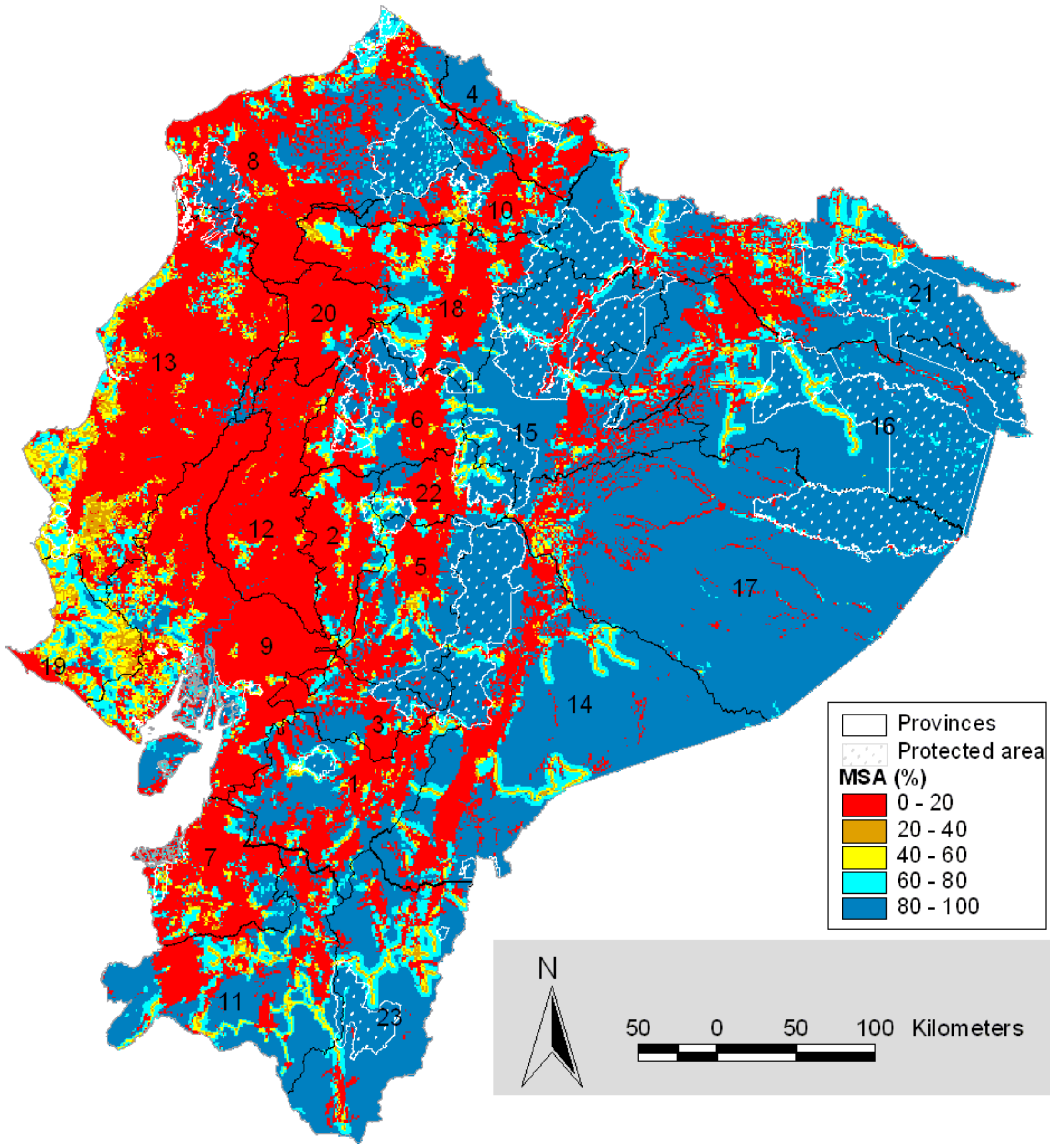


Figure 17 MSA national values for year 2000, year 2030 market forces scenario (2030 MF) and year 2030 policy reform scenario (2030 PR)



Provinces

1 Azuay	6 Cotopaxi	12 Los Ríos	18 Pichincha
2 Bolívar	7 El Oro	13 Manabí	19 Santa Elena
3 Cañar	8 Esmeraldas	14 Morona Santiago	20 Santo Domingo De Los Tsachilas
4 Carchi	9 Guayas	15 Napo	21 Sucumbios
5 Chimborazo	10 Imbabura	16 Orellana	22 Tungurahua
	11 Loja	17 Pastaza	23 Zamora Chinchipe

Figure 18 Remaining MSA for year 2000 in continental Ecuador

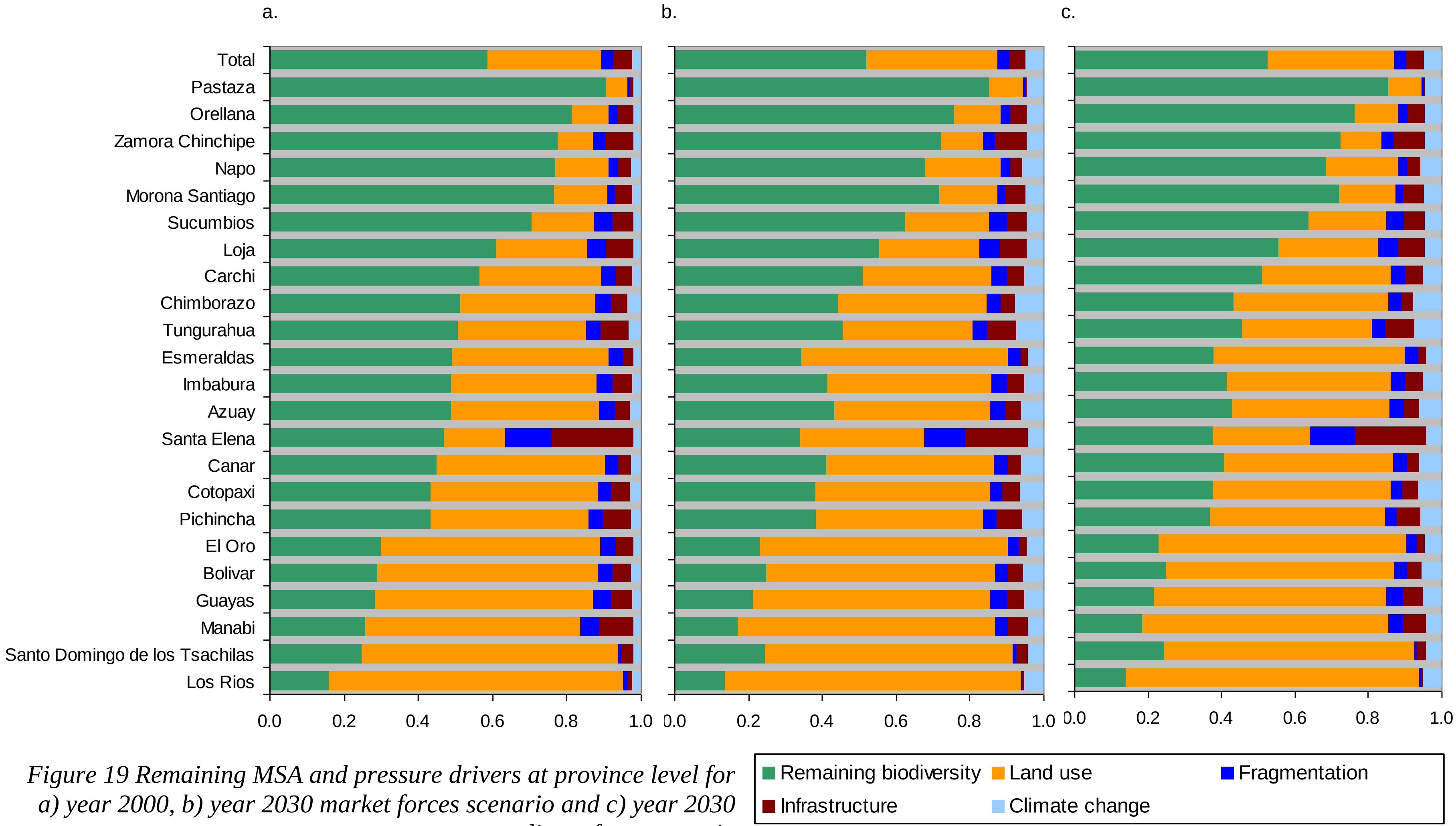


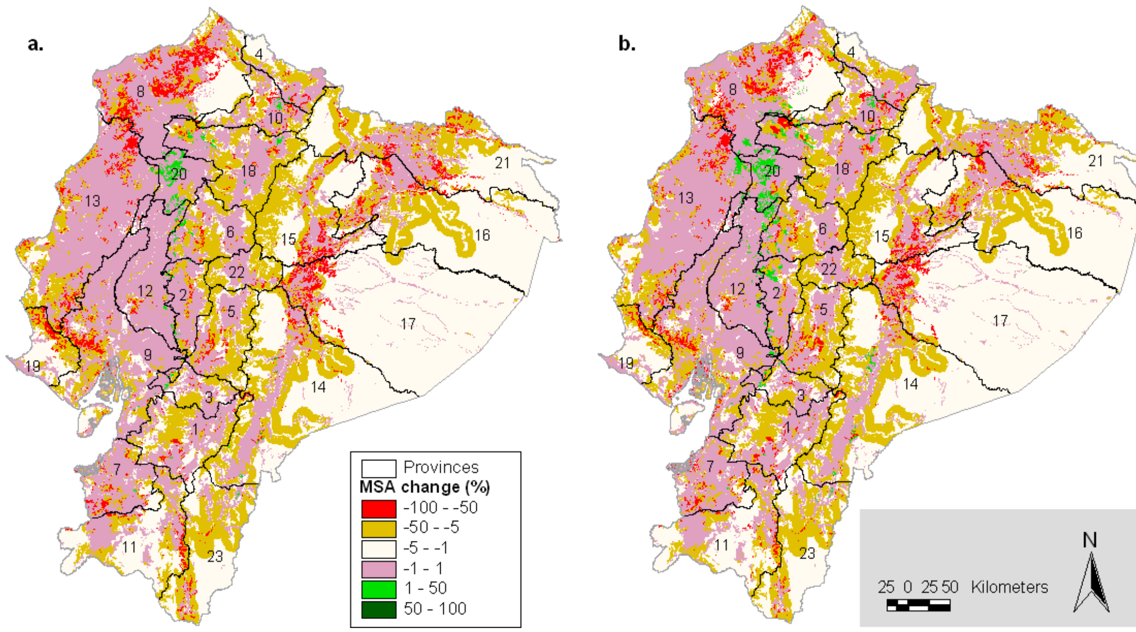
Figure 19 Remaining MSA and pressure drivers at province level for a) year 2000, b) year 2030 market forces scenario and c) year 2030 policy reform scenario

The value of the remaining MSA at the national level calculated using Eq. 1 would decrease from 58.8% in 2000 to 52.1% in 2030 according to the MF scenario, and to 52.65% according to the PR scenario (figure 17). The pressure driver which most contributes to this loss is land use, which grows from around 30% in 2000 to about 35% in both scenarios in 2030. At the province level, the lower levels of remaining biodiversity in 2000 are Los Rios, Santo Domingo de los Tsáchilas, and Manabi, while the highest levels are found in Zamora, Orellana, Pastaza and (figure 19). As in the national level, the most important driver factor is land use in all provinces with the exception of Santa Elena, where infrastructure and fragmentation have a major influence. This is because of the dominance of areas of dry forest in the province, which are the natural areas that are more susceptible to the impacts of the road network and uses associated with them (e.g. extensive grazing).

The projections of change in the MSA show that the provinces that would experience further decline in its remaining biodiversity from the levels estimated in 2000 are Esmeraldas and Santa Elena. In contrast, the provinces that experienced less decrease are Santo Domingo de Los Tsáchilas and Los Rios (table 14). These patterns are explained because the latter two provinces have the lowest levels of remaining biodiversity in 2000. In contrast, in some provinces the MSA change scenarios indicate that at least in some areas the biodiversity state could be improved (table 14). This pattern is particularly noticeable in the western portion of the province of Santo Domingo de Las Tsáchilas (figure 20a). These positive changes in the state of biodiversity are related to areas where livestock systems are replaced with permanent crops according to the scenarios constructed in CLUE.

Provincia	Market forces			Policy reform		
	Min	Max	Avg.	Min	Max	Avg.
AZUAY	-0.862	0.050	-0.053	-0.871	0.050	-0.058
BOLIVAR	-0.817	0.108	-0.041	-0.885	0.108	-0.039
CAÑAR	-0.864	0.108	-0.037	-0.864	0.108	-0.041
CARCHI	-0.853	0.052	-0.055	-0.853	0.052	-0.055
CHIMBORAZO	-0.885	0.093	-0.072	-0.885	0.093	-0.081
COTOPAXI	-0.860	0.115	-0.052	-0.818	0.142	-0.059
IMBABURA	-0.868	0.099	-0.071	-0.856	0.099	-0.073
LOS RIOS	-0.885	0.134	-0.020	-0.900	0.134	-0.018
MORONA SANTIAGO	-0.885	0.118	-0.048	-0.885	0.118	-0.045
NAPO	-0.885	0.000	-0.088	-0.885	0.000	-0.081
ORELLANA	-0.885	0.093	-0.056	-0.885	0.093	-0.051
PASTAZA	-0.885	0.093	-0.055	-0.885	0.093	-0.050
PICHINCHA	-0.869	0.134	-0.049	-0.865	0.134	-0.063
SANTA ELENA	-0.798	0.000	-0.130	-0.798	0.000	-0.092
SANTO DOMINGO DE LOS TSACHILAS	-0.736	0.128	-0.003	-0.689	0.128	-0.005
SUCUMBIOS	-0.870	0.000	-0.081	-0.870	0.093	-0.068
TUNGURAHUA	-0.885	0.000	-0.052	-0.885	0.000	-0.052
ZAMORA CHINCHIPE	-0.873	0.093	-0.055	-0.870	0.095	-0.051
LOJA	-0.864	0.064	-0.056	-0.864	0.064	-0.054
MANABI	-0.885	0.134	-0.087	-0.932	0.134	-0.074
EL ORO	-0.860	0.047	-0.069	-0.853	0.047	-0.072
GUAYAS	-0.901	0.054	-0.070	-0.932	0.094	-0.066
ESMERALDAS	-0.881	0.125	-0.146	-0.881	0.125	-0.113

Table 14 Minimum, maximum and average values of MSA change in the period 2000 – 2030 by province for market forces and policy reform scenarios.



Note: Provinces numbers as in figure 18.

Figure 20 Map of remaining MSA change for a) scenario market forces and b) scenario policy reform

Finally, it is necessary to emphasize that the most important advantage in the use of MSA for land use planning lies in the flexibility that it provides to identify spatial patterns of change in multiple management units. For example, figure 21 contains the distribution of the national system of protected areas in relation to the patterns of change in the MSA in the period 2000 - 2030 for the scenario market forces. The combined analysis of the categories of Parque Nacional (PN) and Ecological Reserve (ER) reveals that the RE Mache Chindul and the RE El Angel would be most affected in terms of loss of remaining biodiversity for the modeled period. In contrast, ER Arenillas, Sumaco - Napo - Galeras and Yasuni would be the least affected.

Name	Type	Market forces			Policy reform		
		Min	Max	Avg.	Min	Max	Avg.
Cajas	Parque Nacional	-0.116	-0.007	-0.070	-0.116	-0.007	-0.070
Cotopaxi	Parque Nacional	-0.087	0.000	-0.070	-0.087	0.000	-0.070
LLanganates	Parque Nacional	-0.858	0.000	-0.054	-0.858	0.000	-0.052
Machalilla	Parque Nacional	-0.442	0.000	-0.047	-0.100	0.000	-0.044
Podocarpus	Parque Nacional	-0.864	-0.003	-0.066	-0.864	-0.003	-0.057
Sangay	Parque Nacional	-0.798	0.000	-0.047	-0.792	0.000	-0.046
Sumaco Napo Galeras	Parque Nacional	-0.864	-0.001	-0.032	-0.864	-0.001	-0.032
Yasuní	Parque Nacional	-0.124	0.093	-0.029	-0.058	0.093	-0.029
Limoncocha	Reserva Biológica	-0.199	-0.002	-0.046	-0.199	-0.002	-0.043
Antisana	Reserva Ecológica	-0.629	0.000	-0.051	-0.629	0.000	-0.051
Arenillas	Reserva Ecológica	-0.215	0.000	-0.036	-0.215	0.000	-0.036
El Angel	Reserva Ecológica	-0.085	-0.003	-0.070	-0.085	-0.003	-0.070
Cayambe Coca	Reserva Ecológica	-0.852	0.000	-0.047	-0.852	0.093	-0.046
Cayapas Mataje	Reserva Ecológica	-0.647	-0.001	-0.070	-0.369	-0.001	-0.066
Cofán Bermejo	Reserva Ecológica	-0.656	-0.003	-0.049	-0.069	-0.003	-0.048
Cotacachi Cayapas	Reserva Ecológica	-0.863	-0.001	-0.043	-0.863	0.095	-0.036
ILinizas	Reserva Ecológica	-0.860	0.000	-0.064	-0.799	0.093	-0.059
Mache Chindul	Reserva Ecológica	-0.869	0.000	-0.307	-0.866	0.093	-0.236
Manglares Churute	Reserva Ecológica	-0.538	0.000	-0.064	-0.486	0.094	-0.063
Pululahua	Reserva Geobotánica	-0.082	-0.001	-0.023	-0.083	-0.001	-0.025
Chimborazo	R. de Producción Faunística	-0.091	0.000	-0.065	-0.091	0.000	-0.065
Cuyabeno	R. de Producción Faunística	-0.260	0.000	-0.030	-0.260	0.000	-0.030
Manglares El Salado	R. de Producción Faunística	-0.429	-0.001	-0.236	-0.691	-0.001	-0.260
Pasochoa	Refugio de Vida Silvestre	-0.074	-0.060	-0.065	-0.086	-0.077	-0.080
Manglares Muisne	Refugio de Vida Silvestre	-0.115	0.000	-0.007	-0.115	0.000	-0.009
La Chiquita	Refugio de Vida Silvestre	-0.035	-0.003	-0.014	-0.035	-0.003	-0.014
El Boliche	Area Nacional de Recreación	-0.005	0.000	-0.003	-0.005	0.000	-0.003
Parque Lago	Area Nacional de Recreación	-0.257	-0.025	-0.099	-0.233	-0.025	-0.090
El Cóndor	Parque Binacional	-0.033	-0.032	-0.033	-0.033	-0.032	-0.033

Table 15 Minimum, maximum and average values of MSA change in the period 2000 – 2030 by protected area for each scenario

However, the map makes it possible to identify areas within the protected area that presents more likely to experience a reduction on their biodiversity (figure 21b). This is the case in the northwestern portion of the PN Yasuní where the main factors of pressure are associated with the impact areas of the Maxus and Auca roads. Similarly, it is expected a greater pressure in the western portions of the Cuyabeno Wildlife Reserve Production, the RE Cayambe - Coca, RE Antisana, PN Llanganates and PN Sangay. The potential areas of future involvement are more widespread within the PN Machalilla, RE Mache - Chindul, PN boxes, and Production Wildlife Reserve Chimborazo. In this example, the MSA can be used to define priorities for intervention in protected areas both nationally and within each site. However, the appropriate scale for which the methodology provides an appropriate platform for decision-making is a function of the quality and level of detail of the data used. Some of these aspects are discussed in the next section.

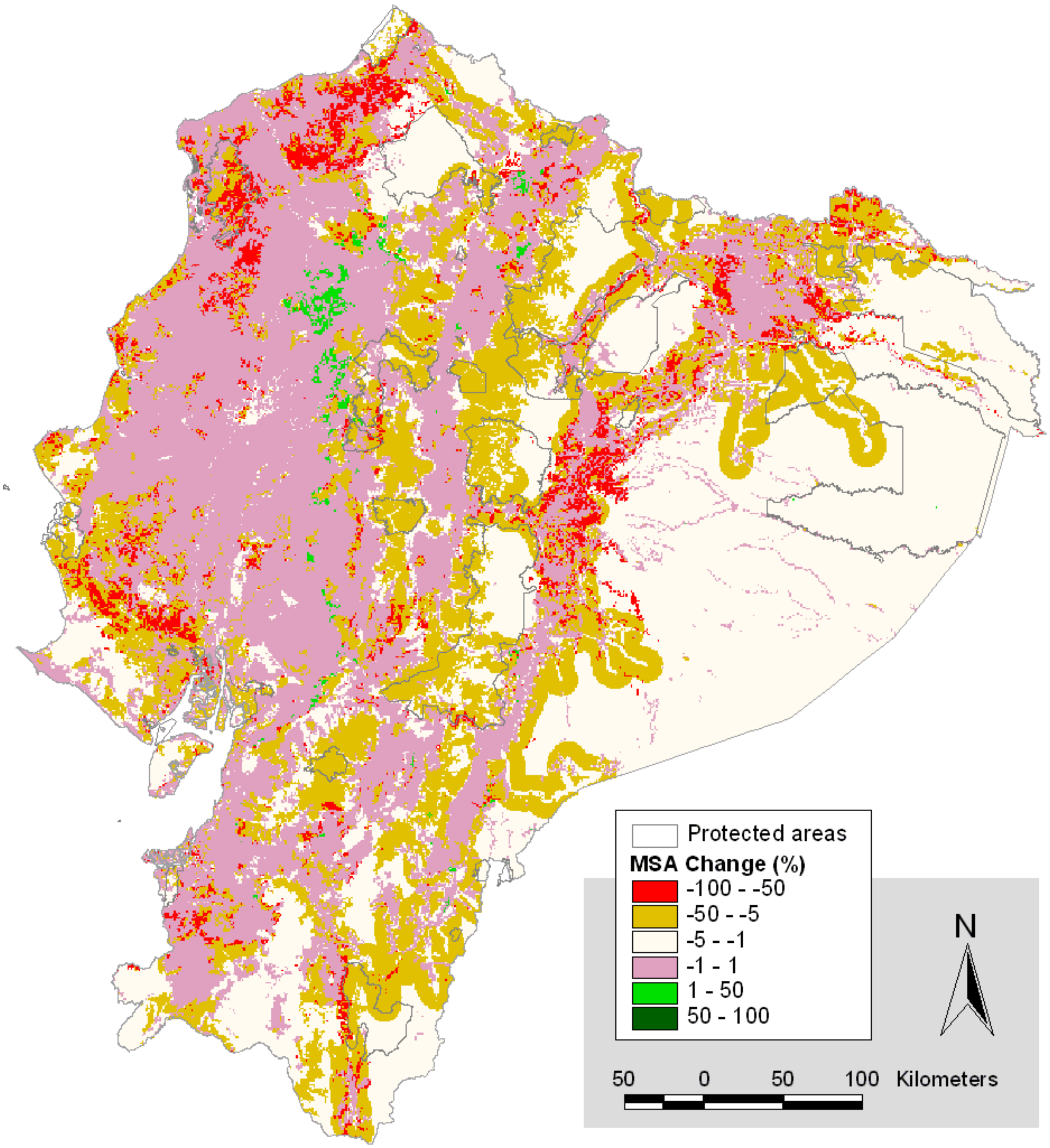


Figure 21 Map of remaining MSA change for scenario market forces and protected areas

3.2.4 Conclusions

The current implementation of the GLOBIO – CLUE methodology provides a solid base to assert that these tools can constitute the core for territorial planning in multiple scales. The main advantages of the tool are related to its capacity to present a spatial synthesis of different drivers acting together. However, there are some methodological problems and knowledge gaps which must be solved to improve its application to support the current decision process.

The methodology allowed us to evaluate the areas under potential risk. This can help us to apply a dynamic perspective in land use management and planning, under the supposition that it is possible to prioritize areas with higher land use change probability. These applications must be done in the frame of the current land use and zoning laws. In this study case, we identified provinces (used as analysis units) with large areas with low intervention levels (Amazonian provinces). We also identified areas where last ecosystem patches would suffer an important process of degradation during the modeled period (coastal provinces). It remains an open issue to define adequate strategies to achieve a balanced use of the landscape without threatening biodiversity in the long term.

Any strategy to implement land use intervention and planning process must couple the analysis of biodiversity state with models and scenarios of environmental services. As this study case has shown, some land use and land cover changes could improve the biodiversity state (for example, a change from man made grasslands to certain types of perennial crops). This kind of land use/cover change dynamic con also lead to other processes, such as carbon sequestration, water regulation, pollination. Concluding, the GLOBIO – CLUE methodology can become a synthesis framework for exploring different paths to design policies for management and conservation of natural ecosystems and their human population support functions.

Two workshops were organized to discuss the methodology and receive feedback from local researchers and decision makers. The participants recognized the potential of the GLOBIO – CLUE methodology as a tool that is able to deliver useful information which is relevant to planning processes at different scales. The main comments to the methodology were centered in the two following topics:

- A revision of the pressure factors considered in GLOBIO is needed in order to incorporate more accurate data. For example, the estimation of the impact of climate change could be done using scenarios that have been calibrated for the Andean region.
- A systematic assessment of future land use and land cover demand is needed to generate spatial predictions that provide useful information for planning at the national level. This would require validation with local expert and the generation of historic land use and land cover data so trends can be identified and projected into the near future.
- The tools should be inserted in ongoing policy formulation processes to explore the spatial consequences of different courses of action. The main policies identified were the promotion of biofuels, the securing of food self sufficiency, and adaptive responses of productive systems to environmental change phenomena.

3.3 Peru

3.3.1 Introduction

In Peru, the current social situation is characterized by enormous internal changes, basically influenced by the set of last governments that try to promote investments in the country and to develop the national road infrastructure. The last two governments have promoted the signature of free trade agreements, among which the already signed agreement with United States, that is currently being implemented, and the agreement with China, which is in negotiation process.

But the economic changes are not the only ones occurring at the present time. There is a group of new important institutional changes, and the most important one is the regionalization process. By means of this process, the old departments become regions with an authority directly elected, as well as a series of functions and competences that were in charge of the central government. This process started several years ago, and it is expected to last several years more until the correct definition of functions is finished and the functions are transferred to each one of the four levels that the Peruvian state will be constituted: national, regional, provincial and district level. The second important change, of particular relevance for the topics in this report, is the creation of an Environmental Ministry. This Ministry has been created by the Executive branch; within the frame of the competences given by the parliament to the executive, for adjusting the national legislation to the Free Trade Agreement with the United States. The structure and functions of this ministry are still under discussion, and it is expected that its constitution will contribute to organize the environmental institutions of the country.

The capabilities of institutions dedicated to environment in the country to face directly the big investment projects, has hardly been questioned in the recent years. One of the most relevant cases is the water contamination with residues of the petroleum production process in some areas of the Peruvian north forest. This type of contamination remained even when the petroleum price had begun an important increase during the last years. Part of pending work is strengthening the economic and ecological zoning processes which are the base for a territorial zoning plan. Zoning should be carried out for every region. Another important environmental task that should be promoted and carried out is the development of the strategic environmental assessments for environmentally related projects.

These tasks become more difficult as long as a severe deficit of cartographic information exists. For example, the soil type maps available have a resolution of 1:1,000,000, which is inadequate for working with the purpose of characterizing the possible land use changes, when the land use base information is at 1:100,000 scale. Likewise, the last agrarian census was carried out in 1994, when the country was still affected by the internal war.

This is a brief review of the context in which the methodology CLUE+GLOBIO 3 was applied, trying to evaluate not only the results of this methodology, but also the viability of its use and its applicability to the national situation. Thus, the methodology showed interesting results at national scale that should be evaluated with more detail. However, the most important result is the helpfulness for stand out the importance of the spatially explicit models to asses the future impacts of the political and investment decisions.

3.3.2 Methods

3.3.2.1 Actual Land Use Map

There was not availability of a land use map for the Peruvian national analysis, so it was necessary to produce it based on maps from other different projects (see table 16). Finally a land use map was obtained with 90 m of pixel side resolution, which was reclassified and aggregated to obtain a 1 km pixel resolution. This aggregation was done according the following rules:

Region	Project Name	Original format	Scale
Dry forest	Pacífico Ecuatorial Ecoregional Planning	Vector	1 : 250 000
Sechura desert	Desierto de Sechura Ecoregional Planning	Vector	1 : 250 000
Peruvian Yungas (clouded montane forest of eastern Andes)	Peruvian Yungas Ecoregional Planning	Vector	1 : 250 000
Tropical rainforest (high mountains and lowlands)	Capacity Building Program for National Managing of Climate Change and Air Pollution impact (PROCLIM)	Vector	1 : 250 000
Bosque amazónico del sureste del Perú	Standardized remote environmental monitoring for SINANPE. Case study I to V	Raster	30 m pixel resolution
Puna	Ecological systems map of Northern and Central Andes. Bolivia, Colombia, Ecuador, Peru and Venezuela	Vector	1 : 250 000
Tropical rainforest (high mountains and lowlands)	Ecological system map of Peruvian and Bolivian Amazon (Nature Serve)	Vector	1 : 250 000
Southeastern lowland forests	Land use monitoring between Puerto Maldonado and Iñapari. Segment III of Southern Inter-oceanic Highway. 1990, 2000 and 2005	Raster	30 m pixel resolution

Table 16 Information sources used to build the land use map for Perú

For rescaling the land use map from 90 m to 1 Km, it was generated one map for each land use types. Pixels of 90 m were group in blocks of 11x11 pixels (that is to say, 990 m side squares) where the percentage of pixels for every class was calculated. Later, every map was rescaled, with the purpose of adjusting it to a 1 km side map, using the tricubic option to estimate the percentage of pixels for each category, inside the new pixel of 1 Km. In this new layer of percentages at 1 Km, values above 100, became 100, and values below 0, became 0. Final category was determined by means of the combination of all the percentages maps at 1 Km resolution, with land use classes and classes without use (classes without information, as clouds or shades were discarded). If the sum of percentages with use overcame 30%, it was assumed the land use with the major percentage. Otherwise, it was considered that the area did not have any use, and, in a similar way, the chosen non use class was the one with the highest percentage.

The resulting land use categories, as well as the area for each of them are shown in table 17. It is important to point out that areas with human intervention, in Peru, are a little overestimated due to the method used for the aggregation process. However, this process helps to have a better overview of the areas with secondary forest caused by processes of shifting cultivation. Likewise, it gives an approach of the area indirectly affected by human activities.

Land use classes	Surface (hectares)
Natural vegetation	89 946 400
Principal rivers	607 900
Irrigated agriculture	1 422 800
Agriculture (includes intensive and extensive management)	8 303 000
Man-made pastures	761 200
Mountain grasslands	27 163 600
Mining areas	11 200
Urban areas	139 500

Table 17 Area covered by each land use type (ha) for Peru

The area with mountain grasslands, where there is extensive cattle, was not possible to identify in the map neither to quantify. For that reason it was assumed that all the mountain grasslands would have an MSA value of 100%. That is to say, they were considered as natural areas in spite of not being it. This implies an overestimation of MSA, however, since the accessibility provided by infrastructure also implies a reduction of MSA, a part of the effect of extensive cattle would be captured by infrastructure effect.

On the other hand, the information coming from land use maps does not discriminate among agriculture types. Irrigated agriculture is significantly different from other agriculture types because it implies a very high transformation level of landscape. The majority of this activity occurs in dry areas, particularly in the coastal areas, changing the natural desert to areas with vegetation. We assumed that irrigated agriculture only occurs in these coastal areas, and also, for this region, this was the only kind of agriculture considered. For the rest of the country a mixed activity was assumed between intensive and extensive agriculture, for which the MSA values of original intensive and extensive agriculture were averaged (see table 1).

3.3.2.2 Land Use Changes

For the purpose of modelling the study area, there have been considered three categories of "without use" land coverages (natural vegetation, puna and hydrography) and four land use types (agriculture, livestock, mining, urban areas). The "natural vegetation" category includes all those sectors that have no current use, that are not puna or are not water. Therefore, a pixel of natural vegetation can refer to a primary forest, a secondary forest, a shrubland or a piece of desert. For purposes of this study, a model of urban or mining growth has not been included, so it was assumed a constant surface for these categories.

Elasticity and transition matrix

Table 18 shows the elasticity of each land use class included on this model (elasticity measures inertia, or tendency of each class to survive along the time) and the transition matrix (potential changes between classes). Areas of land use classes correspond to the land use demand calculated on the basis of previous information. Areas of natural vegetation were calculated as the remaining area. Because of this, we assigned the highest elasticity (minimum inertia) to natural vegetation classes.

Land use classes	Elasticity	Conversion matrix [1]						
		Nat veg	Riv	Agr	Past	Min	Urb	Puna
Natural vegetation	0	+		+	+			+
Principal rivers	1		+					
Agriculture	0,8	+		+	+			+
Man-made pastures	0,5	+		+	+			
Mining areas	1					+		
Urban areas	1						+	
Puna	0,8	+		+				+

Notes:
[1] (+) indicates that row land use type pixel can change into a column land use type pixel

Table 18 Elasticity and conversion matrix for each land use type

Demand

For the projection of land use demand for 2030, we used national statistics of agriculture, specifically those concerning to sown area of major crops for each agriculture season between 1996 and 2006 (MINAG, 2007).

Regressions

Peru was divided into seven regions (see Table 19). The purpose of these subdivisions was to capture the different dynamics that occur in the development of agriculture and livestock, according to the different social, physical and climatic conditions. In all cases, a regression was calculated for agricultural activity. In the case of livestock, regressions were calculated only for Yungas, Amazonian and the Northern Sector regions. This does not imply that there is no livestock in other sectors, but this livestock does not occur on artificial pastures (it may occur in natural vegetation or in barn).

Region	Description
Coast	Desert strip below 1200 meters above sea level, from the south of Lambayeque to Tacna (including Cerro Illescas)
Central Andes	Narrow strip between the coast and the puna from the department of La Libertad to Tacna
Puna	Grasslands of Cordillera de los Andes with the exception of interandean valleys, from the department of Ancash to Tacna and Puno
Yungas	Montane forests of the eastern Andes of Peru, also included the Cordillera del Condor
Amazon	Amazon lowland forest, limited by the Peruvian Yungas on the west, generally below 800 m
Dry forest	Dry forest located on the northern coast of Peru, includes departments of Tumbes, Piura, Lambayeque and part of Cajamarca
Northern region	Region harboring the transition paramo-dry forest-mountain forest in the area of Cajamarca and east of La Libertad and Piura.

Table 19 Regions considered for Peru for unique regression models

To make predictions minimizing the problems of spatial correlation within observations, we chose to do a systematic sampling of points in the study area. The points were obtained following a regular triangular matrix with 3000 meters between each observed point (about 3 pixels away).

The following variables were included in the regressions:

Legal protection system: Natural Protected Areas

Topographic variables: Elevation, slope, shape terrain index, roughness terrain index, total curvature, land convergence index, topographic index of exposure (smoothed and non-smoothed), topographic index of relative humidity, relative position on the slope

Accessibility: Time to travel in hours to an important market (the closest provincial capital). The time was calculated using different speeds according to the type of road or the type of river.

Climatic variables: average annual temperature, annual precipitation, ombrothermic index, ombrothermic index of the driest quarter

All these variables are described in the chapter 2.3.1 and in 6.1. In cases where an index reported a zero value for a pixel, this pixel was completed using the data from the nearest pixel.

Regressions were made using a backward stepwise logistic regression, using R 2.7.0 (NCAR 2008). The R uses the Akaike information criterion for deciding which variables should be included and which ones rejected. This approach allows comparing different models such as logistic regressions. It considers information given for each explanatory variable and to obtain as simple and parsimonious model as possible (Burnham & Anderson 2004).

Future Land Use Map

As in other national case studies, the CLUE program was used (Verburg *et al.* 2002) as an algorithm of demand spatial distribution.

3.3.2.3 Biodiversity Status

The roads used for this analysis were the national, departmental and local roads provided by the Ministry of Transportation and Communication (upgraded to 2003). The pixel resolution was 100 m, to better capture detailed information about infrastructure impact and for the generation of natural vegetation patches to calculate the impact of fragmentation.

To assess the impact of climate change and fragmentation, the WWF ecorregión map was used (Olson and Dinerstein 1998), but modified by CDC-UNALM (2006). From CDC-UNALM map, the ecoregions were grouped into 4 biomes: deserts, shrubs, Puna and rainforest. As mentioned before, for fragmentation, it was considered that the boundary between biomes was a barrier to the movement of species except for the boundary between shrubs and puna.

3.3.3 Results and discussion

3.3.3.1 Land Use Changes

Regressions

Table 20 shows the results of the logistic regressions for every land use class and every natural region. It can be appreciated that natural protected areas contributed to reduce the probability of natural areas to become agricultural areas or man made pastures for livestock. However, the effect was not equally significant in all cases, for example, for the Andean sectors it was less significant than for the Amazon and even coastal areas.

Variables	Agriculture							Man-made pastures		
	Coast[1]	Andes	Puna	Yungas	Amazon	Dry forest	Northern region	Yungas	Amazon	Northern region
Intercept	- (***)	- (***)	- (***)	+ (***)	- (***)	- (*)	+ (***)	-	+ (***)	- (***)
Legal protection system										
Natural protected areas	- (**)	-	- (*)	- (***)	- (***)	- (**)	- (*)	- (***)	- (**)	
Topographic variables										
Elevation	-	+ (***)	+ (***)	- (***)	+ (***)	+ (*)		- (***)		+ (*)
Slope	- (**)	+ (*)	+ (***)		+		+ (***)	+ (***)	- (*)	- (*)
Terrain shape index	- (**)		+ (*)			- (**)				
Terrain ruggedness index	- (***)	- (*)	- (***)			- (***)	- (***)	+ (***)	- (*)	+ (***)
Relative humidity topographic index						-	+ (**)		- (*)	
Total curvature		+ (***)	+ (*)	+ (***)	+ (***)	+ (**)		+ (***)		- (***)
Terrain convergence index	+ (***)	+ (***)	+ (***)		- (*)	+ (***)		+ (***)	+ (*)	- (***)
Topographic exposure index	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (*)	- (***)		
Topographic exposure index (smoothed)										
Relative slope position	- (***)		+ (*)	- (*)	- (***)	- (**)		- (**)	- (*)	
Accesibility										
Travel time to markets	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	- (***)	+ (**)
Climatic variables										
Mean annual temperature	+ (***)		+ (***)	- (***)	+ (***)	+ (*)	- (***)		- (***)	+ (***)
Total annual precipitation	- (***)	+ (***)	+ (***)		+ (**)	- (*)	+ (***)	- (***)	+ (***)	
Ombreothermic index	+ (***)		- (***)	+ (***)	- (***)	+ (*)	- (***)	+ (***)	- (***)	- (***)
Ombreothermic index of the driest trimester	+ (***)	+ (***)		- (***)	+ (***)	- (**)	+ (***)	+	- (***)	+ (***)
Area under de cuve ROC	**0.93**	**0.916**	**0.941**	**0.873**	**0.895**	**0.868**	**0.771**	**0.816**	**0.966**	**0.901**

Notes: Signs for each cell indicates positive relationship (+) or negative (-), asterisks indicate significant degree, (***) < 0,001, (**) < 0,01.

[1] All agriculture was considered as irrigated agriculture.

Table 20 Relationship between independent variables and each land use types, AUC value for each case

Market access was highly significant as a variable to explain the distribution of the different land uses. However, it is striking that in the northern sector access remains significant, but their impact on livestock is reverse: the greater the distance, the more probability for livestock to occur. This may be a reflection of the difficulty for differentiate between the two activities at the central region of Cajamarca department. Table 20 also shows the AUC values for each region. From all the models, the one obtained for agriculture in the northern region showed the lowest performance. The complexity of this area, as being a transition zone of several types of ecosystems, may have been a factor that did not allow obtaining a better model. Additionally, the land use map available for this area does not differentiate efficiently livestock from agriculture, and both of them were categorized as agriculture. This could be another reason why the models generated for this region would not be optimal.

Based on the estimated regressions, probability maps were elaborated for every land use class. The estimated probability maps are presented in Figure 22 considering only the areas were the land use was present.

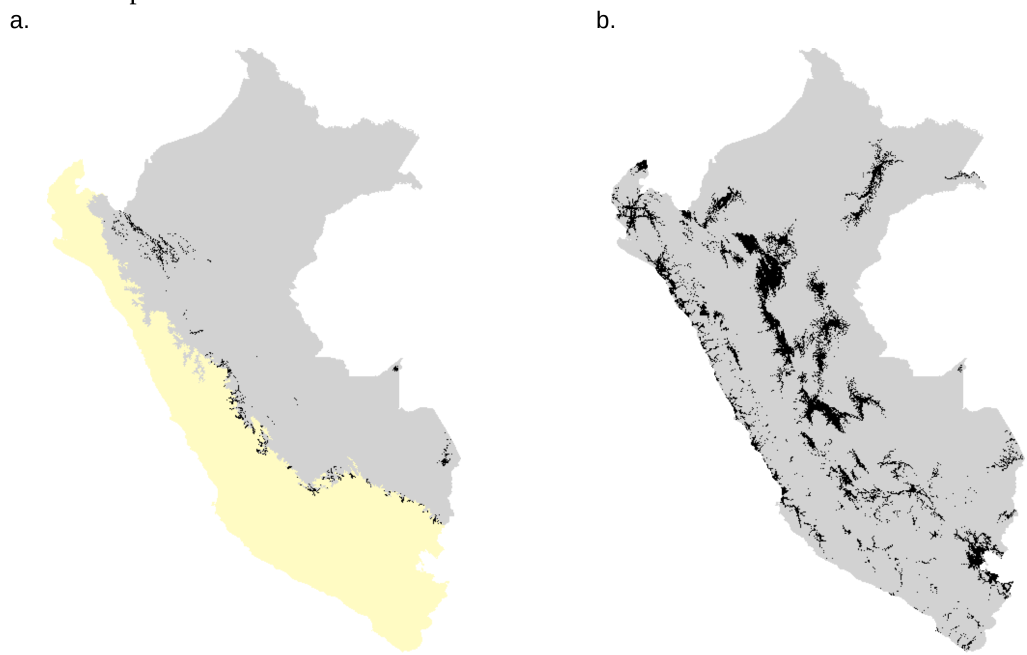


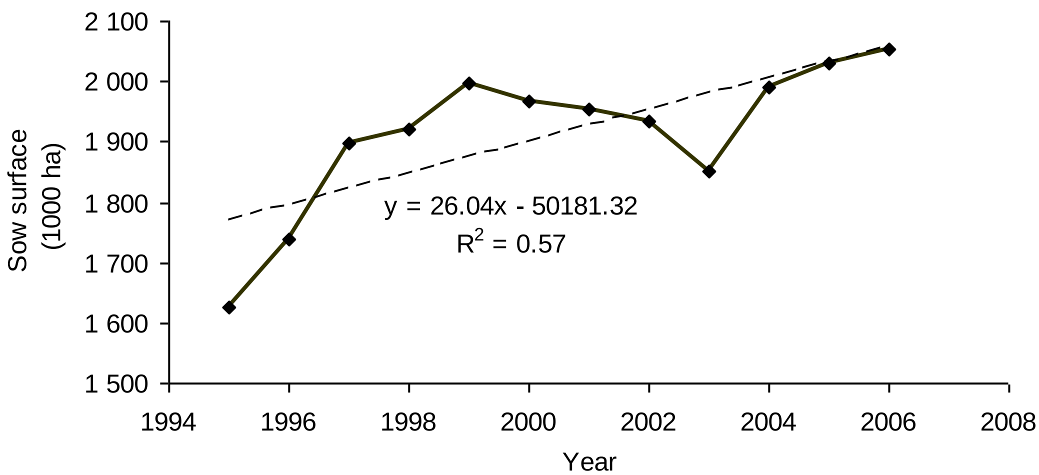
Figure 22 Livestock (a) and agriculture (b) probability maps for Peru

Areas in black refer to the most probable regions to develop these activities, in the case of artificial grass for livestock; yellow colour indicates the regions where the activity is not carried out.

Demand

As previously mentioned, for the land use projection for 2030, we used national statistics of agriculture, specifically those concerning to sown area of major crops for each season between 1996 and 2006 (MINAG 2007). Each agriculture season begins in early July and finishes in August of next year and, in figure 23, the years shown are from the start of agriculture campaign. These data refer to the main transient crops (see MINAG 2007), in this information are not included the perennial crops such as fruit, or cultivated pastures. Therefore, these values are lower than the current area where farming or livestock is carried out, and minor than the area presented on the land use map for 2000.

Some assumptions were done due to the limited available information. First assumption was referred to the trend in the annual variation in perennial crops, which would be similar to the variation for transient crops. Therefore, the curve will not change significantly over time. Figure 23 shows the trend line generated from this information, with the equation associated to this linear regression. The slope of this regression was used as a basis for estimating future trends for market forces scenario, which assumes that current trends continue, as it will be explained later in more detail.



Source: MINAG (2007).

Figure 23 Surface for main crops. From 1995-1996 to 2006-2007.

For the case of livestock, it was taken into account only lands with man-made pastures. Natural pastures were not included in this category to ensure consistency with GLOBIO 3. In the 2000 land use map, the cultivated grasses correspond to the Amazonian and mountain forest that suffer deforestation pressure as a result of this activity. There is not a long time series of man-made pastures area, so in this case, a calculation based on a trend could not be estimated.

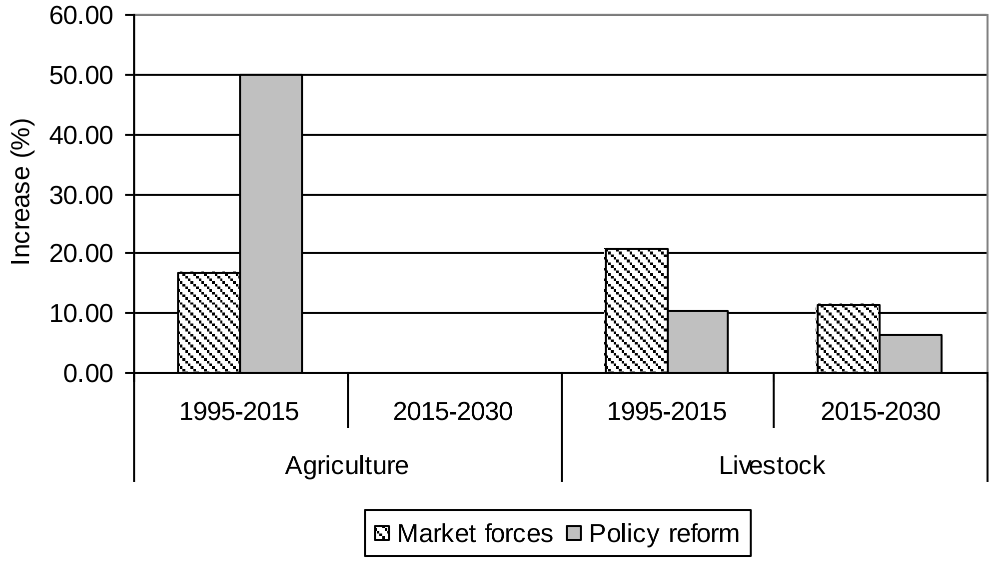
For agriculture, the estimation of the area for 2005 was based on the area recorded from 2000 land use map and the data obtained from the MINAG time series. In this way, the increase percentage between 2000 and 2005 was estimated using the trend line shown in figure 23. To avoid potential problems due to change of scale and the use of different methods, the linear trend observed was used as a guide. However, initial values for agriculture and man-made pasture areas the areas from 2000 map (whichever applies) was used. For both, the scenario of market forces as well as the policy reforms, the same agriculture area was used until 2005. From 2005 onwards, the different assumptions to create the 2015 and 2030 areas were applied. In the case of livestock (man made pastures) it was also assumed that until 2005 the trajectories of both scenarios were identical.

The scenarios of Raskin & Kemp-Benedict (2002), market forces and policy reforms, consider 1995 as the initial year, and projections were estimated for the years between 2002 and 2032 (although in the published document are only the values for the years 2015 and 2032). In these scenarios, there is a trend to increase the agriculture area until 2015, a trend that would slow down by 2030. On the other hand, the projection of Bruinsma (2003) made for FAO suggests a trend to a constant increase of agricultural area until 2030, considering a scenario in which the current trend continues.

Both, the scenario of market forces as well as the policy reforms, consider a rapid economic growth and a convergence of globalized regions towards the standards set by most industrialized countries (Raskin & Kemp-Benedict 2002). However, in the case of market forces, consumism and individualism are core values that prevail. In that sense this scenario considers that economic growth and its incentive to market liberalization, will impact at some point in the alleviation of poverty, because it would have a widespread growth that would come to the poorest. Also, this scenario considers that the same economic growth, even though would have an initial effect of environmental damage, could repair the damage later in terms of having better technology for more efficient use of energy and water. However this scenario is starting to face the first environmental problems related mainly to flooding and climate change with changes in rainfall patterns, due to the low control over gas emissions from the industrialized countries. In the same way, it would continue the environmental degradation processes such as pollution and biodiversity loss, and it would also increase the pressure over land use, with the loss of forests for development of agricultural activity.

On the other hand, the policy reform scenario also considers the economic growth; however there is growing awareness and concern about the environmental and social issues. In that sense, governments reach consensus and there are policies to mitigate the impacts on resources and climate change, that is to say a strategy of sustainable policies. The increase deforestation rate is declining and by 2032 there is stabilization for the recovery of ecosystems. However, it is also considered that even with these efforts, several of the effects of environmental/social problems are difficult to solve such as the supply of good quality water.

The work of Raskin & Kemp-Benedict (2002) which describes the listed scenarios also shows figures of the areas with agriculture and lisvestock. These values are at a continental level or aggregated for groups of countries, and for this work we are using the information generated for South America. Figure 24 shows the percentages of increase derived from the values of the mentioned work. The increase in livestock is higher in the market forces scenario, while agriculture is increased to a greater extent in the case of policy reforms scenario. However, to make a proper interpretation of these values, it must be taken into account that livestock area represents 29% of the total area and agriculture only 6% for the 1995 base scanario. This situation is due to the large extensions of cattle in Brazil and Argentina, which are not representative of the Peruvian case. That is why we decided to work with the percentage increases for each class instead of the area.



Based on Raskin y Kemp-Benedict (2002).

Figure 24 Agriculture and grassland percentage increase for periods 1995-2015 and 2015-2030 for two scenarios

To calculate the growth trend of the agricultural area, growth rates were calculated for 2000-2005, 2005-2015 and 2015-2030 periods, based on agriculture trends provided by MINAG, and considering the interpretation of scenarios made by Raskin & Kemp-Benedict (2002) and Bruinsma (2003). Assuming that 2000 value is 1, we proceeded to calculate how much more would increase each activity at every stage in the next years. These growth rates were applied to agriculture and livestock areas on the 2000 land use map. With these data, we calculated the land use areas for years 2005, 2015 and 2030 for every scenario. To estimate the area between those years it was assumed a linear increase.

Market Forces

In the case of the national level analysis for Peru, and for the market forces scenario, it has been considered that for 2015 the growth trend of agricultural class continues as so far. Therefore, it follows the pattern of the trend line generated by the data provided by MINAG. For the period 2015-2030 the market forces scenario of Raskin & Kemp-Benedict (2002) does not consider an increase in agriculture, but it considers a livestock increase. The study predicts a growth of over 20% for the period 1995-2032 for this activity, percentage distributed for the periods 2000-2005 and 2005-2015. Under this scenario it is supposed a "brazilization" process of the Peruvian rainforest, with the consequent rapid growth of this activity. The percentages of increase used to generate a land demand for agriculture and livestock (man made pastures) are shown in table 21.

Land use type	2000	2005	2015	2030
Agriculture	1	1,07	1,21	1,41
Man-made pasture	1	1,06	1,21	1,34

Table 21 Increase index for agriculture and man-made pasture areas considered for Peru for Market Forces scenario

Since there is a growing trend in the harvested area of agricultural land in the past 50 years, and recent studies in the Amazon suggest an increases of over 100% in agricultural areas in recent decades (CDC, 2004; INRENA et al, 2006 CDC et al, 2007), it was considered that the increase between 2015-2030 would continue. While the original scenario of market forces of Raskin & Kemp-Benedict (2002) finds that there is no growth, this growth can be seen in the projections of Bruinsma (2003) for the period 2015-2030, a trend that seems more consistent with the national reality.

Policy reforms

The policy reforms scenario is similar to the market forces scenario for period 2000-2005 with regard to increasing agricultural activity. This data was retained because we had information until 2005 (MINAG 2007) to calculate the agricultural area. The scenario considers a decrease in the deforestation rate compared with the one resulting from the market forces scenario, due to protection policies of endangered areas and sustainable land use practices.

The results shown by Raskin & Kemp-Benedict (2002) for South America present a notable decline of agriculture activity. However for the period 2000-2015, there is a greater increase in agricultural activity with respect to the one registered for market forces scenario. The slowdown in the increase of livestock land is compensated in some extent with the increase of agricultural production. However, when summarizing the agricultural and livestock areas, the area for 2015 and 2030 is lower on the policy reforms scenario than in the market forces scenario. These considerations were taken into account when applying this scenario to the Peruvian case. The percentage values applied to estimate the demand for land in this scenario are shown in table 22.

Land use type	2000	2005	2015	2030
Agriculture	1	1,07	1,21	1,32
Man-made pasture	1	1,06	1,10	1,17

Table 22 Increase index for agriculture and man-made pasture areas considered for Peru for Policy reform scenario

As in the previous scenario, it was considered that the increase in the period 2015-2030 for the agriculture activity continued. Nevertheless, for this scenario of policy reforms, where some policies lead to decrease deforestation rates, it was considered an increase rate for this period. This value was a half with regard to the market forces scenario. Figure 25 shows the comparison of the two scenarios regarding the area growth of each activity and for every year for period 2000-2030.

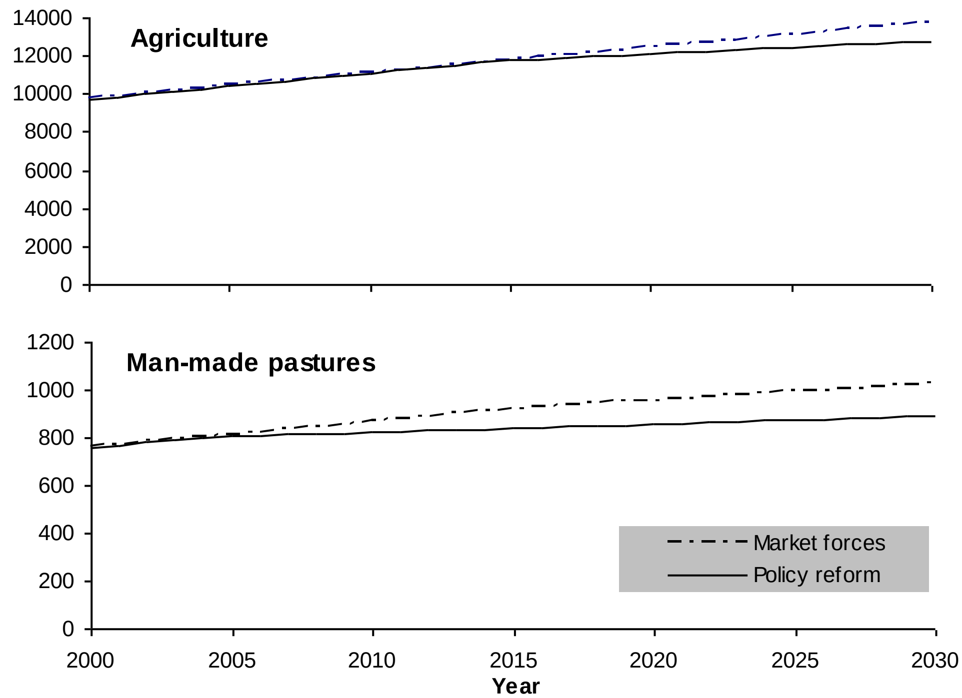


Figure 25 Land uses trend. Observed (2000 – 2005) and future figure (2006 – 2030)) for scenarios market forces and policy reform (1000 ha)

Land use initial map and land use final map

In Figure 26 it is shown the 2000 land use map, obtained from the maps generated by other projects (see methods). It can be seen that the Peruvian north area, specifically in Cajamarca and San Martin have the greatest amount of agriculture. This spatial information is corroborated by the information obtained from the National Agricultural Census 1994 (INEI 1996) in which, 11.3% of the national agricultural area is concentrated in Cajamarca, while in San Martín is the 8.9%.

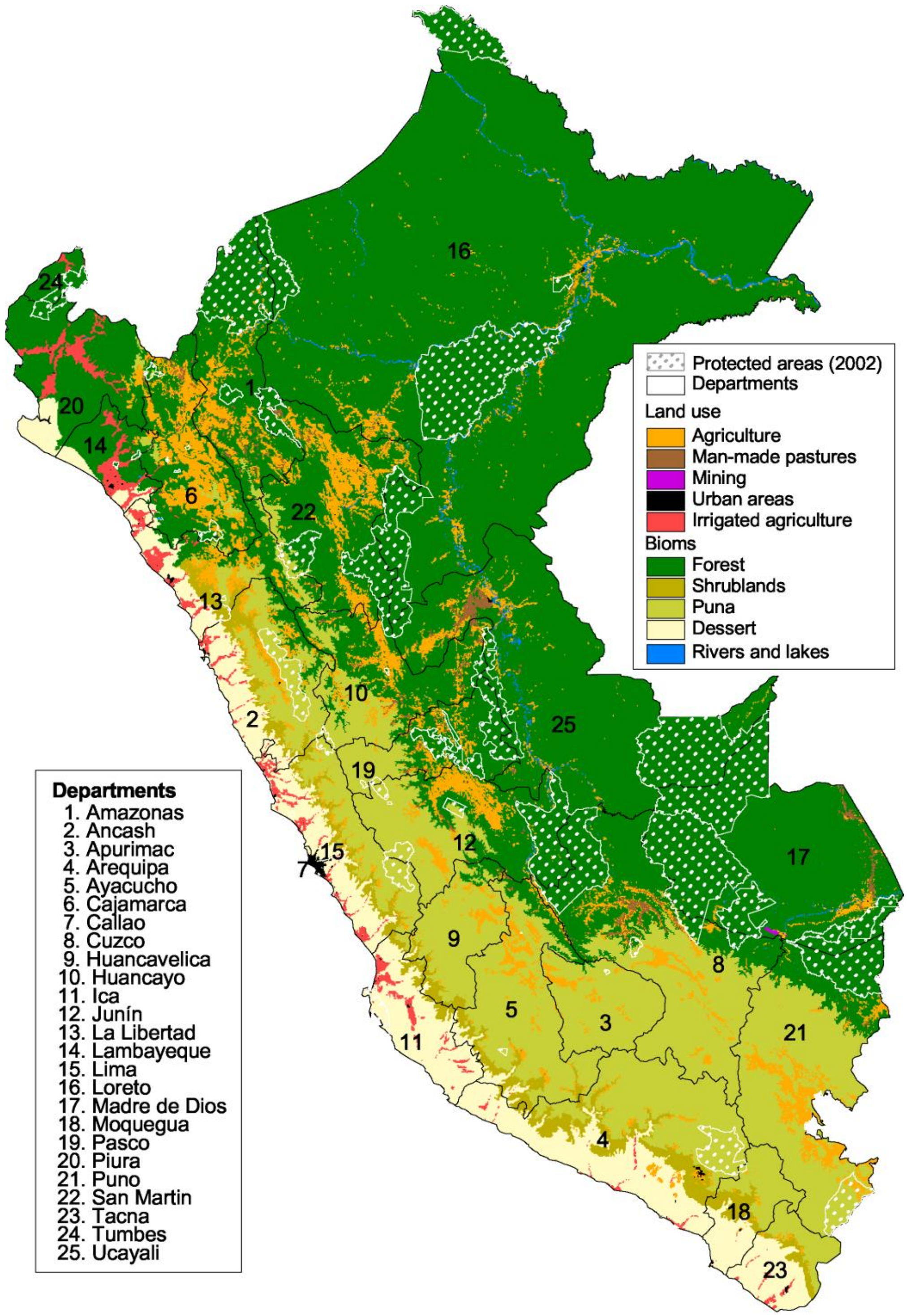


Figure 26 Peruvian Land Use Map for 2000

Cajamarca department includes a group of natural areas with different characteristics, where is possible to find areas with paramo, dry forest areas, Andean regions and some transition to the montane forest. This landscape mixture occurs because in this region is located the lowest level of the Andean mountain range and because of the presence of Huancabamba depression, which makes easier the exchange of species between the eastern side and the western side of the Andes.

In this area, with very low slopes, is located much of the agricultural area. Additionally, the páramo area, especially around Cajamarca city shows a high density of agriculture. However, it is necessary to mention that many of these areas are engaged in livestock and man-made pastures to keep livestock. As previously mentioned it was not possible to obtain a map which distinguishes between these two activities for the central part of Cajamarca department, so it was considered as "agriculture".

In the Amazon region, apart from San Martin department, there are three nuclei around which is developed agriculture and livestock: Iquitos, Pucallpa and Puerto Maldonado. The growth pattern for these three areas is associated with the communication facilities between these three areas and the rest of the country. In Pucallpa and Puerto Maldonado, the growth axis is located around the main roads, which also have ramifications with presence of human settlements in its vicinity. In the case of Iquitos, the main communication route is the Amazon River, for this reason, in this area; agricultural growth is on the riversides.

In the Peruvian yungas (or so called cloud mountain forests), the Alto Huallaga valley, Perene valley and the coffee sow valleys of Cusco (Convention province) are the locations with the highest density of agricultural areas. The first two valleys have roads that date back several decades ago and communicate with Lima city.

Coastal region, as mentioned in methodology section, is the only one for which it was assumed that whole existing agriculture was irrigated agriculture. Areas of northern departments show a major development of agricultural activity. So the dry forests of northern coast seem to gather the best conditions for the development of this activity. Even though the soils of this area are poor (mostly sandy), the largest moisture in the area (with regard to the rest of the coast) and the major irrigation projects, allows the development of crops. Additionally, the temporary presence of El Nino event, favour the occurrence of abundant rains. This contributes to the agriculture and grassland expansion, but also to forest regeneration, while the moisture remains in soil. At the end of water reserves (not only underground but also in the temporary lagoons such as "La Nina" lake), agricultural areas decrease until the El Niño event repeats. Also, as a result of grassland increase, goat livestock is benefited. However, it has not been possible to obtain a dry forest map that includes the area for this type of livestock, or the level of degradation of forest that this activity may generate.

It is worth mentioning that in several valleys of the Peruvian mountain range, it can also be found irrigated agriculture, however, there was no detailed spatial information. For this reason all the Andean agriculture was considered as a mixture of extensive and intensive agriculture, assumption that makes sense considering the spatial resolution of this study (1 km2). Also in the wide puna grasslands (mountain grasslands), agriculture was identified for the main inner valleys. However, agriculture in the Peruvian Andes could be underestimated due to the dispersion and the extension of crop areas. Some crop areas that were smaller than the resolution of the present work, were not possible to be identified. On the other hand, it was not possible to map the development level of extensive livestock. In this way, the impact of land use was underestimated for this region. For this region, the surrounding area of Titicaca Lake (department of Puno) is the one showing the greatest area of agriculture.

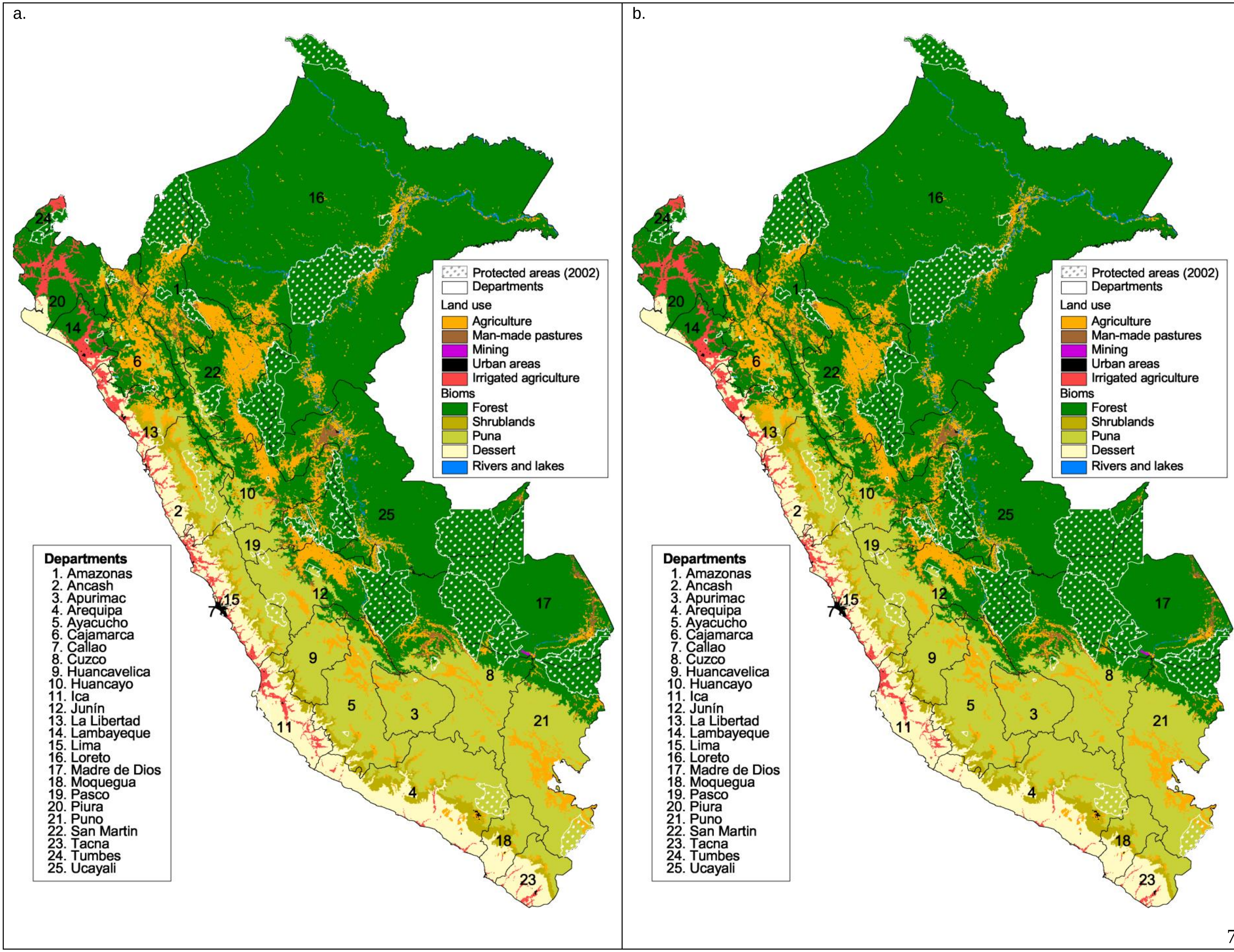


Figure 27 Land Use map for 20030 under market forces scenario (a) and policy reforms scenario (b).

The results modelled by CLUE, referred to the distribution of land use for 2030 predict a growth pattern, distributed mainly around the areas already established. For both scenarios a densification of existing areas with agriculture occurred, that is to say, the area between crops has been reduced by the presence of new agriculture area. For example, areas such as Huancabamba depression would be completely dedicated to agricultural activity, and natural vegetation would almost be completely lost.

On the other hand, in addition to the densification process, the expansion of agricultural frontier would be taking place. Some new areas appear to be located mainly in the Amazon region as expansions of existing agricultural areas. For example, among the most notorious expansions is the adjacent area nearby the highway that runs parallel to Marañón River (Amazonas department) and also by the riversides of this river. The stretch covered by the road and the river, between the towns of Chiriaco and Saramiriza, would become a totally agricultural area.

The agricultural growth in the department of San Martin would be around three areas. Moyabamba Valley is one of them, as well as the areas surrounding the Tarapoto city. The third area is the road sides of the “Carretera Marginal de la Selva” which crosses the department from south to north. The prediction of these areas is linked to the presence of roads and the existing towns. These two variables were combined and synthesized in the variable "accessibility" (see 2.3.1), which is one of the most important variables in the logistic regression model for agriculture. This same situation would also explain the growth mentioned above for Amazonas department.

The roads used for this study were provided by the Ministry of Transportation and Communications. It was assumed that there would be no new roads for 2030 and that the number of towns would not increase. Maybe this would explain why the results do not show at all, a set of new agriculture expansion areas. On the other side, it was not possible to determine which of the roads considered as "neighbourhood road" could become more important in the future. However, the inclusion of "highway dynamics" is possible in CLUE, but it would require a more detailed analysis of which are the factors affecting this dynamic.

Another important area to point out because of the level of agricultural expansion is the sector of Ucayali River, near to its river mouth with the Amazon River in Loreto department. Also, the last segments of the Tambo and Urubamba rivers and their confluence into Ucayali River shows considerable agricultural expansion. Particularly, this last area has a large agricultural area, as well as the riversides in the first segment of the Ucayali River. The combination of physical factors and accessibility determines this area as favorable for the development of agriculture. In both areas, Loreto and Junin departments, the main factor would be the rivers, because they were also considered as part of “accessibility variable". However, unlike roads in Amazonian region where agriculture is predicted in almost all the roadsides, only portions of major rivers present an agriculture development.

As mentioned above, there is a great agricultural expansion in the forest, however it is necessary to take into consideration that it was not possible to have a soil type map, or a fertility map. In that sense, some of the areas that are suitable for agriculture, according to the logistic regression, could be with some estimation error. For example, not all roadsides in the forest are suitable for agriculture development. Sometimes these roads pass through swamps in which agricultural activities are not possible, so without the information about soil type it is not possible to distinguish these areas. On the other hand, the dynamic of cutting trees, crop development and posterior burn s is also based on the low fertility levels of Amazonian lands, Therefore, without a fertility map, it is not possible to establish what areas would be likely to develop agriculture on a more permanent way.

On the other hand, neither on the coast nor in the mountains a growth or agriculture expansion is registered, as the one observed for the Amazon region. So, most of the valleys remain with similar areas, although some of them would be increased slightly. The northern part of the coast is where the largest agricultural expansion is present, in comparison with the rest of the cost.. These results appear consistent with the fact that the agriculture expansion on the coast would inevitably be associated with the water infrastructure expansion. However, it was not considered the development of new irrigation systems in any scenario.

It is worth mentioning that for the coastal region, the logistic regression model reported one of the highest AUC values, and it indicates that the model is a good reflect of the current distribution. Assuming that future spatial distribution pattern will remain essentially the same, we can conclude that future scenarios are quite likely, considering that new irrigation projects are not carried out in these 30 years.

Difference between scenarios, can be seen in the extent of the area covered by human activities for both cases. The description of each scenario itself has no more information than the values that describe future trend in agricultural production and demand for livestock area. The scenarios do not describe the spatial patterns of growth in agriculture and livestock. Even if it exists, the implementation of a similar model would be much more complex. In that sense a policy reform scenario could not only consider the fact of reducing the rate at which natural lands are converted to agricultural land and livestock, but also propose a planned growth in terms of space.

One way to assess the validity of the national model predictions is to contrast the results of certain localities with expectations and projections of people living in these localities. The same methodological framework was applied at local scale with higher resolution to a lowland sector of the southeastern Amazonian region of Peru (see section 3.4). Thus, it is possible to compare the national results for this area with those derived from the local model.

In both cases, national and local level, the same two scenarios were considered: Market Forces and Policy Reform. However, the rate of increase in deforested area between 2000 and 2030 for the southeastern Amazonian area was lower for the national model than for the local model (see table 23). There are at least two reasons that may explain this difference. One possibility is that the predictions of local scenarios are more related to the Brazil’s dynamic than to Peru’s dynamic. That means greater development of agriculture and man-made pastures for lowland forests, than the one expected for the national model. In this case, it would be more useful to make a model including the dynamics of land use changes for the Amazon basin. Secondly, the method for estimating the probability of land use (logistic regression of the current distribution of each use) may not be the most efficient method to characterize the likelihood of agricultural expansion. Agriculture and man-made pastures are concentrated along roads and rivers, however, these areas are surrounded by large extensions of forest. Consequently, the regression would tend to give greater weight to areas with existing agriculture or man-made pastures, creating a bias. Both considerations are in conflict with one of the strongest assumptions of Clue, which is that all sectors of the study area are equivalent. In that sense, an agricultural sector in Puno can be replaced by an agricultural sector in Cajamarca, without considering the restrictions of movement for people, for example.

Study area	Scenarios (2030)	Agriculture	Man-made pastures	Agriculture and man-made pastures
Peru	Market forces Policy reform	41 32	34 17	41 30
Madre de Dios (Nacional case)	Market forces Policy reform	40 33	62 23	49 29
Madre de Dios (local case)	Market forces Policy reform Order from inside	114 77 57	179 95 55	130 82 57

Table 23 Relative increase of agriculture and man-made pastures for Peru and for Southeastern Amazonian (national and local outputs) for each scenario (values represent percentages of change with respect to 2000)

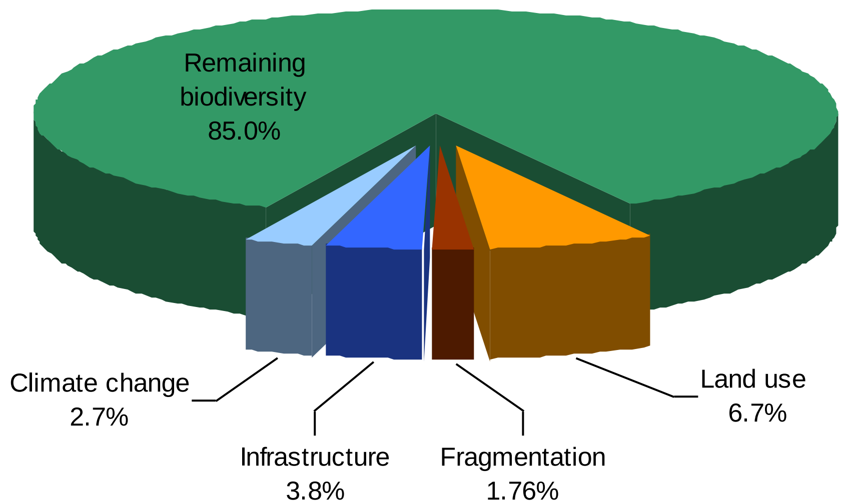
CLUE includes some options for increasing the likelihood of a land use class in particular sectors of the study area to reflect, for example, development policy options. These options require estimating the effect of policy on the likelihood of a class in a particular region. Doing this requires a more detailed review and the search of ways to justify these valuations. It is important to point out that these options do not change a fundamental element of CLUE which is that any sector with the same probability in the study area will be equivalent (a reasonable premise to assess the probability of agricultural expansion associated with outside investors but not to assess local agricultural development, which leads to an expansion of agriculture sectors in less likely places, as long as they are near to the work area). This is because although CLUE may include variables that change dynamically according to the changes on the land use map (which allows to include aspects similar to the cellular automata) the final decision of whether a pixel in the study area is included or not in a land use class lies in the probability analysis of all pixels, and not in the surroundings pixels.

3.3.3.2 Biodiversity Changes

Figure 28 shows the summary results of GLOBIO at national level for 2000. Remaining biodiversity evaluated by MSA value, is 85%, while the other 15% of biodiversity is lost due to land use factors, infrastructure, fragmentation or climate change. Within these factors, land use is responsible for 6.7% of biodiversity loss, being the main loss factor, followed by infrastructure. It is important to mention that biodiversity loss by land use changes is probably underestimated due to the absence of maps identifying selective extraction and maps of natural grassland dedicated to livestock. Although this effect was partially incorporated with the measurement of the infrastructure impact, it is possible that some sectors remain with higher MSA values than they should be. For that reason, values of MSA should be interpreted as maximum values. This issue become more important in forest, due to timber selective extraction and, in mountain natural grasslands due to the extensive livestock that is developed there.

Figure 29a shows the map with the spatial distribution of MSA values for 2000. The colour scale shows in red the areas that lost more biodiversity due to any factor cited for the analysis (land use, infrastructure, fragmentation or climate change). In blue are shown the areas that have the highest value of remaining biodiversity. Consequently, it can be seen that the northern part of Peru has the lowest value of remaining biodiversity, for both, coastal and andean areas. On the other hand rainforest has been strongly impacted principally in the range from Junin to San Martin.

Figure 28 MSA values of Remaining Biodiversity and factor contribution to biodiversity loss for year 2000



In order to have a complete vision of biodiversity status, MSA was calculated for each department and the results are presented in Figure 29b. The departments have been sorted in descending order of MSA. So it can be seen that Cajamarca has the lowest remaining biodiversity value (52.4%) in 2000, followed by Lambayeque, La Libertad and Tumbes. On the opposite, Loreto has the highest remaining biodiversity value (96.1%). Cajamarca, La Libertad, Lambayeque and San Martín, lost biodiversity due to land use change, which values were considerably larger than any other considered factor. For Tumbes, Arequipa, Tacna, Apurimac, Huancavelica and Moquegua, the main factor causing biodiversity loss was infrastructure.

In general, departments located in the Amazon region are the best preserved with the greatest remaining biodiversity values. Ucayali, Madre de Dios and Loreto are included on this list, and are, in turn, the largest departments of Peru. The lack of accessibility to many of these areas is probably the main factor allowing this degree of conservation. However San Martin, also located in Amazon region is not as well preserved as those mentioned above. The Marginal de la Selva highway passes through this department and it can be seen that the main biodiversity loss is located along this road (see Figure 29a).

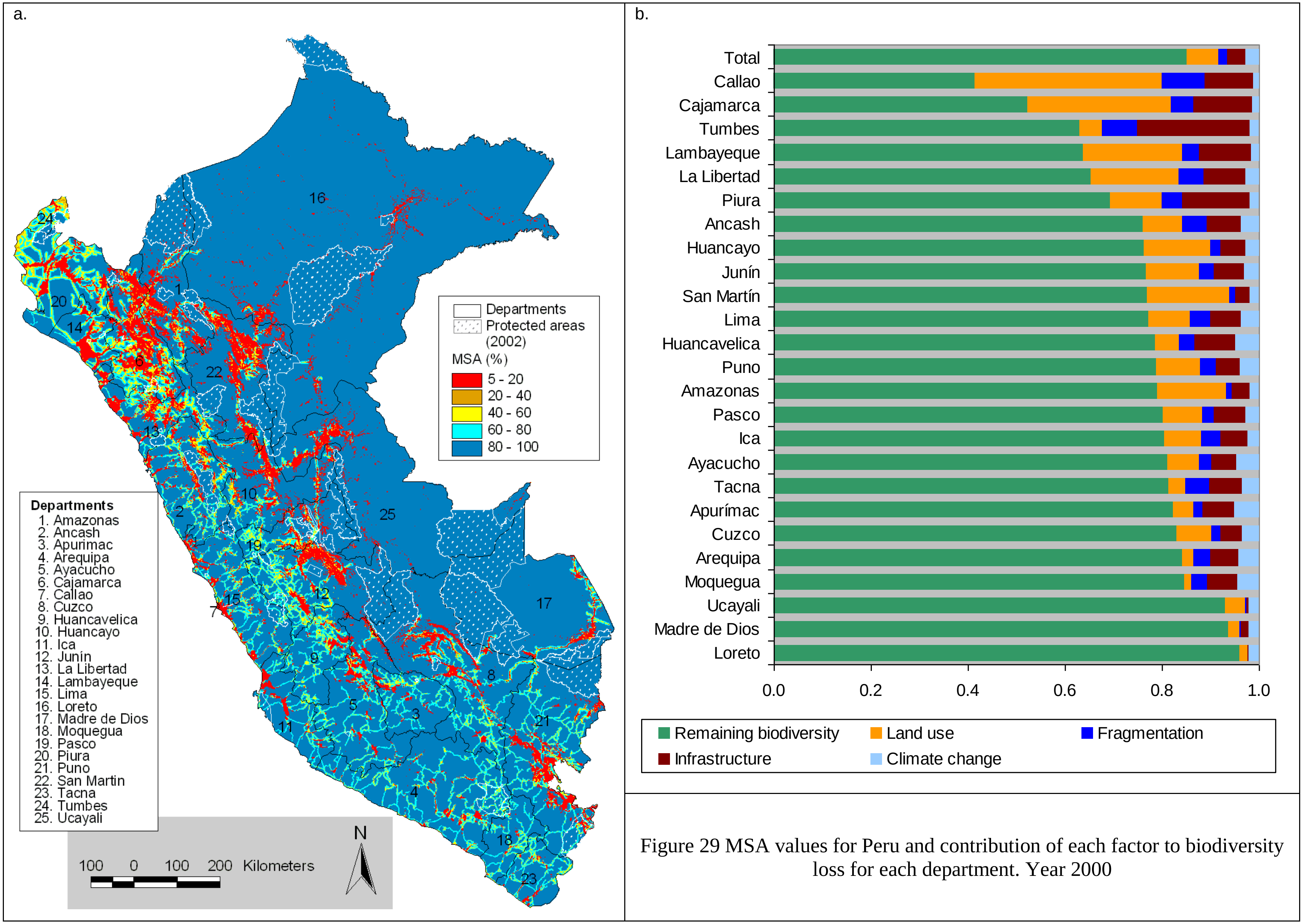


Figure 29 MSA values for Peru and contribution of each factor to biodiversity loss for each department. Year 2000

The remaining biodiversity value was lower for the market forces scenario (79.7%) than for policy reforms scenario (80.2%), as it was expected. However, the difference was not large between those two values. As it can be seen in Figure 30, the most important factor is climate change. By the year 2030, in both scenarios, about 6% of biodiversity will be lost because of this factor, that is to say 3.8% more than in 2000. In that sense, it is important that Government, private institutions and civil society become aware about this issue. While currently, the problem of climate change has its greatest exemplification in the retreat of glaciers (clearly evidenced in Huascaran peak), this is only the beginning of a series of situations that compromise availability of water resources. Regimes of rain will be altered, and hence this will compromise agriculture at the national level. The strip of western Andean valleys would be the most affected by the decrease of water supply. In turn, it becomes evident the importance of negotiation mechanisms with other countries that have contributed and are contributing more to the total of greenhouse gases. The potential impacts of these temperature changes in the environmental services of these ecosystems are a pending issue that needs to be evaluated.

Figure 30 also shows that for the *policy reform* scenario, biodiversity loss by land use change is only marginally lower with respect to the *market forces* scenario (8.5% vs. 9.1% respectively). This leads us to believe that, even when the correct steps were taken to control the increase of agriculture area and man made pastrues; these measures will have no impact on the next 20 years. However, it is possible to combine the growth reduction (lower demand for land) with a planned territorial zoning, to have a more effective measure. That is to say, not only to reduce production but to locate areas where agricultural expansion is less detrimental (causing minor fragmentation, for example). Likewise, the increase in productivity would also be an option that avoids the expansion of agricultural frontier, and even continue covering the demand for food required for the population by 2030.

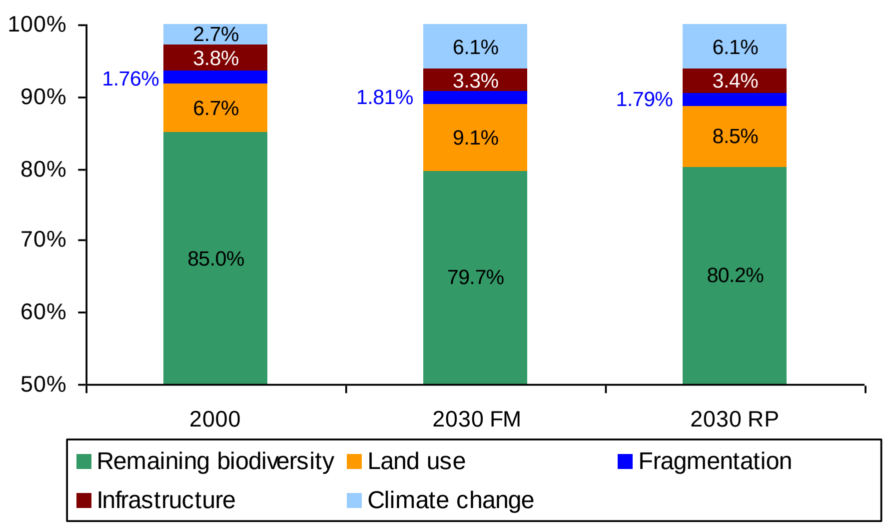


Figure 30 Comparison of MSA values for 2000 and the two 2030 scenarios

In third place of importance is the biodiversity loss percentage caused by infrastructure, this value is slightly diminished by the year 2030, mainly due to two reasons. First, it has not been considered the construction of new roads by 2030; the only one consideration is that for 2006 the Southern Interoceanic road would be paved. Even though the impact of infrastructure includes a mechanism for estimating the impact growth on natural environments, it is possible that this algorithm should be calibrated for national and local levels. The second reason is that infrastructure impact is measured by the proximity of natural areas to roads. By 2030, many of the natural areas near roads would have been transformed into agricultural lands or pastures. Therefore biodiversity loss would be estimated with factor “land use change” and no more with “infrastructure” factor. For this reason, a slight decline in the values of biodiversity loss due to infrastructure occurs.

Figure 31 shows the map of MSA changes for both scenarios on 2030. Figure 32 and Figure 33 show the values of remaining biodiversity for every department in each scenario. The general spatial patterns for 2000 are maintained for both scenarios. The difference between them is found in the densification of areas with lower value of remaining biodiversity for the market forces scenario. The intensity of use and the covered area are the main differences. According to the land use demand defined, the difference between agricultural and livestock areas is 1 051 271 ha, which represents 0.8% of the national area. This explains why the value of biodiversity loss caused by infrastructure in the policy reform scenario, is just slightly greater than the one found for market forces (8.5% vs. 9,14%).

A more clearly way to appreciate the changes is shown in Figure 31a.y Figure 31b, negative values indicate that MSA was reduced in the area between 2000 and 2030, while positive values indicate an increase in MSA. Areas with a loss between 95% and 50% of remaining biodiversity are found around areas that already had MSA values lower than 20% in 2000. It can be seen that the andean strip between Puna and coast has a decrease value between 50% and 8%. This is related to the fact that biomes with shrublands will be most affected by climate change.

The biodiversity loss is closely associated with the patterns described for the land use change, prior to this section. Thus, it appears that Amazon region is the one that carries the greatest biodiversity loss compared with other regions of Peru. It is worth mentioning that several areas with greatest MSA loss are close to important natural protected areas (ANP). In this sense, Santiago Comaina Reserved Area, Cordillera Azul National Park, Pacaya Samiria National Reserve, and the complex of natural protected areas located in Vilcabamba Mountain range, would be those potentially more affected. The vicinity of these ANP to areas with greatest biodiversity loss is a potential problem that needs some alternatives. In that sense, the authority in charge of ANP’s has in this diagnosis, a tool that could help to plan the future preventive actions with for avoiding biodiversity loss in the mentioned ANP’s.

Additionally, this results not only can direct actions focused on issues of national interest such as ANP, but also at local scale, regional governments can have a diagnosis of their region or department. It is possible to do a regional analysis to show which ones had the highest biodiversity loss for this thirty year period. Figure 34 shows these results, and Tumbes and San Martin departments have the biggest percentage or biodiversity loss for both scenarios. In this way, although the case of Cajamarca is critical because of its lower MSA value (Figure 32 and Figure 33) attention should be payed to Tumbes and San Martin. A possible strategy for Cajamarca would be "ecosystem recovery" rather than prevention of biodiversity loss, because much of the department area has a 1% decrease in the MSA values. However, it is not the same case with San Martin and Tumbes, where the decline is much more significant (up to 100% of biodiversity loss). In this way, other strategies should be developed to those areas that have greater potential of biodiversity loss. It is also a wake-up call to policy makers for leading efforts that could stop this situation.

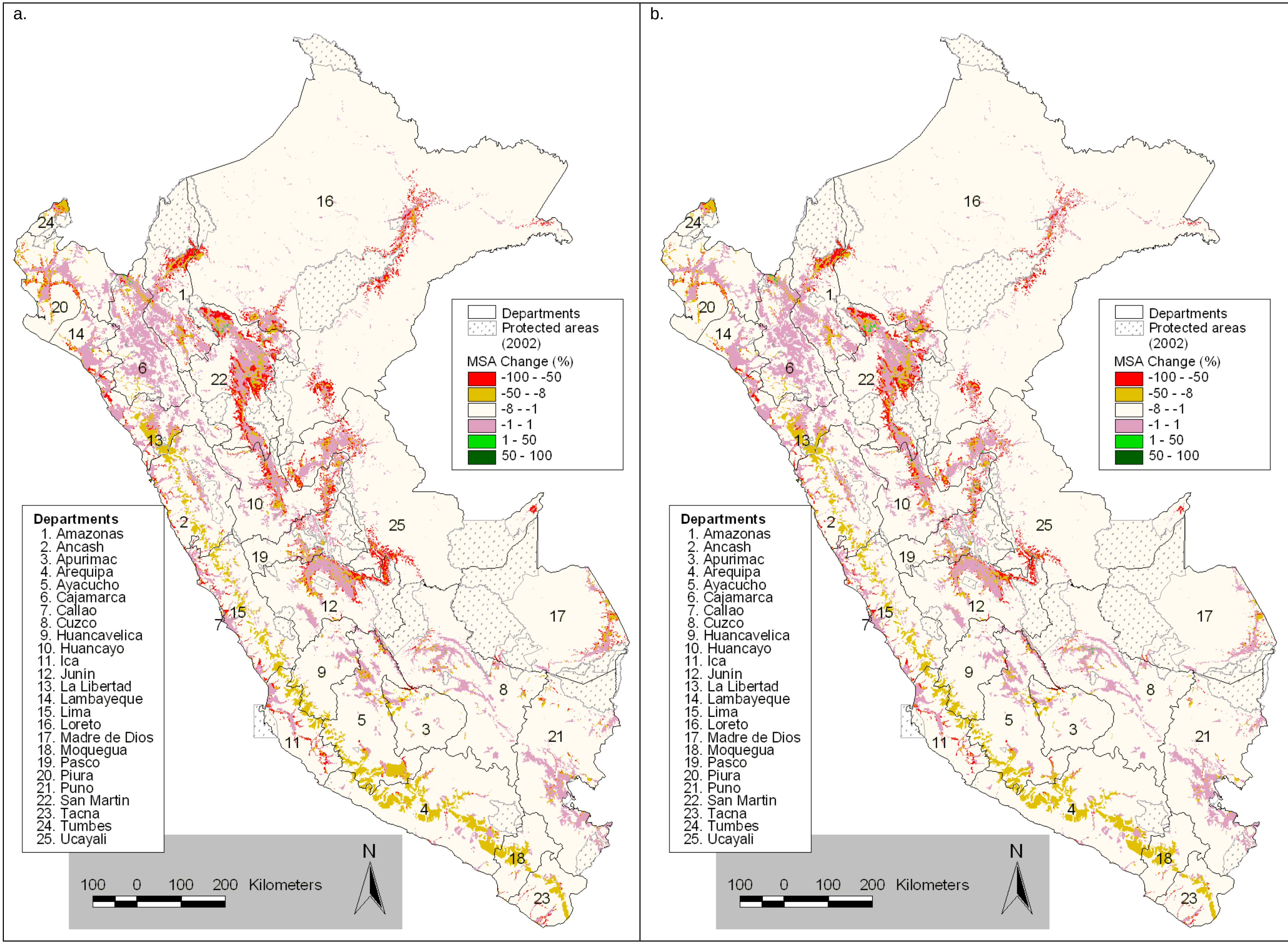


Figure 31 Map of remaining MSA change in Perú for year 2030 according to (a) market forces and (b) policy reform scenarios.

Figure 32 Remaining MSA and pressure drivers at department level for year 2030 market forces scenario

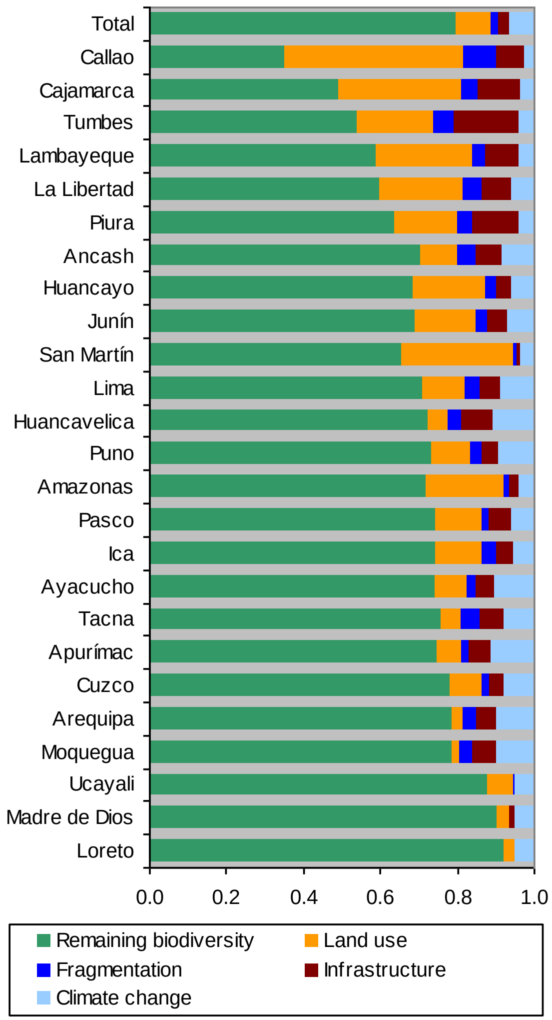


Figure 33 Remaining MSA and pressure drivers at department level for year 2030 policy reform scenario

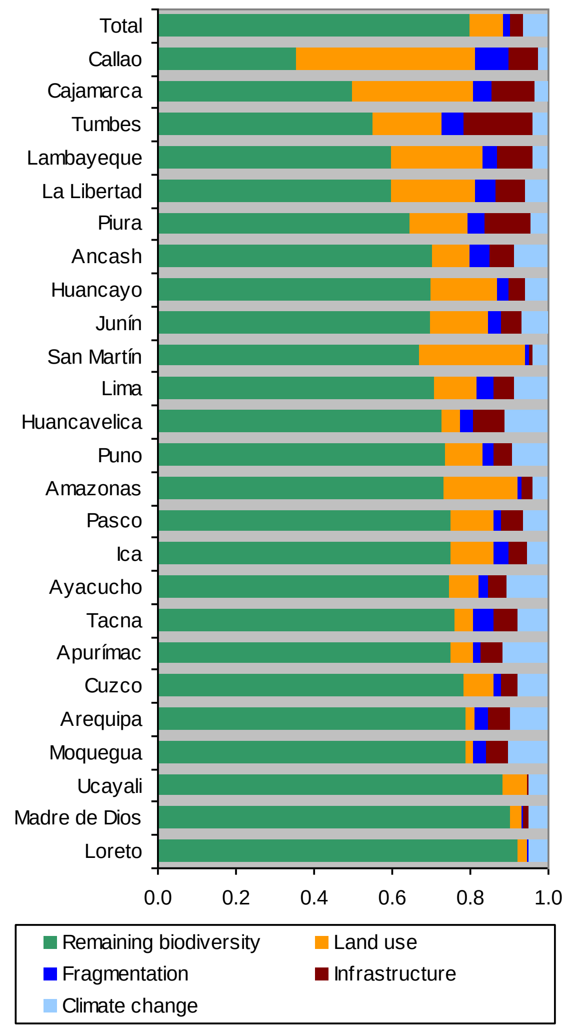
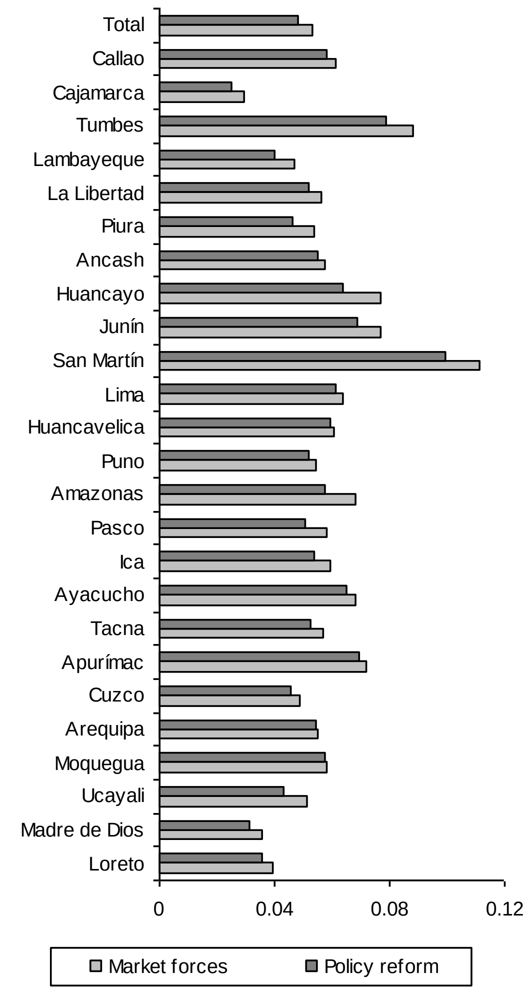


Figure 34 Remaining MSA reduction between year 2000 and 2030 by department for both scenarios



The outputs of both scenarios are a diagnosis of possible future biodiversity based on a combination of local and international trends. While it is still necessary to refine national information (such as trends in land use based on more current agricultural census) we believe that the results draw attention to the most vulnerable areas today. Also factors that may be causing this decrease in biodiversity values have been identified. This case study worked only with two scenarios, but these have been characterized and described in the current context of global development. However it is possible to propose different scenarios. Therefore,, both, the central government and local governments, by means of using GLOBIO-CLUE methodology, have an alternative to assess the impacts of their decisions. Possible outcomes before they take decisions on agricultural policy, territorial zoning, environmental policies, and new road infrastructure, among others are some examples of this.

3.3.4 Conclusions

In general, it is necessary to keep in mind that the results shown are an example of the potentiality of the combination of the GLOBIO 3 and CLUE models. Even when there are so many assumptions and certain limitations such as the information availability and limitations on the model development, a level of consistency exists in the outlined scenarios. As shown in the land use maps for 2030, the spatial patterns of growth for the Amazonian region will be larger than those of the Andean and coastal region. This reality reflects the trend of the last years of accelerated growth (CDC-UNALM) and the existence of a combination of favourable variables for the development of this activity (evidenced in the logistical regressions) that differ from the characteristics in the mountains and the coast. For that reason, it is important to stand out that the geographical heterogeneity plays an important role in the establishment of land use change dynamics. In accordance with this result, it is necessary to outline different strategies for each one of the analyzed regions, due to these different dynamics.

There are two concrete results obtained by this case study: the areas that have lost a great part of its biodiversity between the year 2000 and 2030, and the importance of the factors causing this loss. In that sense, regional governments and/or central government can guide restoration actions to the affected areas, or future actions to foresee the biodiversity loss. Also, it is of special importance that the impact caused by climatic change has had the biggest increment between 2000 and 2030. It is necessary, to give more attention to the government policies focusing on this situation.

Besides these concrete results, this study allows the evaluation and potential of the tool for diagnose and evaluate decision making. This methodology can be used to foresee how our decisions could affect territorial zoning in the future. The development of several future scenarios is perfectly possible and it gives to decision makers the capability to choose within a variety of options.

On the other hand, it is still necessary to make some adjustments in the methodology used for this study case. To estimate the remaining MSA of Peru, the main driver was based on the land use and on biodiversity loss estimation made for each land use type. Some types of land use have not been included, like mining, presence of oil extraction, and extraction of natural resources (flora selective extraction and hunting). Although this last factor is included indirectly in the infrastructure factor, a major development of the impact of these activities on Peruvian biodiversity assess is necessary.

With respect to the lack of information, the major shortage was found in statistical data for supporting the land use demand future projections. Although the available information was an interesting one, this was provided at a national level and not for department level. The information for cattle activity areas was not possible to get as a time series. The most recent detailed spatial information of land use is the one obtained from the 1994 agricultural census. No detailed information is available neither for the variables describing the land composition and land quality, nor for climate. These reasons force us to use global database sets with data of low precision for mountain areas, or, in some cases, variables had to be discarded.

This first attempt of biodiversity diagnose, shows the impact of land use, fragmentation, infrastructure and climatic change on biodiversity, in a combined analysis, and for the first time for Peru. The construction of a land use map for the year 2000 is another important contribution of this work, although there are still some unresolved issues. For example, some areas have more detailed information than others and it is necessary to unify the resolution level and quality of information. However, this is the first approach that will be improved in the future.

Considering the results, and taking into account that the spatial data gives only an impression of the real land use distribution in Peru, it is especially important to verify this information. For this purpose, it is necessary that the government invests in a new agrarian census to obtain the most updated information. More detailed land use intensity information, as irrigation type in agriculture areas, crop types, natural pastures, man-made pastures and livestock amount, could be helpful to have a better diagnosis of land use. Thus, combining this information with spatial information would help to construct a more complete vision of agricultural reality at a national level.

Furthermore, it is necessary to elaborate a soil type map of high and medium resolution, which will allow the inclusion of this variable in the regressions, and improve the identification of the most suitable places for each human activity type. Some Amazonian regions could produce a better model with the inclusion of this variable.

The development of models including the construction of new highways could provide an insight of its future impact. It would be also advisable that, Transports and Communication Ministry, as well as the regional governments with plans of new roads construction, can make use of this and other available tools to measure the impact of future projects. Overall, the use of tools become crucial to estimate impacts on biodiversity and environmental services in the medium and long-term national policy, as well as large investment projects (such as mining, oil, or bets by forest development), and should be included in the balance sheet of the impacts of these activities on the welfare of the country population. This is the challenge for researchers and scientists focused on issues of conservation and rural development.

In the workshop in Lima, these results and ideas were presented to economists, geographers, biologists, forest managers, and other professional mainly from NGOs, ministries and universities. Some of them express their intention to continue the diffusion on their own institutes. We also received some other comments that agree in the idea that these tools and results can be used as a starting point to promote discussions about the potential impacts of economic activities on biodiversity and potential mitigation measures. However, some researchers were worried about the use of the results, because the uncertainty of the models requires that the information produced must be used carefully by stakeholders and policy makers. The use of scenarios would be really important to reduce this risk. Another idea was to develop a friendly-user software that can allow the stake holders to change easily each parameters and evaluate their sensitivity and its impact on land use and on biodiversity.

3.4 Peruvian Southeast Amazon forest

3.4.1 Introduction

In the local scale case, we decided to apply the methodology on Southeast Peru, covering part of Madre de Dios, Puno and Cuzco departments, containing part of the South Inter-oceanic Highway impact zone. The activities on this highway are part of the Initiative for Integration of Regional Infrastructure in South America (IIRSA by its Spanish acronym), and are focused on the pavement of an existing road (currently, a seasonal road) between the major city of Madre de Dios, Puerto Maldonado, and the rest of Peru (including some Peruvian harbors on the Pacific Ocean), and with Brazil. Most people in Peru forecast an important socio-economic positive impact of this highway on the area, due to its current isolation.

However, this highway is also source of concern (SPDA & Futuro Sostenible 2008), because it can promote dramatic land use changes on an area that is one of the most important biodiversity and endemism hotspot along the world. People working and studying in this area have completely different predictions for the potential impacts, especially for cattle development and the creation of man-made pastures. Some researchers consulted in the framework of this project indicated us that interest of local people on cattle has been decreasing for the bad economic results. However, Rubio (2008) wrote about the possibility that Madre de Dios would suffer a great expansion of cattle activities, with farmers holding thousands of cattle, influenced by the big pressure on forest reported in Acre, Brazil. This last opinion is the common sense for many people concerned about conservation.

Mining is another problem in this area. The high gold prices and a low land use change control capacity allowed a “gold rush”. Forest destruction is increasing rapidly, and rivers are polluted with mercury and solid sediments. The mining areas are increasing and have begun to growth toward protected areas in the study area.

On the other hand, the institutional Peruvian structure is suffering several changes, due to the recent creation of the Environment Ministry and the current decentralization process, where several competences for development activities, planning and zoning are currently been transferred to local governments (mainly to the departmental government).

Madre de Dios is one of the regions where the zoning process is more advanced. Even before this decentralization process began, on 2001 their authorities published their economic and ecologic zoning (IIAP & CTAR Madre de Dios 2001) and currently the regional government is updating it to include the Interoaceanic highway impacts. On this study case, we tried to evaluate the potential use of GLOBIO and CLUE to provide useful information for the study area that could also support the regional zoning process. We assessed the impacts of land use demand growth and of different land management options for 2030 spatial distribution of land use and remaining biodiversity, focusing on low land forest near the Interoceanic highway in Peru. This area is also one of the most important areas for biodiversity, because it is well conserved and has a high natural richness.

We presented the first set of results to other academic and technical researchers of several governmental and NGOs institutions. The results and methodology gave a positive impression in the participants. After the workshop, we scheduled some meetings and diffusion activities with researchers and Environment Ministry staff. We used the inputs and suggestions of this workshop to improve the model. For example, after a discussion with other researcher working with other land use change models, we compared and found similar land use change amounts for the area next to Puerto Maldonado. We also included some variables as forest type, and changed the way we incorporated forest concessions. In addition, with these inputs we changed the demand scenarios.

Our results and the opinion of participants to the workshop, encourage us to support the use of this kind of tools at sub national scale models to provide information for regional policy makers, and also for other regional level initiatives (for example, private conservation areas).

3.4.2 Methodology

3.4.2.1 Study area

The study area was selected as a rectangle of lowland forest around the Interoceanic Road South, which includes the entire sector III and part of the sectors II and IV of this road. This area mainly belongs to the Madre de Dios department, but includes a section of the Puno department (mainly within the National Park Bahuaja Sonene) and a small sector of Cuzco department. Manu National Park, Alto Purús National Park and Amarakaeri Communal Reserve, which covers almost the rest of Madre de Dios, were only partially included. For this work, we chose to work with cells or pixels of 90x90 meters due to the topographic information has this resolution.

3.4.2.2 Current land use map

The current land use map was built based on previous works done by the CDC-UNALM (CDC-UNALM et al. 2007, INRENA et al. 2005a, 2005b, 2006). These works produced maps of the entire study area at 30 meter resolution, which identified forests, rivers, barren land, population centers, agriculture (including small-scale livestock), medium and large-scale livestock, mining and clouds. The reduction of scale from 30 meters to 90 meters was done following these rules:

- For a group of 9 cells of 30 meters, if more than 3 cells were deforested, the new pixel of 90 meters was considered deforested. If at least one cell of the nine belonged to urban class, the new pixel became a urban class. The same last procedure was followed for mining and livestock.
- If there were not 3 deforested cells, the class with majority was assigned.
- In case of equal number of cells for cloud and bare land or cloud and forest: cloud
- In case of equal number of cells for barren land and forest: barren land.

This rule increases slightly the proportion of areas with use in relation to rivers and natural vegetation classes. However, it allows a better control during the re-scaling process, reducing the likelihood that secondary forests pixels would be classified as forest.

3.4.2.3 Land use changes

We considered two types of natural land cover (natural vegetation and rivers) and four kinds of land use (agriculture, livestock or man made pastures, mining, and urban areas) for the study area. The natural vegetation category includes unaltered forest and those sectors that have had some type of activity and then have been abandoned. The determination of the type of vegetation remaining in the natural vegetation category (e.g., primary forest or secondary forest) was made after the modeling process, calculating the number of years since that pixel was used for the last time. For purposes of this study, we have not included a model of urban growth, so it was assumed that urban areas have a constant area.

Elasticity and matrix

Table 24 shows the elasticity of each land use class included on this model (elasticity measures inertia, or tendency of each class to survive along the time) and the transition matrix (potential changes between classes). Areas of land use classes correspond to the land use demand calculated on the basis of previous information. Areas of natural vegetation were calculated as the remaining area. Because of this, we assigned the highest elasticity (minimum inertia) to natural vegetation classes.

Class	Elasticity	Conversion matrix [1]					
		Nat. Veg.	Riv	Crop	Mmp	Min	Urb
Natural vegetation	0	+		+	+	+	
Rivers	1		+				
Cropland	0,2	+		+	+	+	
Man-made pastures	0,5	+		+	+	+	
Mines	1	+				+	
Urban zones	1						+

Notes:
[1] A (+) sign indicates that a pixel can change from the row class to the column class.

Table 24 Elasticity and conversion matrix used for the land use model

Demand

For this study case, we used land use maps for years 1990, 2000 and 2005 to construct the future land use change trends for cropland, man-made pastures (for livestock), mines, urban areas, natural vegetation (including primary and secondary forests) and rivers. We made future demand analysis only for land use categories except for urban zones which remained constant. Rivers are assumed to be constant. Natural vegetation is the difference between total area and the demand of all the other land use types.

Regressions

To reduce spatial autocorrelation problems, we sampled the area using a triangular kernel with 900 meters between observed points (10 pixels approx.). The variables included in the regressions were:

Management legal support: Includes forest concessions (and other concessions for forest management), protected areas for indigenous in voluntary isolation and natural protected areas.

Topographic variables: Altitude, slope, terrain shape index, terrain ruggedness index, total curvature, terrain convergence index, topographic exposure index (smoothed and not smoothed)

Forest type: Dummy variable that states whether a forest is permanently (i.e., swamps), not permanently flooded, or non-flooded forest.

Accessibility: Distance to the existing mining concessions (as a proxy of areas of interest for miners), distance to rivers, minimum time to access a road or a river from a pixel, and minimum travel time using roads or rivers to access market place.

Climatic variables: Mean annual temperature, total annual precipitation, ombrotermic index, and ombrotermic index of the driest trimester.

The concession maps for forest timber production, Brazilian nut, conservation and ecotourism were obtained from INRENA, the road map from Ministry of Transport and Communications and the map of mining concessions from the Instituto Nacional de Catastro Minero. We used the map of ecological systems (Josse *et al* 2007) for determining forest types.

Most of these variables are described in 2.3. However, there are some other variables that were included for this case study. Land reserves for indigenous in voluntary isolation is one of them. Others have been included to improve the description of the spatial relationships at this level of analysis (such as those related to flooded forests, distance to rivers and distance from mining centres). The variables of accessibility are discussed below.

In contrast to national scale, at this local scale, the spatial distribution of land use is influenced by the rivers; therefore, they are explicitly included (distance to rivers). Even though the effect of rivers was already included in the calculation of access times, this does not consider the effect of the agricultural areas along the rivers. Given that occupation in this area was first along rivers and afterwards along roads, distance to river is an important variable to consider. Also, by including mining, it was necessary to include a variable that could represent the distribution of the resource. We used a proxy distance to the existing mining concessions, under the assumption that those who have applied for a concession are more informed about the current location of this resource.

Finally, we split market access in two indicators: time required to access the market itself (T_M) but also the time required to access the nearest track or main river (T_{NT}). This allows differentiating transport of agricultural crops made by walk and transport using vehicles (cargo boat, car or truck). Given that total time to reach the market would be T_M plus T_{NT}, we can assess the impact of each one of these aspects on the land use probability.

Regressions were made using backward stepwise logistic regression, using R 2.7.0 (NCAR 2008). R uses the Akaike information criterion to decide which variables should be included and which ones should be rejected. This approach allows comparing different models (such as logistic regressions). It considers information given for each explanatory variable and to obtain as simple and parsimonious model as possible (Burnham & Anderson 2004).

We used the area under the curve (AUC) of a receiver operating characteristic (ROC) curve to assess the quality of the regressions using the library verification of R (NCAR 2007). The value of the AUC ranges between 0.5 and 1. Values closer to the unity represent the best adjustment of the estimate, while a value of 0.5 indicates a completely random estimate. In order to assess the CLUE supposition that the regressions remained valid throughout the years, ROC curves were estimated using the observed data in 1990, 2000 and 2005 and the values predicted by the regressions of 2000.

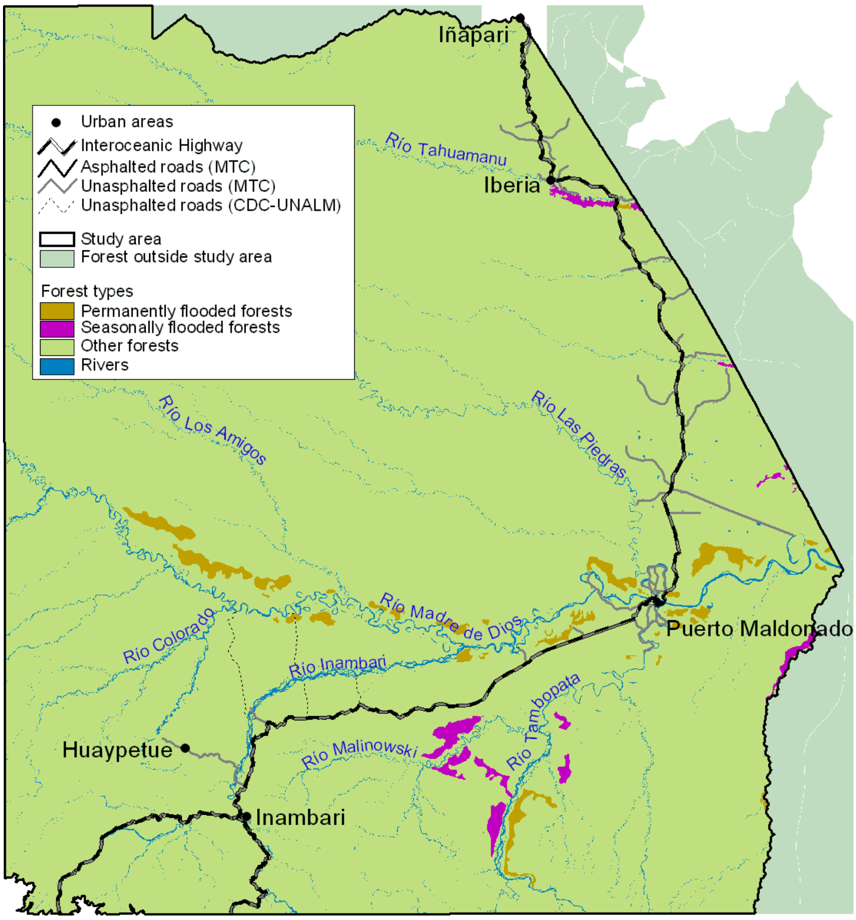


Figure 35 Potential forest types in the Peruvian Southeast Amazon study area included in the model

Future land use map

For this case study, an algorithm resembling CLUE process (Verburg et al. 2002; see methodology) was developed for land use allocation.. In a first step, the algorithm separates all pixels that will not change. For the remaining pixels, the algorithm sorts the pixels in terms of land use class probability of occurrence plus its inertia (which may be different from zero if the class does not change). Once sorted, the algorithm selects as many pixels as needed for each class to complete its demand for this year (from higher to lower probability plus inertia value). If two classes selected the same pixel, the pixel is assigned to the class with the highest value of probability (coupled with the inertia if needed). This will cause some classes end up this step with fewer pixels than needed. In this case, the algorithm starts the procedure again, working with the pending demand and the unassigned pixels. This will stop when all the pixels needed for each class, for the year under review, have been assigned. The algorithm is repeated for each of the years. This algorithm was implemented in R (version 2.6.0, R Development Core Team 2007). It is important to note that while the regression model was done on a random sample of pixels, the probability maps constructed with the logistic regression are good estimators of the probability of each of the uses for each pixel (Keating & Cherry 2004).

The road layer of the MTC was modified for future probability maps with some information. We added roads identified by satellite image of year 2000, and it was considered that Interoceanic highway was pavement. Considering this, we calculated new values of accessibility using the same methodology described in section 2.3.

3.4.2.4 Biodiversity state

To measure the impact on biodiversity we used GLOBIO 3 methodology. This methodology has been developed to work at scales of 1 km resolution, but in this case study we applied to a more detailed scale to asses its applicability. Unlike national case study, this study did not include the population density in an explicit way, letting the model determine which the most affected areas are. In this sense, the model assumes land use changes as a proxy for changes in population density. Therefore, we employed a simplified formula that assumes no changes in population density:

$$MSA_{INF} = \alpha * \ln(dist + \delta + 0.01) \quad (2)$$

Where δ and α are specific parameters for the types of land use and land cover defined in table 1 and *dist* represents the distance to the considered infrastructure (i.e. roads).

Following the GLOBIO 3 methodology we defined analysis zones according to some specific interest. These areas included: protected natural areas (zones 1-5), territorial reserves (zone 11) and buffer zones (zones 21-24). The area not covered by any of these categories is called "complementary zone" (CZ), (Zones 41-43), and was subdivided into three segments: a mining CZ, which covers the southern sector around to the mouth of the river Inambari in the Madre de Dios River; an agricultural CZ, which includes about 30 km of roads existing around the year 2000 including most area of cropland and man-made pastures, located north of the mining zone; and a third area, west of the CZ agricultural, dominated by forest concessions, and where it is expected a minor impact of deforestation, called "minor impact CZ". In total, 13 zones were identified, which can be seen in figure 40. Finally, we defined the complete study area (called CA) as another analysis zone.

3.4.3 Results and discussion

3.4.3.1 Land use change

Regressions

To characterize the land use distribution of year 2000 we used backward stepwise logistic regression for each class. Table 25 describes which variables were used and which of them provided information to the regression. It also shows the sign which indicates the relation between the probability of the land use type and each of the variables. The ROC value is presented at the bottom of the table. The calculation of the AUC was made using the observed land uses for the years 1990, 2000 and 2005, to confirm the assumption that the regressions were consistent throughout the years. As shown in the table, the high AUC values confirm the working hypothesis.

Table 25 Relationships between independent variables and land use types for Peruvian Southeast Amazon forest, showing the observed probability range and AUC values

Variables	Cropland	Man-made pastures	Mining
Intercept	– (***)	– (***)	– (***)
Management legal support			
Forest concessions	– (***)	– (***)	– (***)
Protected areas for indigenous in voluntary isolation			
Protected areas for conservation	– (***)	– (**)	
Forest type			
Permanently flooded	– (***)	– (**)	–
Seasonally flooded	– (**)	–	
Topographic variables			
Altitude		– (*)	+ (***)
Slope	+ (***)	+ (***)	– (***)
Terrain shape index		– (***)	– (***)
Terrain ruggedness index	– (**)		– (***)
Total curvature	+ (**)		
Terrain convergence index	+ (**)		
Topographic exposure index	+ (**)		
Topographic exposure index (smoothed)	– (***)	– (***)	– (***)
Accessibility			
Distance to the existing mining concessions	+ (***)	+ (***)	– (***)
Time to access a road or a river from a pixel	– (***)	– (***)	– (***)
Travel time using roads or rivers to access a market	– (***)	– (***)	
Distance to rivers		+ (***)	– (***)
Climatic variables			
Mean annual temperature	+ (***)	+ (***)	
Total annual precipitation	– (***)	– (***)	
Ombrotermic index			
Ombrotermic index of the driest trimester	+ (***)	+ (***)	
Probability range	0 - 0,994	0 – 1	0 - 0,912
Model fit for several years			
AUC 1990	0.943	0.976	0.995
AUC 2000	0.926	0.973	0.984
AUC 2005	0.901	0.974	0.982

Notes: Every one regression followed a similar pattern, starting with the same variables. The variables that in a first run produced incoherent pattern were not included in the final regression (gray cells). The empty cells represent variables discarded during stepwise regression. The sign in the cell indicate if the relation between the variable and the probability of the class is positive (+) or negative (-). The symbols inside brackets refer to the signification level, (***) < 0,001, (**) < 0,01, (*) < 0,1.

Mining probability was calculated without climatic variables because we assumed it would not affect mining distribution. In the case of territorial reserves this variable led to inconsistent results for agriculture land use, so we decide to exclude it from the regression. Something similar happened for mining with the variables travel time (to access market) and with protected areas for conservation. Figure 36 shows the most probable areas for each land use predicted by the regression results.

Gray dark areas shows the most likely areas for each activity (selecting as many pixels as needed to achieve the highest demand foreseen in the model). Roads are shown in black and rivers in white.

Figure 36 Map of the most likely sectors for man-made pastures, cropland and mining

Table 25 shows some interesting results. First, it shows a negative relationship between protected areas for conservation and probability of cropland and man-made pastures. In contrast, there is no relationship between protected areas and mining. Territorial reserves (like Madre de Dios Reserve) were not significant for any land use type probability. This last result related to protected areas for indigenous, must be evaluated in larger areas, including more areas than only Madre de Dios Reserve. On the other hand, the bad relationship between mining and protected areas for conservation suggests that this last one has been unable to control the mining expansion (mainly advancing by Malinowski River). Among the forest management options, we must highlight the negative relationship between forest concessions and all the land uses identified in this study. This relationship should be confirmed in more detailed studies.

There are two factors that have discouraged the land use change in the study area. The first is the flood regime, because whether forest are permanently flooded or seasonally flooded, both show a reduction - of varying intensity – in the chance of forest use. The second factor is the time of access to markets, particularly the time it takes for people to move from a pixel to a road or a main river. As expected, the distance to mining concessions serves as a good proxy for the mining distribution, but also provides information on where croplands and man-made pastures will not develop.

For climate, high temperature seems to encourage the development of the agricultural and livestock activities. These activities also are favored by lower rainfall and seasonal sectors.

Finally, it is important to keep in mind that these regressions do not explain the reasons for land use change, only give information on the patterns now observed in the study area. Therefore, it would be important to review in detail the models to assess which of these data reflects direct processes. Also, it is important to identify which variables only reflect indirect process in order to replace it with a direct variable.

Demand scenarios

To estimate the possible land use changes, we used as major inputs land use maps of years 1990, 2000 and 2005. We also used as a reference the document of Raskin & Kemp-Benedict (2002), which defines the global context of the scenarios that we used. It is important to note that considerations included in the model have been used to assess the potentiality of the modeling tool. Consequently, they do not try to reflect fully realistic scenarios.

To build the demand, we assumed that the value of land use area in 2000 was equivalent to one. Then we estimated on-year change rates between 1990 and 2000 and between 2000 and 2005. With these rates, the qualitative scenarios described in Raskin & Kemp-Benedict (2002), and some qualitative data, we defined three alternative scenarios, as described below. In general, the **market forces** scenario assumes that the current market trends continue. There is a rapid increase in deforestation and land management strategies are little viable. However, in this scenario, some forest products are enforced due to economic interest of some high value markets. **Policy reform** scenario assumes an international consensus on policies that allows a reduction in more damaging uses. That is reflected in a decrease of severe deforestation for cattle ranchers, but does not have a great impact on deforestation for agricultural purposes. This would be associated with an increased need for expanding the agricultural frontier for food and biofuels. Forest products are not particularly benefited. The third scenario, **order from inside**, is based on a political decision within the region. The policy ensures a high level of protection in the area, promoting alternative development strategies. In this scenario, land use promotes the uses of forest without loss of forest cover (ecotourism, Brazil nut, shiringa, sustainable logging, among others), which is reflected in reduced demand for agricultural area.

Growth effect for each land use type for the years 2015 and 2030 for each scenario, can be seen in Table 26. The whole trend can be observed in Figure 37. Curves were constructed assuming a lineal trend between observed years (1990, 2000 and 2005) For the period 2006-2029 we assumed a linear variation in the percentage held by each category of use. To soften the trend a moving average was applied considering two values before and two after each year (for the years 2006 and 2029 we considered a moving average with only one value before and one after).

Table 26 Deforested forest used for each land class. Observed values for 1990, 2000 and 2005, and estimated values for 2015 and 2030 (surface of each class during year 2000 = 1)

Class	Observed			Market forces		Policy reform		Order from inside	
	1990	2000	2005	2015	2030	2015	2030	2015	2030
Croplands	0.798	1.000	1.190	1.569	2.138	1.569	1.771	1.427	1.569
Man-made pasture	0.323	1.000	1.277	1.954	2.786	1.700	1.954	1.555	1.555
Mining	0.624	1.000	1.581	2.744	4.489	2.744	3.308	2.163	2.445

Market forces

> *Foreign demand controls the land use, which helps to protect the areas under conservation, concessions and other forest friendly with value-added products or uses, but also demand for agricultural and mining areas greatly increases. Even livestock expands by the entry of Brazilian players on the market.*

Due to these considerations, this scenario shows a significant growth in all activities during the period 2005-2015, driven by the development of the road and international demand. Years between 2015 and 2030 show a relative slowdown of the growth, resulting from the saturation of the territory. During the first ten years (2005-2015), for agriculture, we assumed an increase comparable to that observed for 2000-2005 period (the highest observed for this land use class in this study). In the period 2015-2030 the annual growth rate of deforestation would be lower, comparable to that observed in the period 1990-2000. Man-made pastures has a similar pattern: the period 2005-2015 is comparable to the period 1990-2000, the highest, while the following 15 years the annual rate is comparable to that seen in 2000-2005. This figures are consistent with the pattern reported in Raskin & Kemp-Benedict (2002), the relative growth in livestock is higher than in agriculture.

The growth in mining, pushed by high international gold prices and low capacity of institutional control of the activity, remains similar to that seen in 2000-2005.

Market development with environmental agreements, such as the one found in Free Trade Agreement between Peru and United States, leads to a strengthening of the market for managed forest products, which stops deforestation in forest concessions.

Policy reform

Despite the fact that domestic policies are weakened, international relationships becomes favorable to encouraging a global balanced development. The demand for livestock land is heavily restricted, and alternative uses are developed, reducing mining pressure over forest. However, the demand for agricultural land is strong, this, coupled with the low local valuation given to remant forest, avoids a better management.

While this scenario represents a considerable improvement in the total deforestation, the story is not uniformly better. This is reflected especially in agriculture, whose expected increase is greater than or comparable with the market forces scenario (Raskin & Kemp-Benedict 2002). In the case of livestock, this scenario assumes a steady increase for the initial period (2005-2015) with a lot of inertia in its growth, equivalent to 63% of the total increase in the period 2005-2030. After 2015, it is assumed that the effect of international policies becomes more important, which greatly reduces the increase in the man-made pastures for livestock. For 2030 the livestock area is comparable to that observed for 2015 in the market forces scenario. However the sum of agricultural and livestock areas is lower than that of market forces.

For mining, we assumed that land use has the effect of creating an organized growth. Regardless of this, high prices of gold and large number of people involved in this activity makes that only in 2015 the mining activity would be reasonably ordered. For all this reasons, we assumed that, until 2015, its rate of increase remains similar to that seen between 2000-2005. Between 2015 and 2030 the rate is similar to that observed in the period 1990-2000.

In this scenario, the forest concessions reduced the likelihood of agriculture, man-made pastures and mining, according to what was observed in the logistic regressions.

Order from inside

The local policies and planning for land use are maintained and consolidated, favored by an international context that promotes sustainable use of forest. The consensus becomes contrary to local livestock, which stops its growth. Agriculture maintains a steady growth, but orderly, with little practices degrading the forest. Likewise, the mining growth is controlled, through alliances with the mining sector.

This scenario assumes a very strong regional strategy aimed to preserve the forest areas, based on a regional purpose for alternative development. This purpose is also supported by an international recognition of the importance of this region due to its natural diversity. In this context, agricultural development would be low enough to ensure that the area with agricultural use is equivalent to the area observed the for policy reform scenario in the 2015 (63% of it happening until 2015).

Livestock maintains certain inertia of growth until 2015. Then, its growth would be stopped due to: international context that discourages it, consistent territorial management of the regional authority, and the widespread awareness of local producers that it was a less profitable activity than others in the medium and long term. Something similar happens with mining, its increase to the year 2015 and 2030 are equivalent to half the figures in the policy reform scenario.

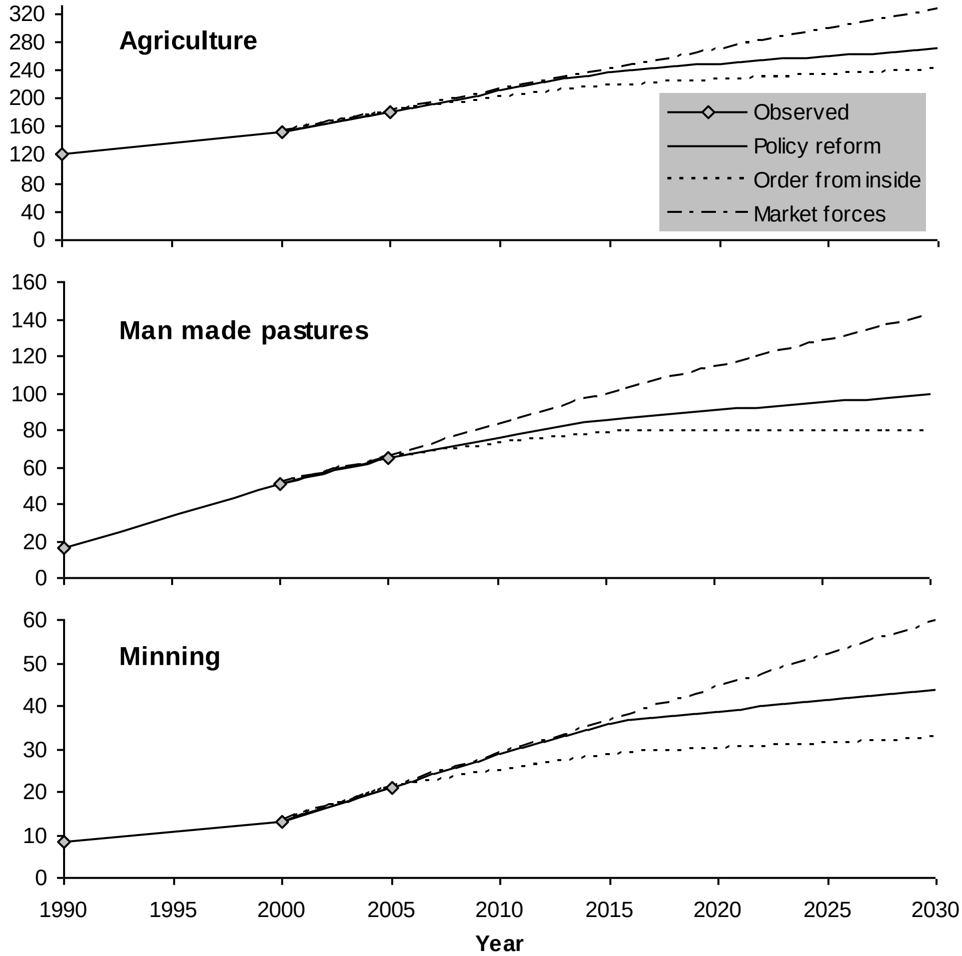


Figure 37 Land use trend observed (1990-2005) and expected (2006-2030) for the scenarios market forces, political reform and order from inside (values in thousands of hectares).

Initial and final land use maps

Figure 38 shows land use maps for 2000, based on satellite image interpretation. It also presents the concessions granted to management of forest covering major sectors of the forest. Huaypetue mining area can be easily seen, as well as agricultural lands and man-made pastures from the south of Puerto Maldonado to the border with Brazil. Likewise, one can see that most of the area is still forested. In fact, much of this forest would correspond to primary forest or near-primary. In many cases there is selective logging of the most valuable commercial species, but without other important changes in forest composition. However, it is important to indicate that the presence of forest does not imply the absence of villagers. In this region there are several indigenous groups, some of which maintain their nomadic or semi-nomadic habits.

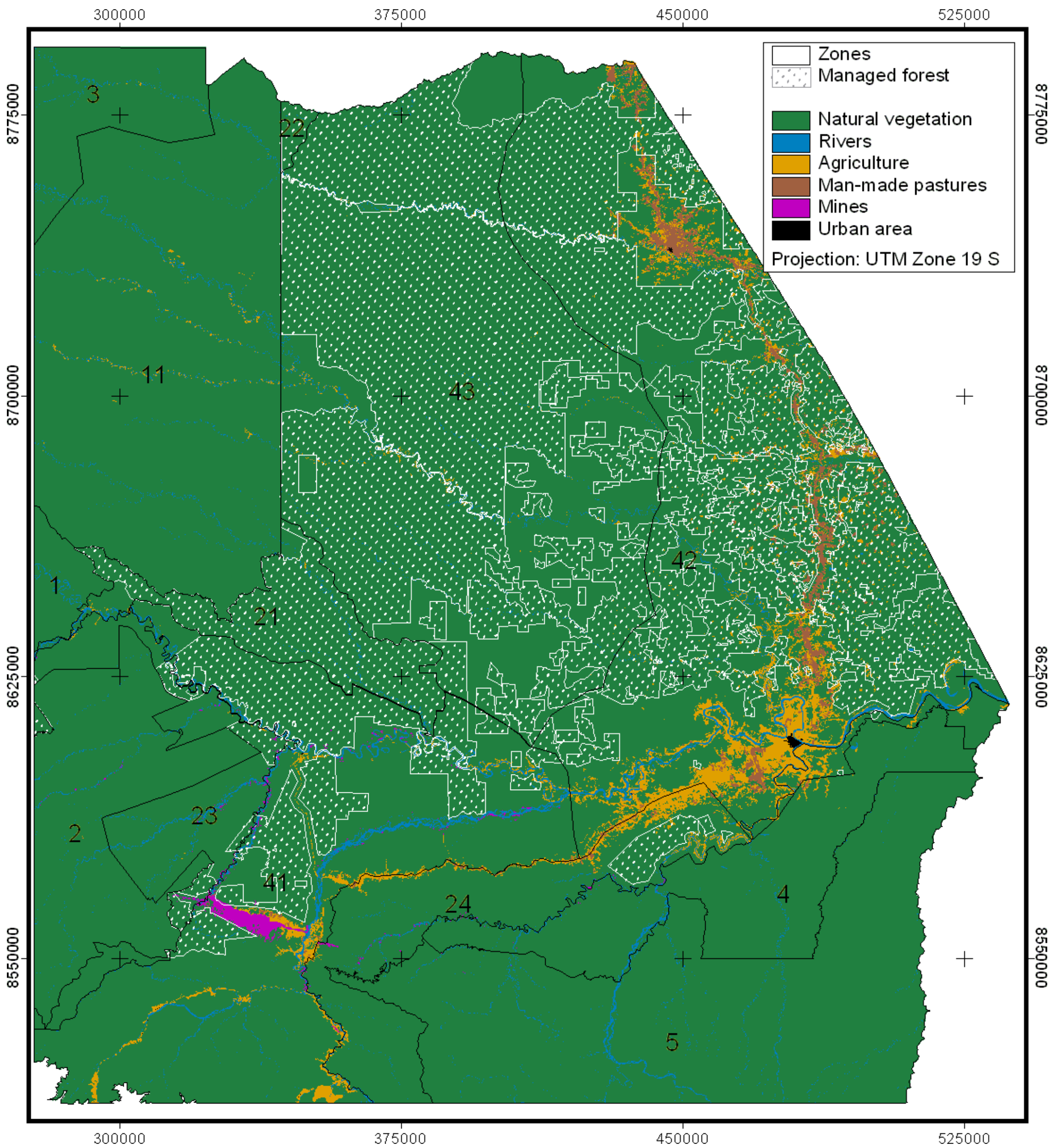


Figure 38 Land use map observed for year 2000

Zones: 1. PN Manu, 2. RC Amarakeri, 3. PN Alto Purús, 4. RN Tambopata, 5. PN Bahuaja Sonene, 11. RT Madre de Dios, 21. ZA Manu, 22. ZA Alto Purús, 23. ZA Amarakaeri, 24. ZA Bahuaja Sonene, 41. Mining CZ, 42. Agricultural CZ, 43. Minor impact CZ

Figure 39 shows the land use maps projected for 2030 for each scenario. As shown, the model provides a differentiated increase of agriculture and man-made pastures, with the livestock sector preferably north of the area and the agricultural sector in the south. The mining industry is expanding significantly around the area of Huaypetue.

The different scenarios show some interesting similitude and differences. For example, despite the protective effect generated by managed forests in policy reform and order from inside scenarios, there is an advance of cattle ranching and agriculture in the northern sector of the study area. In fact, it would need strong incentive to reduce degradation of these forests, as we included in the market forces scenario. On the other hand, in this last scenario, although the progress of the pastures is effectively controlled by the external economic incentives, the strong demand for livestock lands, force it to expand by the South of Puerto Maldonado. These maps reflects three areas of interest: a first sector on the road between Puerto Maldonado and

Huaypetue, another in the diversion to Colorado and a third in the far south west of the study area, in the form of small livestock sectors accompanied by agricultural sectors.

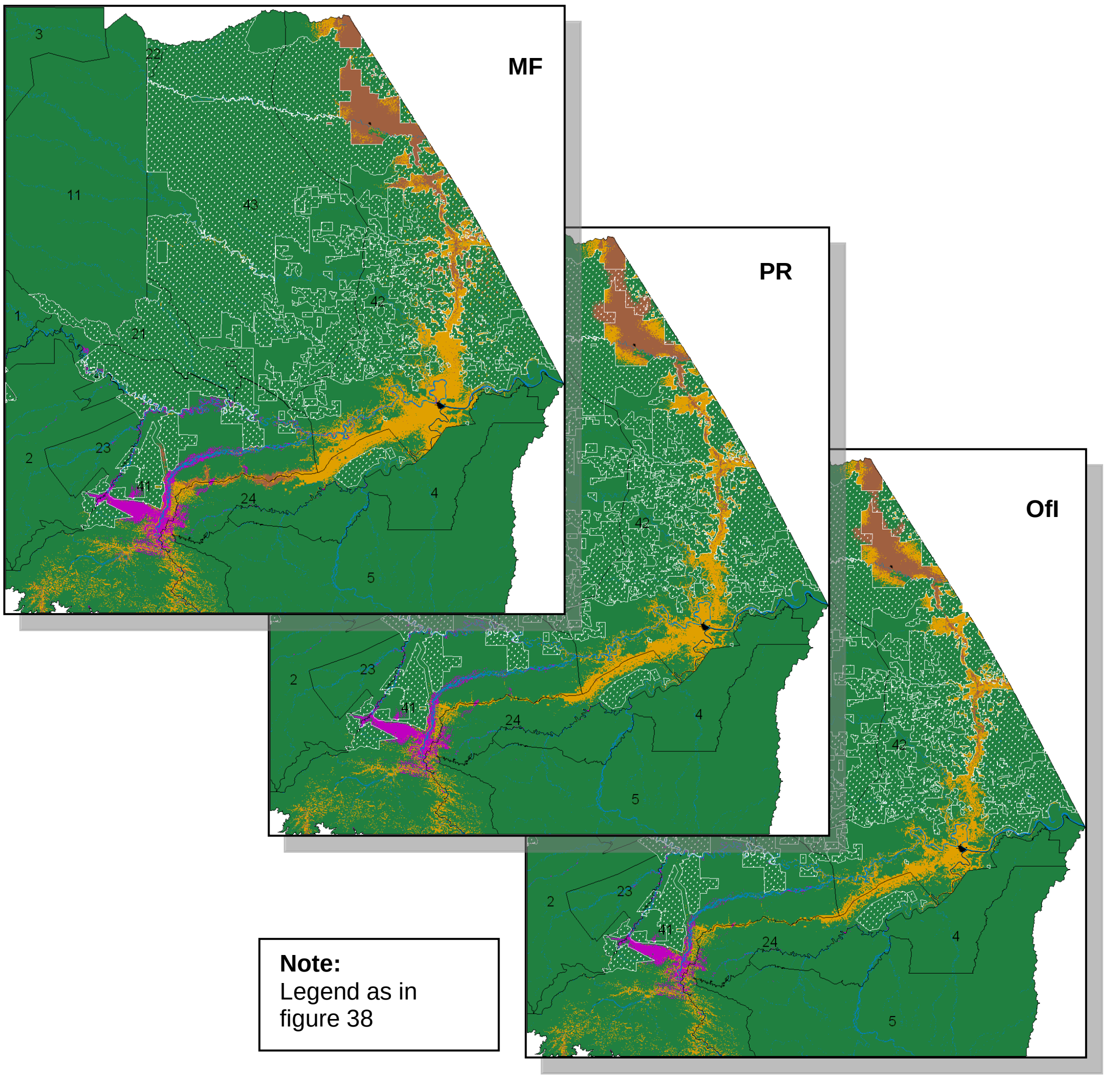


Figure 39 Land use maps for year 2030 according market forces (MF), policy reform (PR) and order from inside (OfI) scenarios.

An important element is that the model is not representing properly small agriculture that takes place in banks of several rivers. This may be caused of the absent of a variable that would "explain" why agriculture was developing there. However, a more important reason is that we did not distinguish subsistence farming from commercial agriculture linked to the national economy. As this second type of agriculture is much more important in extension, its effect dominates over the first one.

Spatial distribution of land uses was slightly more aggregated than observed in all land use classes. Mining is probably the most complicated case, because it is expected that this activity will disperse when the existing mining sectors exhausted its reserves. This pressure will remain high as long as the international gold price remains high, which is expected in the coming years. However, there is one situation when gold production will maintain even when prices fall. This can be produced when high price of gold has justified the purchase of heavy machinery. Since the investment has already been done, the production can maintain, and moreover, increase sediment removing for increasing production if the owner must pay a loan.

There are important factors that can alter the probability of each land use. In particular, it would be important to have high-resolution soil map (90 meters). Although we included a map of forest types, it was not possible to include a map of fertility itself. Another factor that has not been included is the effect of deforestation on the neighborhood of a particular sector. This effect could be incorporated into the CLUE-s with a cellular automaton approach using "enrichment factor" (Verburg 2002). The inclusion of other options in CLUE-s, as obligatory changes from one land use class to another, or other time restrictions of the conversion matrix could be another way to improve the model.

These adjustments could increase the probability of deforestation near small and isolated farm sectors, stabilizing their dynamic in the surrounding areas. However, we have identified some processes harder to capture with the CLUE-s. For example, population density was not included explicitly or implicitly. Population may have different levels of affinity to their current town or locality. For example, settlers and miners would have lower affinity than indigenous population. Another factor that was not included (because it requires more detailed work) is the land tenure and land ownership. This factor is rather more complicated because it implies that different actors should have different probabilities to deforest different sectors of the forest. Assess future trends of tenure and land ownership is even more complicated.

Another difficulty is that the maps do not reflect a random process, although they originate from a set of logistic regressions that incorporate randomness explicitly. That is, it is unrealistic that the model should perfectly select the most likely pixels for each class. This sounds contradictory, but it can be reflected with the following analogy: the odds of obtaining a 1 after throwing a dice are 1 to 6, or 16.7%. But if we throw the same dice 20 times, the probability of having at least 1 rises to 97%. In other words, we should expect that not all the most likely pixels become agriculture, and also that some of the pixels unlikely to become agriculture, become into it. There are also other sources of uncertainty that have not been incorporated into these models in this first approach. Future work should assess these uncertainties and include them in an explicit way. For this, it is important to note that the output maps for each scenario only identified areas most likely to use, even when not explicitly incorporate a measure of uncertainty.

Finally, while it is possible to incorporate some of these changes directly to CLUE-s, other changes are more difficult to incorporate into this model (some of these changes could be incorporated more easily to the adapted version of CLUE-s for this model, but other changes could be hard to include to any of them or to any other model which works in a similar way). Despite this difficulties, CLUE-s’ basic idea of including an absolute demand for each land use type seems useful. It is particularly interesting how this option can simplify the dialogue between social scientists (whose sources of information are usually un-located) and scientists dedicated to landscape changes (which often do not dedicate enough time to understand the interactions and importance of the social, economic and political aspects that affect an area).

3.4.3.2 Biodiversity changes

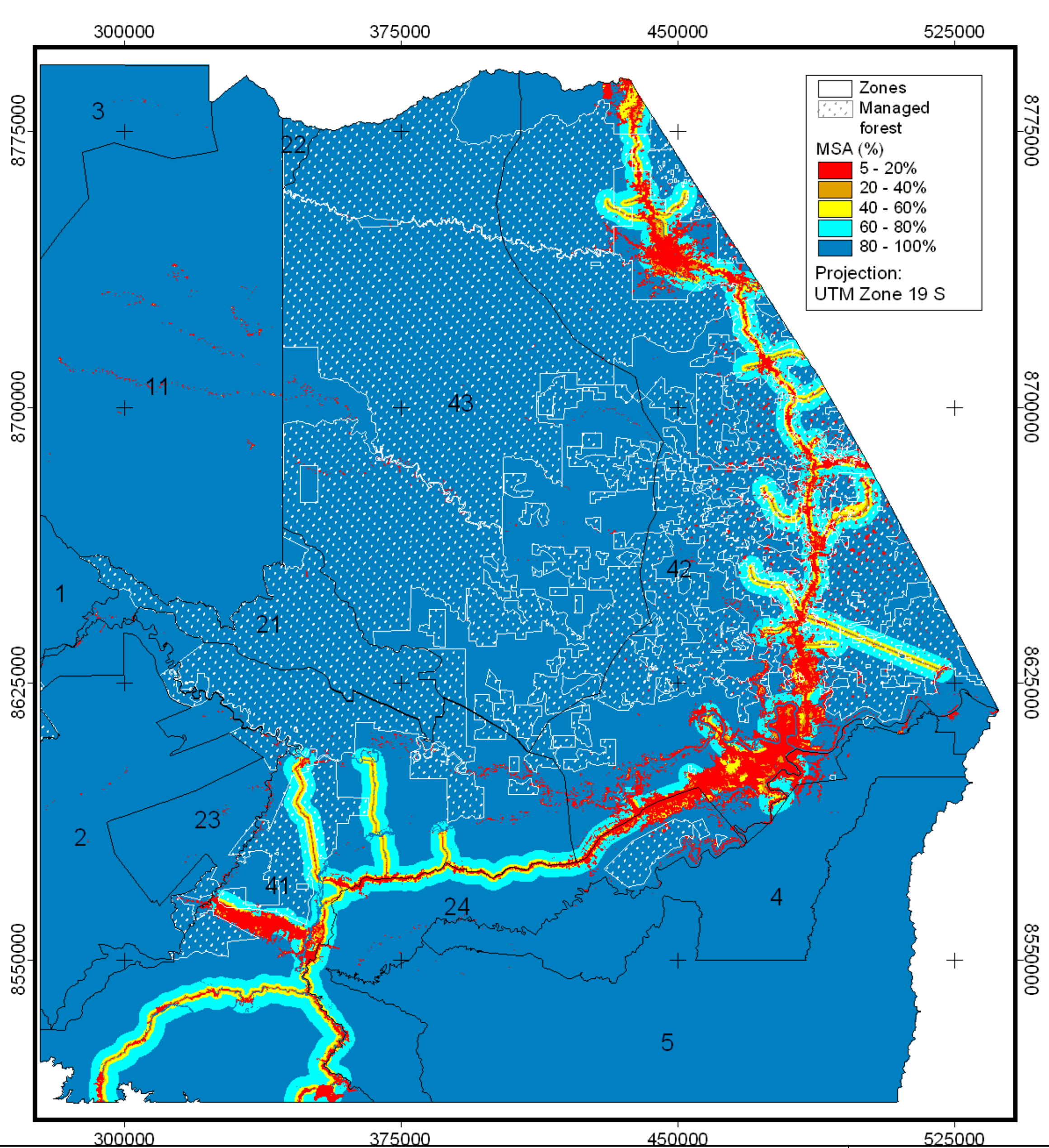
Figure 40 shows a map of MSA for 2000 and the impacts on the biodiversity of each of the factors considered in this study, in the zones of the work area. As can be inferred from the map, the current remaining biodiversity is considerable high, with an MSA value of 91%. However, this value does not include specific models of timber extraction, or biodiversity loss in managed forests. Therefore, it is possible that there is some overestimation, and the MSA value should be understand as the maximum possible value.

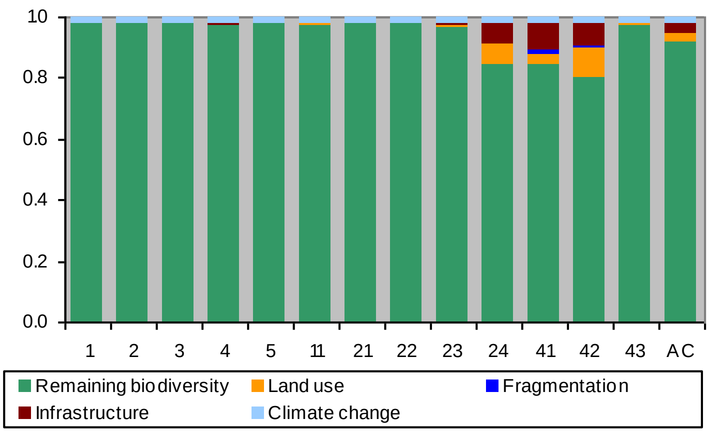
The main cause of biodiversity loss in the region is associated with indirect impacts related to infrastructure, such as hunting and resource extraction, which accounts for 3.2% of losses. The second cause is the land use change, which is responsible for 2.9% of biodiversity loss. The effect of fragmentation (0.33%) is less important than the impact on climate change (2.1%). This area is contiguous to a well conserved sector of Bolivia, which made that the fragmentation of the areas to the north of Puerto Maldonado was avoided.

These results are consistent with the fact that this is recently colonized area. Indeed, just in 2005 the government began asphalting the road that links this area with the rest of the country and with Brazil, as part of IIRSA. When this via would be finished, the transit between the Atlantic and Pacific will be completed.

Figure 40 also shows that sectors with less biodiversity correspond with complementary zones (i.e., areas that are not included in any protected area or buffer zone) near the road. Puerto Maldonado, Iberia and Huaypetue were the most impacted. The areas surrounding Madre de Dios River also presents significant reductions in biodiversity. However, it is interesting that there are few sectors with connectivity or fragmentation problems. In this regard, while the road divides the area into (at least) two parts, each of these two sections is found to be large enough to contain nearly all of its original biodiversity (over 10 million hectares, following Alkemade *et al.* 2006). It is important to note that there are some fragments of forest next to Bolivia which low fragmentation was explained by the forests preservation across in Bolivia. Likewise, the fragmentation observed in this study relates only to the lowlands forest. It does not include the effects of fragmentation in the Yungas, where it is expected that these problems are much more serious. On the other hand, the model is not considering the fragmentation that might arise from the presence of large rivers. It is important to note that the rivers, particularly the very wide ones, are a natural source of fragmentation for many species. However, the GLOBIO 3 does not include them as a source of fragmentation.

Figure 41 shows the potential impacts on biodiversity by 2030 under the considered scenarios, in comparison with the biodiversity for 2000. In 2030, the largest impacts are caused by land use change and the effect of climate change. It is worth mentioning that only the scenario of market forces showed a greater impact of land use change than that of climate change. Another pattern that draws attention is the reduction of the impact of infrastructure. This is explained because most of the impact of the roads would now be on agricultural or livestock, and no longer on natural forest. This would mean, for example, that hunting will focus increasingly on animals typical of secondary forests, as the majaz, *Cuniculus paca.* Also, accesibility to primary forest resources would be diminished, increasing the use of agricultural and livestock resources. It is important to indicate that we did not include a model of roads development. Consequently, it is possible that this impact is underestimated, since it is expected that the agricultural expansion also implies expansion in network roads.





Zones:
1. PN Manu
2. RC Amarakeri
3. PN Alto Purús
4. RN Tambopata
5. PN Bahuaja Sonene
11. RT Madre de Dios
21. ZA Manu
22. ZA Alto Purús
23. ZA Amarakaeri
24. ZA Bahuaja Sonene
41. CZ Mining
42. CZ Agricultural
43. CZ Minor impact
CA. Complete

	area
Figure 40 MSA estimated for year 2000	

Between 2000 and 2030 the biodiversity loss caused by fragmentation was almost null (see Figure *41*). It was caused by the protected areas and the large areas of well conserved forests that will exists at both sides of the Interoceanic highway (Figure *42*, Figure *43* and Figure *44*), in Peru and Bolivia.

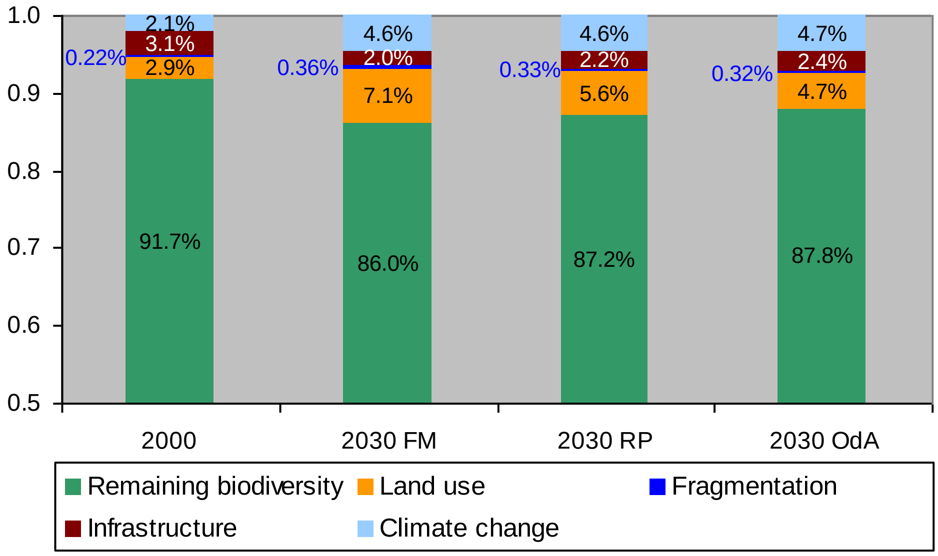


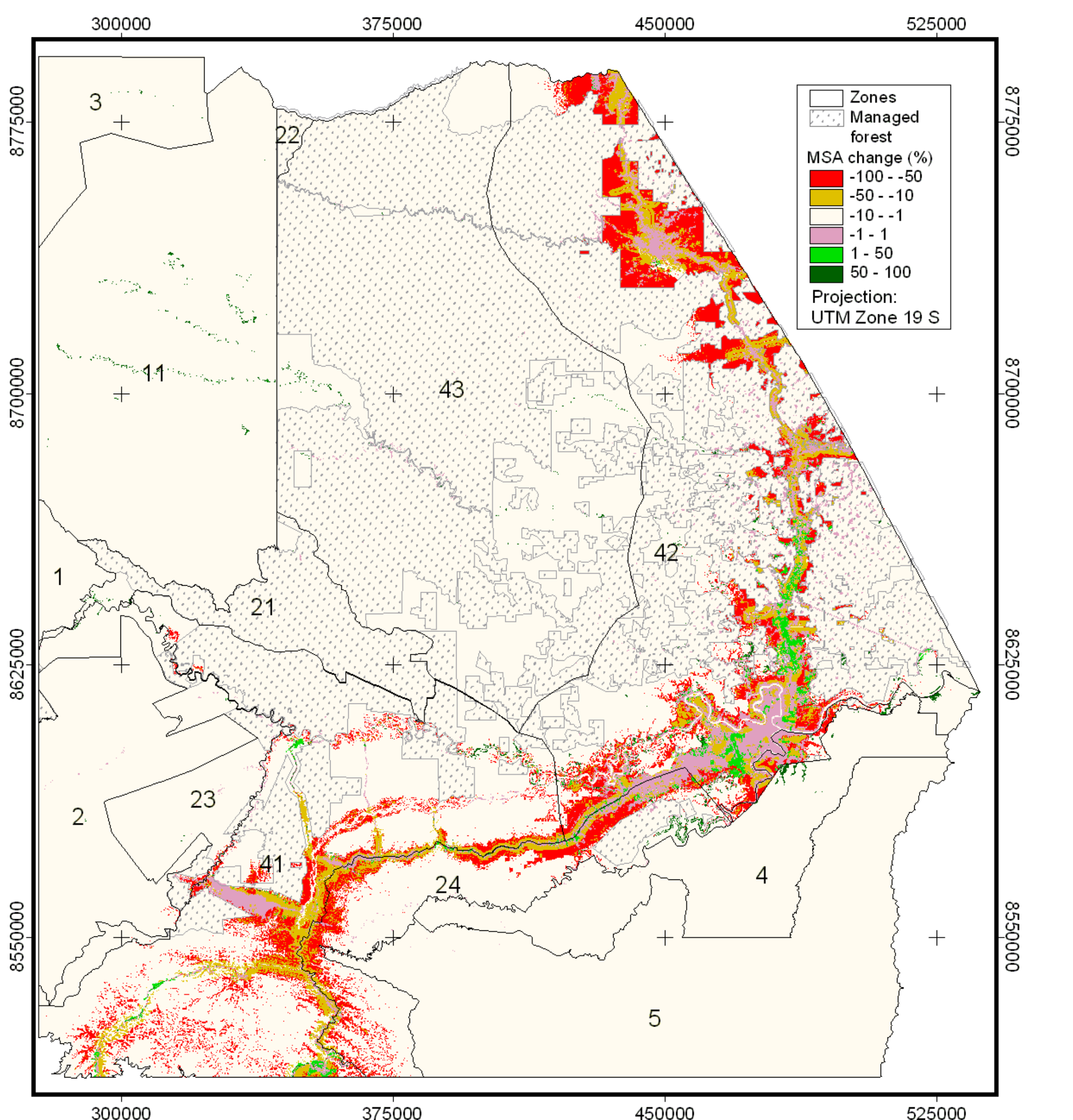
Figure 41 Comparing remaining biodiversity and the impact of drivers on biodiversity loss for 2000 and 2030 scenarios

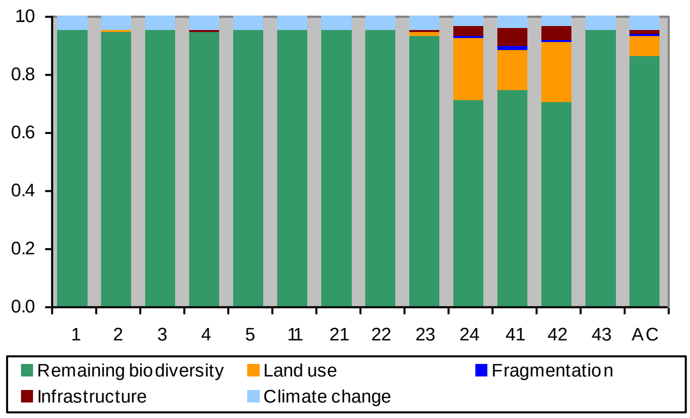
An important aspect is that the model predicted a high concentration of the land use change in the mining and agricultural complementary zone. These sectors will concentrate almost all of the impacts on land use change, leaving most of the rest of the area without significant impacts. Another sector that presents significant impacts is the buffer zone of Bahuaja Sonene National Park. This buffer zone would have most of the agricultural and mining growth, so its integrity is seriously compromised, even more than the mining complementary zone.

This draws attention to the importance of management in this sector, where agriculture and livestock is allowed. However, these activities should not to put at risk the integrity of Bahuaja Sonene National Park or the Tambopata National Reserve. In fact, the models predict that the pressure on the northern sector of Tambopata National Reserve is very high in all the scenarios. This would have as a consequence that real impact inside National Reserve would be higher than predicted by any model. These impacts would be caused by roads and even by the increase in pressure on land use. Models also predicted problems in the buffer zone of the Communal Reserve Amarakaeri, mainly because mining increase.

In the case of mining impacts, it is important to indicate that the MSA is only evaluating the state of remaining biodiversity for terrestrial systems. It means that we did not include any impact of mining on river ecosystems, such as mercury pollution or sediment generation.

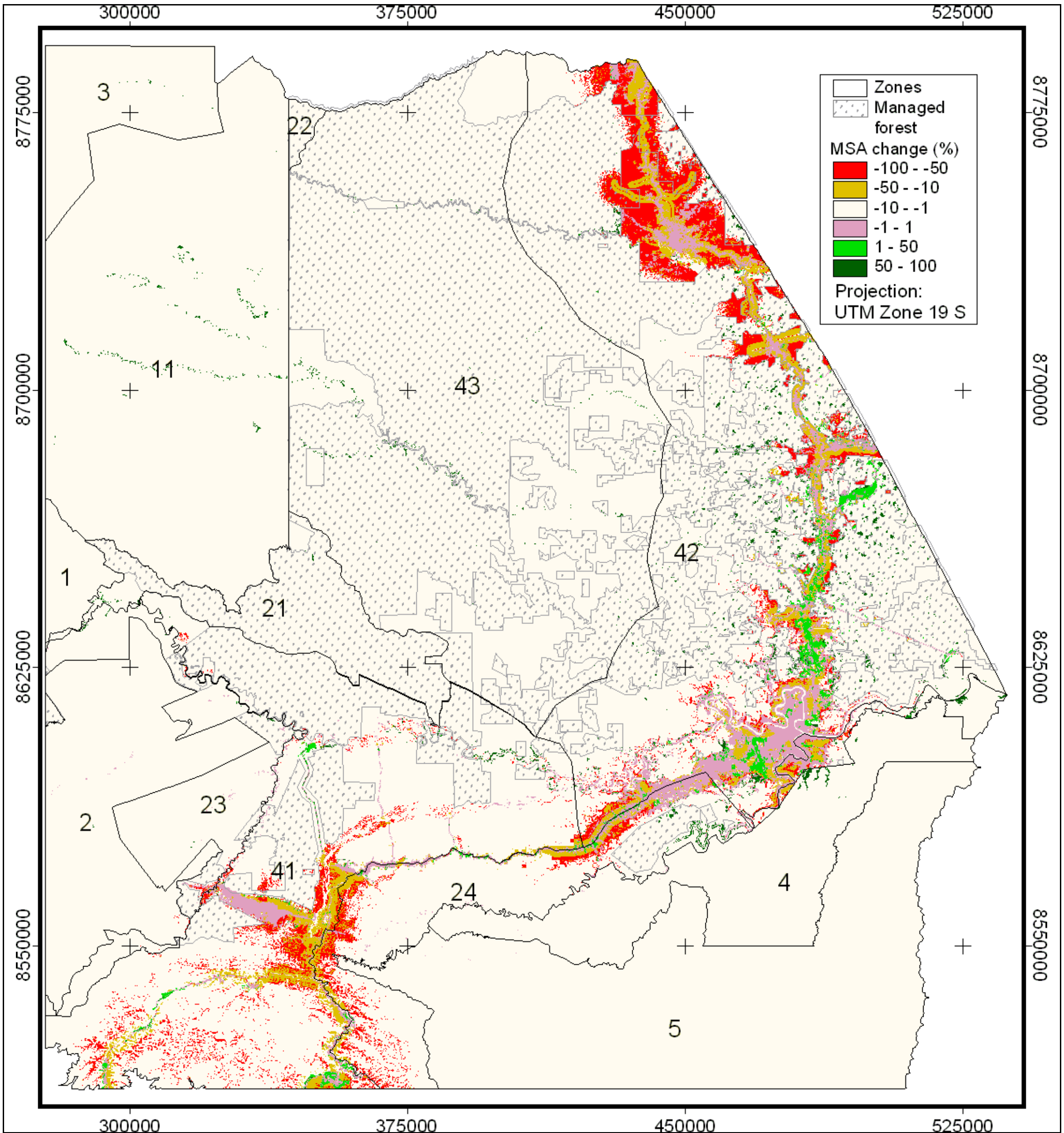
Some sectors improve their MSA near Puerto Maldonado. These improvements are the result of land use changes from livestock to agriculture, and are in the order of 10%. They are caused by the strong concentration of livestock (understood as large artificial pastures) and agriculture (which may also include small areas with livestock activities) in the north and south of the study area, respectively. It will be important to assess whether this recovery can really occur, in the sense that the area can change from livestock to agriculture use, and in the sense that such change does not involve a permanent biodiversity loss.

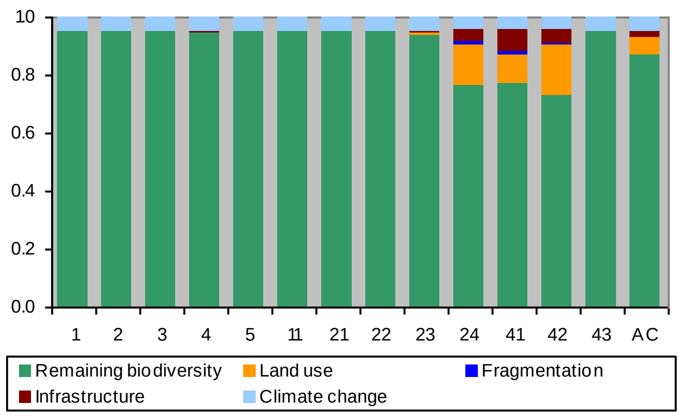




Zonas:
1. PN Manu
2. RC Amarakeri
3. PN Alto Purús
4. RN Tambopata
5. PN Bahuaja Sonene
11. RT Madre de Dios
21. ZA Manu
22. ZA Alto Purús
23. ZA Amarakaeri
24. ZA Bahuaja Sonene
41. CZ Mining
42. CZ Agricultural
43. CZ Minor impact
CA. Complete area

Figure 42 MSA change map between 2000 and 2030 expected for market forces scenario and MSA estimation.





Zones:
1. PN Manu
2. RC Amarakeri
3. PN Alto Purús
4. RN Tambopata
5. PN Bahuaja Sonene
11. RT Madre de Dios
21. ZA Manu
22. ZA Alto Purús
23. ZA Amarakaeri
24. ZA Bahuaja Sonene
41. CZ Mining
42. CZ Agricultural
43. CZ Minor impact
CA. Complete area

Figure 43 MSA change map between 2000 and 2030 expected for policy reform scenario and MSA estimation

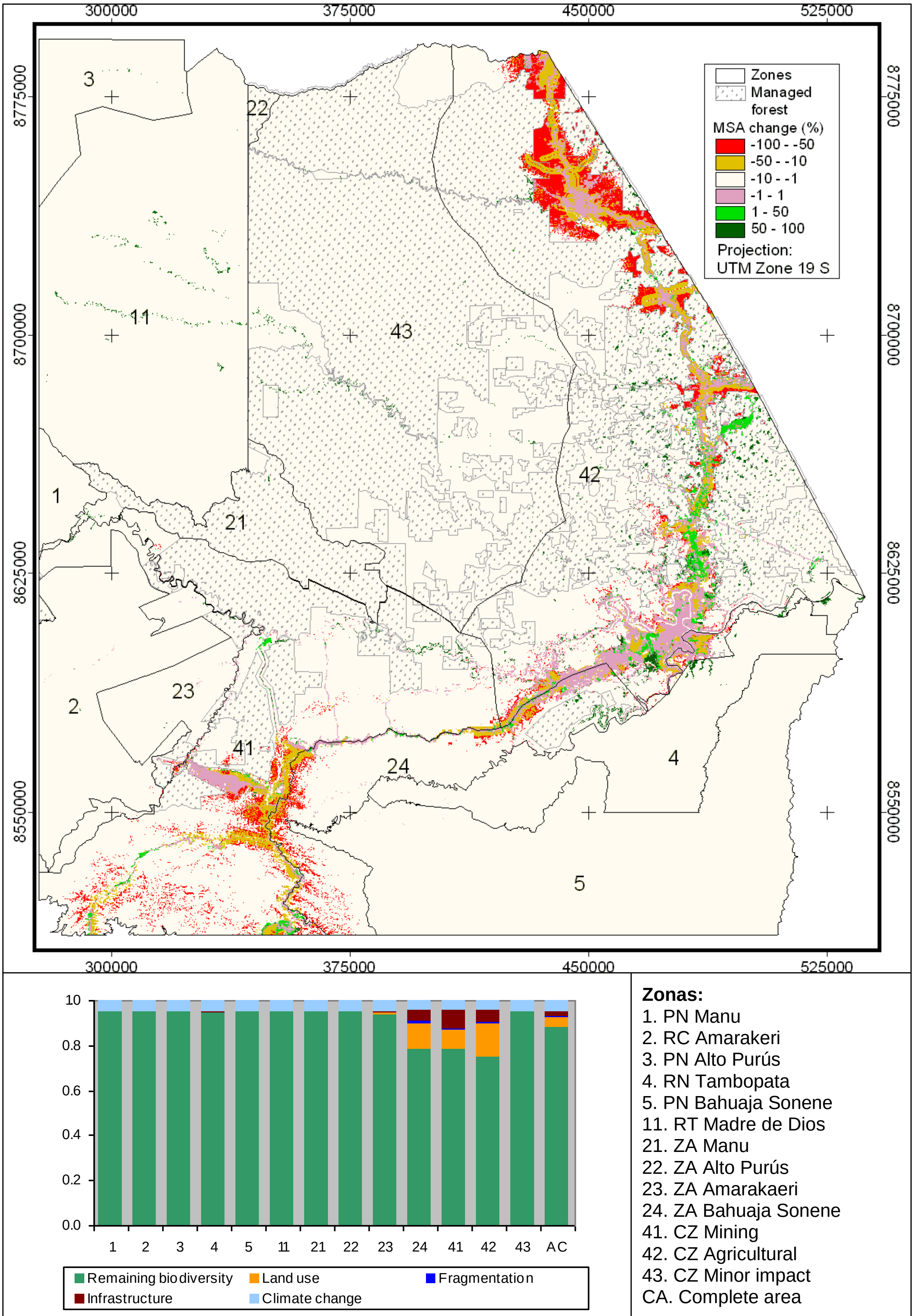


Figure 44 MSA change map between 2000 and 2030 expected for order from inside scenario and MSA estimation

In the case of policy reform and order from inside scenarios, the agriculture and livestock located within the interior of the forest concessions between Puerto Maldonado and Iberia migrate to other more favorable regions. Favorable areas are usually closer to the roads (in market forces scenarios, the areas inside the concessions could not change their use). Other favorable areas are other sectors of managed forests, mainly in the north, near Iñapari. In the case of policy reform scenario, the strong growth in agriculture leads to a significant biodiversity loss in the north end of the study area, entering heavily in sectors considered under forest management. However, unlike the market forces scenario, there is a significant biodiversity loss near the road between Puerto Maldonado and Huaypetue.

The analysis of the MSA maps also helps to identify potential critical areas to ensure connectivity between forests of the east and west of the highway. In this case, we identified three areas that can be seen in Figure *45* (indicated by arrows). These correspond to areas with lower agricultural development around the road for 2030. The comparison of Figure *42*, Figure *43* and Figure *44* shows impact of different scenarios. The comparison between the scenarios showed that strengthening the management of forests in forest concessions would imply a serious threatens in the critical central area. The opposite situation, biodiversity loss in the north critical area and better conservation of the critical central area, occur when we reduced the demand and assumed the forest management will continue as observed in 2000. On the other hand, connectivity through the south area is very critically threatened by the rise of agriculture and livestock activities. The dispersion of these activities implies that the threat to the hunting species will be quite high, even when connectivity of the entire forest would subsist. Finally, it is important to indicate that connectivity through the critical central area should be assessed in terms of the impact of rivers in fragmentation. For instance, whether a forest cross by Madre de Dios river (approximately 300 meters wide) should be considered as connected, or as two separated areas. (Note that if we considered that the major rivers cause forest fragmentation, the MSA of the critical central area will be lower due to isolation from the broad section of northern forest.)

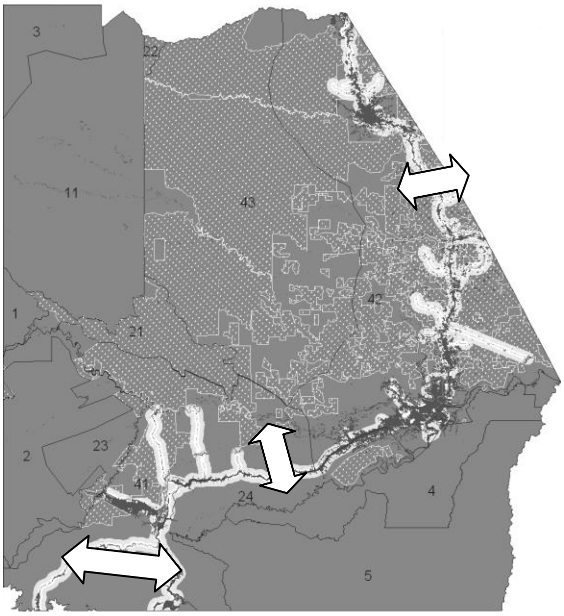


Figure 45 Critical areas for connectivity based on year 2000 MSA map (arrows shows the connectivity pathways)

On the other hand, the CLUE-s model distributed the uses in areas more dense than observed in 2000. Then, it is likely that the model slightly overestimates the remaining biodiversity in complementary sectors, such as low-impact zone, buffer zones of protected natural areas, and even protected areas. On the other hand, indirect impacts (hunting, gathering, selective logging) are only assessed through impact around roads. Impact next to agricultural areas is not considered, even when, at this level of analysis, becomes important. For this reason, it is likely that the model underestimates the effect of habitat fragmentation, particularly for species subject to hunting.

It is important to note that both the Madre de Dios Reserve and the protected areas for conservation maintained high levels of remaining biodiversity. We found statistical evidence indicating that protected areas for conservation reduced the risk of deforestation, while there is no evidence to make such a statement regarding to territorial reserves. This result may be because the only territorial reserve study is far from the roads and main access roads, so the impact of the territorial reserve could stand confused with that of the roads. The importance of these forest areas for the survival of human isolated groups highlighted the importance of a deeper analysis on the efficiency of these reserves for both, forest conservation, and human groups living there.

As we mentioned before, the assessment of fragmentation impact presented another obstacle, and was the non-inclusion of the rivers as potential sources of fragmentation. The non-seasonal rivers constitute natural barriers to the movement of various species, but not all. In general, those species that can fly could to cross a river. The same occur with species that can swim. Although, in this case, if the river is polluted by mining activity, or is used by means of regular transport it is unlikely that it can serve in the same way to connect populations at both sides. If we considered that rivers could fragment the space, the sector between Huaypetue, the Madre de Dios River and the Interoceanic Highway would be fragmented from the rest of habitats. This would mean significant biodiversity loss and highlights the fragility of the connection between forests in the east and west of the highway. If we include this effect and the biodiversity loss expected around the farm plots, we will observe a sharp decline in biodiversity towards the southern sector of the study area.

It is worth to indicate the importance of the climate change impact on the region predicted by the model. This impact had the same magnitude as the impacts of changing land use and infrastructure. It is essential the recognizing of this sector as part of the world and the importance of international policy decisions in the future of this and any other area. In addition, it is possible that this impact was under-represented for three reasons: First, because we used OECD projections, for temperature, which are more optimistic than those of the IPCC. Secondly, MNP methodology estimates climate change impact based on loss of biomes, instead of any other classification of "finer grain". Therefore, slopes presented in table 2 are probably lower than the slope using smaller ecosystems. For example, according to this table, glaciers and ice have the smallest loss rates of MSA by climate change. This is probably influenced by large extensions of ice in Antarctica and Greenland, more stable areas than Tropical glaciers, which suffers higher area loss due global warming. Third, because recent reports indicate that in last years the emission of greenhouse gases has exceeded the expectations of the worst scenarios of the IPCC (Calvo, E. 2008, at the International Forum “Cambio Climático - Diagnóstico y Propuestas del IPCC”).

The effect of climate change on biodiversity loss forced us to face the need to communicate trends in biodiversity at the regional, national and supranational level. A similar problem appeared when national decisions had local impacts, such as road constructions or implementation of policies that may alter expectations regarding the productivity of different land use types. In all these cases, decisions are often beyond the influence of local or regional authorities. In this regard, the MSA serves as an indicator relatively easy to be transmitted and interpreted by decision makers and the general public. This indicator can serve as the basis for a diagnosis system of multiple scales to help carry out the spatial planning of territory.

3.4.4 Conclusions

The model predicts that impact on biodiversity will be higher on the more populated sectors near the highway. The secondary roads have little impact on biodiversity loss patterns. There are some areas close to the North side of Tambopata National Reserve that could probably receive a huge land use pressure, mainly for agriculture, since everyone model report them as an area where land cover should change.

Analysis of MSA maps helped to identify critical areas for forest connectivity at both sides of the highway. Using this approach, we identified three critical areas, and we were able to evaluate the impact of different demand scenarios on land use change in those areas. The analysis showed that the south corridor would be endangered mainly by hunting in the neighbourhood of several small croplands (this impact is not measured by GLOBIO3, but can be expected due the predicted crop distribution). This happens for every scenario, but in different levels. It also showed that if the current land uses trends continue, the central corridor will suffer a huge pressure. An extension of agriculture, man-made pastures and mining pressure will increase the pressure on the remaining forests. Since the managed forests are mainly in the north side of the study area, an increase in the value of managed forests could reinforce the protection of the North corridor, but deforestation will expand in the Central corridor (with forest non-managed). On the other hand, if managed forests can only protect the forest in the same degree than observed now, the North corridor would halt and reduce pressure over the central corridor. The biological value of each corridor should be studied on the field, and should consider the presence of roads and rivers, because the central corridor is cut by Madre de Dios River.

This analysis shows that both strategies must be taken into account, in order to improve connectivity: Land use demand must be reduced and there should be strong support for managed forest production.

However, according to the model, one of the most important causes of biodiversity loss is climate change. This characteristic deviates from most other countries in the world. It can be explained by the relative large area without human land use. Climate change can explain 2% of the MSA loss, using OECD baseline scenario, which is more optimistic than the IPCC scenarios. This result shows that biodiversity support, even in this well conserved and relatively isolated area, is strongly related to global decision and trends.

We found two important problems when evaluating biodiversity. The first one was related to mining pollution of rivers, and the second one was the lack of specific models for some resources that are especially important for this area. Both problems are outside the range of MSA index, but are important enough to introduce some complementary index to assess their impact. However, both problems, together with the lack of information of selective logging areas, imply that MSA values could be overestimated. Besides the complementary index we should highlight the importance of aquatic ecosystems, environmental services and wild populations under specific pressures (hunting, logging, etc.).

Lastly, we must indicate the importance of continue developing modeling land use changes and its impact on biodiversity. The new models should be fed with data of higher quality, including a better description of the soil types and their properties, climate properties and variability, areas dedicated to selective logging, among others. Even more, due to the great interest of several national and international institutions it is possible that during the next years large amounts of information will be acquired, supporting and validating the MSA estimates and procedures.

4 Methodological conclusions

These studies highlight the importance of global environmental assessments and their application for management plans. The results can be used at regional, national and subnational scales to support the development of long term policies and to analyze their consequences. It is important to note that the main focus is on the total biodiversity and not only in flag, endangered, protected or managed species. Although, usually, there is more information about these species, this assessment tries to identify the biodiversity state as a whole, including those species that we do not know yet. Biodiversity is threatened by land use changes, presence and development of roads and by the current global changes such as climate change.

We propose the use of CLUE and GLOBIO 3 as a framework to assess the biodiversity state and future trends at national and local scales. However both tools required some adjustments for their fulfilled applicability to different context. Besides it is also necessary to review some assumptions and algorithms to make them compatible with local situations. Fortunately, the conceptual simplicity of the procedures made it easy to apply adjustments even when data quality varied for each study case. It is also possible to make more sophisticated or complex analysis in case that for one important pressure more information is available. Improvements for both the land use model change (CLUE) and the remnant biodiversity model (GLOBIO3) are possible.

Nevertheless, conceptual simplicity should not be interpreted as “easy to use”. Both tools need users to be trained in GIS, and regression techniques. Modellers also need broad access to land use change information at the national level. Even when this is a very interesting option for developing interdisciplinary work, major communication efforts are required. These were not included in the main objectives of the present studies. The application of the tools requires time for training in order to manage, the not so user friendly software and to run it. In the case of CLUE this software could not provide a solution for the local case in Peru, while GLOBIO3 still needs to be adapted to each reality. Finally, it is important to mention the lack of accessible basic information as one of the most difficult points during the application of this methodology. The main conclusions and final remarks for each tool are detailed below.

4.1 Land use change model: CLUE

Regarding land use modelling, it would be interesting to review the stochastic aspect of the pixel distribution process for each land use class. This procedure starts with the logistic regressions (probabilistic results). These regressions are included in the Clue, and their results are used in a deterministic way during the pixel allocation. This deterministic way to model the pixel allocation was a limitation at local scale, where the necessity of recovering this randomness is more obvious. For instance the probabilities obtained using logistic regressions are not perfectly accurate and its estimation includes an evaluation of its precision. Even if all the parameters estimated with a logistic regression would have no errors, the straightforward interpretation of this probability curve should make us to conclude that it is unlikely that all the most probable pixels would be selected, and also that none pixels of the less probable ones would be selected (even an unlikely result of an incident can happen if the incident is repeated enough times). It is important to say that there are some ways to use Clue in order to simulate probability values (e.g.., using a random location specific preference addition). However, it could be helpful to include some of these tools in the Clue software. In this way, it could be possible to easily choose if the stochastic mechanism should work on the pixel probabilities at the beginning of the run or also during the experiment, and how many times the user would like to run the model. On the other hand, and thinking not only in Clue model, it would be useful to review the statistical properties of logistic regressions error terms to support several decisions about how to include the random process for each regression. This information could support the decisions about the distribution of the random numbers (uniform, normal, etc.), its parameters, and the best way to include them (e.g. after or before log-it transformation).

At national level, with bigger pixels, other problems come up such as the presence of many natural vegetation classes and land use classes in one pixel. This creates problems for regression analysis itself. In those cases it would be useful to analyze whether the presence of one class is conditioned by the presence of neighbour pixels. In this regard, the inclusion of mechanisms considering spatial autocorrelation could help. Clue includes a tool to include neighbourhood effects (enrichment factor, Verburg *et al.* 2003) that can be used for that purpose.

At the local scale we noticed that land access regulation and land property should be explicitly incorporated into the model. One option is to integrate the effect of different kinds of land property (i.e. communal or private land) into the probability of being classified as a specific land use class (as a regression variable). Nevertheless, this approach has two main problems that should be analyzed. First of all, it is possible that incorporation of this variable requires a model based on individual behaviours, which would make generalizations more difficult. Secondly, information regarding property tenure is highly dynamic and difficult to model.

Modelling land use change requires not only the pattern description of the current uses (i.e. logistic regression) but also to develop models that allow the user to understand the causes of those patterns that can be calibrated with historical available information, as was suggested during the Lima workshop. In the same way this kind of models could help us for modelling potential future changes. For instance, climate change models could be included. Using the results of these models as inputs in the proposed framework GLOBIO-CLUE, it would be possible to assess the impact of climate change on agricultural distribution.

There were some other important factors affecting land use change that were not taken into account due to the complexity of their incorporation in the model. Socioeconomic and demographic variables are the more important among the missing variables, such as: population density, poverty indexes, inequality and life quality, types of markets, energy use, etc. Some of these variables could be included as proxies in a relatively simple way. However, estimation of future values can be really hard because of the high variability of some of these variables. At regional level, the incorporation of these proxies faces the lack of standardized available information that can be comparable between countries. Even when it was not possible the inclusion of these proxies for the present work, it should be considered as a next step. Moreover it would be important to elucidate the validity of these socioeconomic proxies versus the current variables used for the study cases.

Having multiple scenarios becomes useful for analyzing the spatial change in the patterns due to different policy decisions. These scenarios should include land demand, land use restrictions, individual behaviours and changes in context variables (like climate change). Land demand scenarios can be improved by means of a more detailed research work. Key researches are future tendencies of this land demand and a monitoring system for evaluating future changes. Indeed one of the main difficulties faced by the study cases was the lack of these tendencies or the information to build them both, at national and local scale.

Future work includes the development of a common framework for modelling land use change at a regional level, involving Andean countries. The first step is to define how to couple land demand from different countries. One option is simply to sum all the land demands coming from different countries for the regional model. Another more complex option could be to conduct a regional study that incorporates positive and negative interactions between land demand in the countries. It would be also necessary to review the allocation distribution for each class, given that CLUE does not consider borders. For instance, a decrease in the land demand of coca crops in Peru and Bolivia causes an increase in land demand for this crop in Colombia (International Crisis Group 2005). Model should deal with this “crop migration” but it should also guarantee that farmers would stay in their own countries. In other words, the model should be able to make the difference between the product and the producers. Even when the product “migrates” to one country it will not be the case for the workers who sustain the development of that product. Extreme scenarios can be managed such as 1). Each country works with its own land demand and with its own characteristics (semi permeable frontiers scenario), 2) Land demand is aggregated for all countries and also probability functions (no frontiers scenario). To solve these problems, it could be useful to review IMAGE and EURURALIS models. This last one uses GTAP to couple national and global agriculture demand (Verburg *et al.* 2008).

4.2 Biodiversity model: GLOBIO3

The main advantage of the MSA is that integrates the impact of multiple factors on biodiversity and, at the same time, analyzes the contribution of each factor for a specific place (pixel). In this sense, a biodiversity assessment can be carried out for different scales and for different territorial units (i.e. departments, regions, municipalities, protected areas, watersheds, etc), recovering spatial effects from the included processes. Those spatial effects are usually not linear.

Although MSA calculations are very simple, this contrasts with ecosystems complexity. For this reason it is important to analyze the global model calibration and evaluate its assumptions for Andean countries. This could be done using fieldwork information, coming from existent reports or planning ad-hoc research on land use change, fragmentation, infrastructure or climate change. Besides it should be considered any other relevant factor that affects biodiversity at national and local scale. The results of this research could be also useful for developing and calibrating an index set (including MSA) for improve environmental planning in the future.

GLOBIO results can be shown to policy makers as maps for baseline scenarios and for each future developed scenario. However, it is more useful to use change maps where differences between present and future can be highlighted. Since similar assumptions are used for the present and future calculation the absolute accuracy of the MSA value becomes less important and therfore hardly affects the trend itself, as was commented by some participants of the workshop. The maps can be used as inputs in discussions among policy makers, offering them possible future changes on the basis of different territorial policies.

We also have some suggestions for improving MSA calculations and procedures:

- Calculation of biodiversity loss for extensive use around used areas. This could be done following a similar methodology like the one developed for infrastructure, but considering land use areas instead of roads. If we suppose that new used areas should be connected by roads to other areas, this approach could be considering the effect of expansion of local roads.
- The use of more detailed ecosystem classification instead of biomes, with better resolution that allows distinction between montane forest and dry forest, for instance.
- Estimation on field of the effect of nitrogen deposition on the biomes of the region.
- Estimation of climate change impact for more specific ecosystems. A first approximation could be to use biogeographic realms (Udvardy, 1975) or Bioregions (WWF). This would avoid for some inconsistencies such as a low climate change impact in glaciers.
- The use of more detailed climatic information, produced by regional or global models. It could be possible to measure the impact of climatic change on each pixel, which could be useful for mountain areas.
- Include as “context conditions” global model results of land use change, in this way, frontiers or other borders in the study area will not generate false natural fragments.

We also have some ideas that we are still discussing inside the group about their applicability and convenience:

- Use biome borders and main rivers as patch constraints in fragmentation. Even when animals and some plants can cross the river, the smaller ones would be limited for rivers. In this way meta population concept is also included (because fragmentation could be more related to subpopulations colonization and survival than to genes flow).

- In order to include the impact of rivers and biome borders as source of fragmentation, the procedure to estimate it should change to include the ratio between the surface of current patch and original patches. The procedure could use a species-area approach, similar to those applied by Thomas *et al.* (2004) and Hubbell (2001).

Another pending task is the inclusion of uncertainties in MSA estimates, but it could probably require the improvement of the current GLOBIO 3 model at each scale.

4.3 General Conclusions

Seen all the tools, it is important to note also that the methodological framework presented provides integrated work between experts from different disciplines. To achieve the final goal, the analysis can be divided in three components:

1. a model of demand for different land uses,
2. a model of distribution of that demand (with changes between land uses in question)
3. a model of impact on the biodiversity of these land use changes.

The first and second components are the better option to include different scenarios. The difference between scenarios can be reflected in land use demand, climatic change patterns, land use change rules, and any other CLUE-s setting. The third one must remain unchanged when trying to evaluate the impact of different scenarios.

Another kind of problem arises when researchers try to incorporate the interrelationships between these aspects, but once again, the simplicity of the model makes it easy to include any change in the model. Thus, the door remains open to include, for example, the effect of decreasing forest cover on an economic variable that in turn will impact on demand.

Lastly, we believe that this methodology is important because it facilitates the evaluation of local changes produced by regional, national and supranational institutions and their subsequent communication to decision makers and the general public. This was the same general opinion of participants of the workshop where the advances have been presented. This methodology, by its conceptual simplicity, provides a transparent analysis of problem. However, several of the amendments raised here must be incorporated to take more accurate assessments of what could happen in the future for this region. It is worth to emphasize that these changes should maintain the line of principles and procedures easy to identify and modify found in the CLUE-s and GLOBIO. This helps to easily compare various scenarios and considerations, which is essential for decision-makers become familiar with the characteristics and limitations of the model and to evaluate the potential impacts of decisions. In this context, we once more emphasize that these tools can serve as a support for evaluations of policies, development plans and large investments at national and regional levels.

Seen all the tools, it is important to note also that the methodological framework presented provides integrated work between experts from different disciplines. To achieve the final goal, the analysis can be divided in three components: a model of demand for different land uses, a model of distribution of that demand (with changes between land uses in question) and a model of impact on the biodiversity of these land use changes. The first and second components are the better option to include different scenarios. The difference between scenarios can be reflected in land use demand, climatic change patterns, land use change rules, and any other CLUE-s setting. The third component must remain unchanged when trying to evaluate the impact of different scenarios.

Another kind of problem arises when researchers try to incorporate the interrelationships between these aspects, but once again, the simplicity of the model makes it easy to include any change in the model. Thus, the door remains open to include, for example, the effect of decreasing forest cover on an economic variable that in turn will impact on demand.

Lastly, we believe that this methodology is important because it facilitates the evaluation of local changes produced by regional, national and supranational institutions and their subsequent communication to decision makers and the general public. This was the same general opinion of participants of the workshop where the advances have been presented. This methodology, by its conceptual simplicity, provides a transparent analysis of problem. However, several of the amendments raised here must be incorporated to take more accurate assessments of what could happen in the future for this region. It is worth to emphasize that these changes should maintain the line of principles and procedures easy to identify and modify found in the CLUE-s and GLOBIO. This helps to easily compare various scenarios and considerations, which is essential for decision-makers became familiar with the characteristics and limitations of the model and the potential impacts of decisions to be evaluated. In this context, we once more emphasize that these tools can serve as a support for evaluations of policies, development plans and large investments at national and regional levels.

5 References

- Alkemade R, Bakkenes R, Bobbink R, Miles L, Nellemann C, Simons H, Tekelenburg T. 2006. GLOBIO3: Framework for the assessment of global terrestrial biodiversity. In:Bouwman A, Kram T, Klein K, editors. Integrated modelling of global environmental change: An overview of IMAGE 2.4. Bilthoven, The Netherlands: Netherlands Environmental Assessment Agency (MNP); p 171-185.
- APCI, CONAM, Municipalidad de Miraflores, SPDA, CEPAL, DED, GTZ; Cooperación República del Perú – República Federal Alemana. 2008. *The climate is changing, so is my life. 30 testimonies.* Lima. 32 p.
- Armenteras D., y Villa C.M. (Eds.) 2006. Deforestaciónón y Fragmentación de ecosistemas naturales en el Escudo Guayanés colombiano. Instituto de Investigación de Recursos Biológicos Alexander von Humboldt e Instituto Colombiano para el Desarrollo de la Ciencia y la Tecnología "Francisco José de Caldas" – Colciencias-. Bogotá, D. C: - Colombia. 122 p.
- Armenteras, D. y Rodríguez, N. (Eds.). (2007). Monitoreo de los ecosistemas andinos 1985-2005: Síntesis y perspectivas. Instituto de Investigación de Recursos biológicos Alexander von Humboldt. Bogotá, D.C. Colombia. 174 p.
- Balcázar, A., Vargas A., Orozco M. L. 1998. Del proteccionismo a la apertura ¿El Camino a la modernización agropecuaria? Centro de Estudios Ganaderos y Agrícolas (CEGA), Misión Rural, IICA – TM Editores. Bogotá
- Caviedes, C., and G. Knapp. 1985. South America. Prentice Hall, Englewood Cliffs.
- Centro de Información Ambiental del Ministerio del Ambiente (CIAM). Cobertura del sistema nacional de áreas protegidas. 2003. Escala 1:250.000
- CEPAL, Anuario estadístico de América Latina y el Caribe, 2006
- Cuesta F, Peralvo M, Ganzenmüller A, Sáenz M, Novoa J, Riofrío G, Beltrán K. 2007. Identificación de vacíos y áreas prioritarias para la conservación de la biodiversidad terrestre en el Ecuador continental. In: Campos F, Peralvo M, Cuesta F, Luna S, editors. Análisis de vacíos y áreas prioritarias para la conservación de la biodiversidad en el Ecuador Continental. Quito: Instituto Nazca de Investigaciones Marinas, EccoCiencia, Ministerio del Ambiente, The Nature Conservancy, Conservación Internacional, Proyecto GEF: Ecuador Sistema Nacional de Areas Protegidas, Birdlife International y Aves & Conservación; p 15-36.
- DANE. 2007. Colombia: Departamento Administrativo Nacional de Estadística, Indicadores de producción agropecuaria Internet in: http://www.dane.gov.co/index.php?option=com_content&task=category&sectionid=18&id=41&Itemid=152
- DANE 2008. Producto interno Bruto. Segundo trimestre de 2008 Base 2000. Departamento Nacional de estadística. Available online in: http://www.dane.gov.co/files/investigaciones/boletines/pib/presen_PIB_IItrim08.pdf
- Davis, S.D., Heywood, V.H., Herrera-Mac Bryde, O., Villalobos, J and Hamilton, A.C. (eds.). 1997. Centres of Plant diversity: A Guide and strategy for their Conservation (Vol3 The Americas). WWF and IUCN publications unit, Cambridge (U. K.).
- Denevan, M. D. 1992. The pristine myth: the landscape of the Americas in 1492. Annals of the Association of American Geographers 82:369-385.
- Geist HJ, Lambin EF. 2002. Proximate causes and underlying driving forces of tropical deforestation. Bioscience 52(2):143-50.
- Hanski I. 1998. Metapopulation dynamics. Nature 396(6706):41-9.
- Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978 Kapos V, Lysenko I, Lesslie R. 2000. FRA 2000: Assessing Forest Integrity and Naturalness in Relation to Biodiversity Rome: Forestry Department, Food and Agriculture Organization of the United Nations; 65 p.
- Hubbell, S.P. 2001. The Unified Neutral Theory of Biodiversity and Biogeography. Princeton University Press. ISBN 0-691-02128-7.

- IDEAM, IGAC, IAvH, Invemar, I. Sinchi e IIAP. 2007. Ecosistemas continentales, costeros y marinos de Colombia. Instituto de Hidrología, Meteorología y Estudios Ambientales, Instituto Geográfico Agustín Codazzi, Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Instituto de Investigaciones Ambientales del Pacífico Jhon von Neumann, Instituto de Investigaciones Marinas y Costeras José Benito Vives de Andréis e Instituto Amazónico de Investigaciones Científicas Sinchi. Bogotá, D. C, 276 p. + 37 hojas cartográficas.
- IIAP & CTAR Madre de Dios. 2001. Madre de Dios camino al desarrollo sostenible: Propuesta de zonificación ecológica económica como base para el ordenamiento territorial. Puerto Maldonado, BID, 2001. 135 pág.
- Jarvis, A., Castaño, S.E., Hyman G., Gebhardt, S., Guevara, E., Castro, M., Touval, J., Sotomayor, L. (2006). TNC Threats Assessment Version 1.1. Available online: http://conserveonline.org/workspaces/ersm.pilots/pilot/SACRThreats/view.html
- Kok, K., Veldkamp, A., 2001. Evaluating impact of spatial scales on land use patern analysis in Central America. Agriculture Ecosystems &Environment 85, 205–221.
- Liverman D, Yarnal B, Turner BL. 2004. The human dimensions of global change. In:Gaile GL, Willmott CJ, editors. Geography in America at the Dawn of the Twenty-First Century. First ed. Oxford: Oxford University Press; p 267-282.
- Loh J, Green RE, Ricketts T, Lamoreux J, Jenkins M, Kapos V, Randers J. 2005. The Living Planet Index: using species population time series to track trends in biodiversity. Philosophical Transactions of the Royal Society B-Biological Sciences 360(1454):289-95.
- MAG-IICA-CLIRSEN. 2002. Informe Final: Proyecto "Generación de Información Georeferenciada para el Desarrollo Sustentable del Sector Agropecuario" Quito: Ministerio de Agricultura y Ganadería, Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos, Instituto Interamericano de Cooperación para la Agricultura.
- Murphy, P. G. and A. E. Lugo. 1986. Ecology of tropical dry forest. Annual Review of Ecology and Systematics 17:67-88.
- Myers, N. 1988. Threatened biotas: Hotspots in tropical forests. The Environmentalist 8(3):1-20.
- Pimm SL, Russell GJ, Gittleman JL, Brooks TM. 1995. The Future of Biodiversity. Science 269(5222):347-50.
- Rubio, F. 2008. ¡La ganadería amazónica se viene con todo! (II). Brasil, Primer exportador mundial de carne… a costa de su Amazonía. VOL: 19 de mayo de 2008. URL: http://www.viajerosperu.com/articulo.asp?cod_cat=7&cod_art=933 Last revision: June 15, 2008
- Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH. 2000. Biodiversity - Global biodiversity scenarios for the year 2100. Science 287(5459):1770-4.
- Sanderson EW, Jaiteh M, Levy MA, Redford KH, Wannebo AV, Woolmer G. 2002. The human footprint and the last of the wild. Bioscience 52(10):891-904.
- Secretariat of the Convention on Biological Diversity (2006) Global Biodiversity Outlook 2. Montreal,81 + vii pages
- Sierra, R. 2000. Dynamics and patterns of deforestation in the Western Amazon: the Napo deforestation front, 1986-1996. Applied Geography 20:1-16.
- Sierra, R., and Stallings, J. 1998. The dynamics and social organization of tropical deforestation in northwest Ecuador, 1983-1995. Human Ecology 26(1):135-161.
- Sierra, R., 2001. The role of domestic timber markets in tropical deforestation and forest degradation in Ecuador: implications for conservation planning and policy. Ecological Economics 36:327-340.
- SPDA & Futuro Sostenible. 2008. Taller: El monitoreo independiente para el megaproyecto de la Carretera Interoceánica Sur. Informe final de Relatoría. 37 pág.

- Thomas, Chris D., Alison Cameron, Rhys E. Green, Michel Bakkenes, Linda J. Beaumont, Yvonne C. Collingham, Barend F. N. Erasmus, Marinez Ferreira de Siqueira, Alan Grainger, Lee Hannah, Lesley Hughes, Brian Huntley, Albert S. van Jaarsveld, Guy F. Midgley, Lera Miles, Miguel A. Ortega-Huerta, A. Townsend Peterson, Oliver L. Phillips & Stephen E. Williams. 2004. Extinction risk from climate change. Nature 427, 145-148 (8 January 2004)
- UNODC, 2008. Colombia Coca Cultivation Survey. United Nations *Office on Drugs and Crime* (UNODC) and Government of Colombia. Available online in: http://www.unodc.org/unodc/en/crop-monitoring/index.html
- Verburg, P.H., de Koning, G.H.J., Kok, K., Veldkamp, T.A., Bouma, J.,1999. A spatial allocation procedure for modelling the pattern of land use change based upon actual land use. Ecological Modelling 116, 45–61.
- Verburg, P.H., Soepboer, W., Veldkamp, A., Limpiada, R. and Espaldon, V. 2002. Modeling the spatial dynamics of regional land use: the CLUE-S model. *Environmental Management*, 30(3): 391-405.
- Verburg, P.H., T. de Nijs, J. Ritsema van Eck, H. Visser, K. de Jong, 2003. A method to analyse neighbourhood characteristics of land use patterns. *Computers, Environment and Urban Systems*, 28 (6): 667-690
- Verburg PH, Veldkamp A. 2004. Projecting land use transitions at forest fringes in the Philippines at two spatial scales. *Landscape Ecology* 19(1):77-98.
- Walsh, S. J., Messina, J. P., Crews-Meyer, K. A., Bilsborrow, R. E., and Pan, W. K. Y. 2002. Characterizing and modeling patterns of deforestation and agricultural extensification in the Ecuadorian Amazon. In Walsh, S. J., and Crews-Meyer, K. A. Linking People, Place, and Policy: a GIScience Approach. Kluwer Academic Publishers, Boston. Pp 187-214.

6 Appendix

6.1 Main variables used for landuse probability maps

Variable	Method / Description
Topographic variables	
Elevation	DEM obtained from the HydroSHEDS database (Lehner et al. 2006). Resampled from the original resolution of 90m to 1000 m.
Slope	Derived from *elev* in degrees using ArcGIS' Spatial Analyst.
Planiform curvature	Across slope curvature. Source: ArcGIS Desktop help 9.2 (http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?topicname=how_curvature_(3d_analyst)_works)
Profile curvature	Downslope curvature. Source: ArcGIS Desktop help 9.2 (http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?topicname=how_curvature_(3d_analyst)_works)
Relative slope position	Generates ridge lines and streams using flow accumulation data. The value of rsp represents the relative distance (in percentage) between ridges and streams. Source: rsp.aml by F. van Manen, USGS-LSC-SAFL based on Wilds (1996).
Terrain convergence index	Calculated using flow accumulation area (in ha) and slope (tan B = % rise / % run): *tci* = ln(flowacc_area / tanB) Source: tci.aml by F. van Manen, USGS-LSC-SAFL based on Wilds (1996).
Terrain ruggedness index	Square root of the average of the squared differences between the focal cell and the eight adjacent neighbors. Soure: ruggedness.aml available at http://www.blm.gov/nstc/ecosysmod/surfland.html calculated based on Riley et al. (1999).
Topographic relative moisture index	Proxy of the relative availability of moisture on the soil. The original version is calculated using *aspect*, *slope*, *curvature* and *rsp*. In this project the index was calculated without including the influence of aspect. Source: trmi.aml by S. Wilds based on Parker and Branner (1982) modified by J. Young and F. van Manen, USGS LSC. AML. AML available at http://www.lsc.usgs.gov/gis/data/shen/LandscapeGradients.asp
Topographic exposure index	Measures topographic exposure (e.g. ridges, valeys) at different scales and integrates these measures in a single grid. Soure: toposcale.aml by Niklaus E Zimmermann. AML available at: http://www.wsl.ch/staff/niklaus.zimmermann/programs/aml4_1.html
Terrain shape index	Index of terrain shape (i.e. concave, flat, convex) calculated using the difference between the focal cell and its eight neighbors. Source: tsi.aml by F. van Manen, USGS-LSC-SAFL based on McNab (1989). AML available at: http://www.lsc.usgs.gov/gis/data/shen/LandscapeGradients.asp
Climatic variables Source: Rivas-Martínez 2005 (Available online http://www.ucm.es/info/cif/book/namerica2/namerica_02_1.htm)	
Yearly average temperature	Yearly average temperature in centigrade negrees.
Yearly Annual precipitation	Yearly total precipitation in mm.
Ombrothermic index	Io = (Pp/Tp) 10. Ten times the quotient resulting value between the yearly positive precipitation in mm (Pp) (total average precipitation of those months whose average temperature is higher than 0ºC) and the yearly positive temperature (Tp) (In tenths of degrees Celsius, sum of the monthly average temperature of those months whose average temperature is higher than 0ºC.).
Ombrothermic index of the 2(3) driest months	Ombrothermic index within the driest two (three) months of the year.
Thermicity Index	It = (T + m + M) 10. Ten times the sum of T (yearly average temperature), m (average minimum temperature of the coldest month of the year), M (average maximum temperature of the coldest month of the year). Coldest month of the year: the one which has the lowest monthly average temperature (Tmin).
Accesibility variables	
Time to market	Time from each point to the closest major city of the first political division of each country. Based on Jarvis *et al.* 2006, without including a change by altitude. Values measured at 100 meters and rescaled to 1 Km.

Variable	Method / Description
Legal protection system	
Natural protected areas	Protected areas for conservation and management included in national systems.

References

- Jarvis, A., Castaño, S.E., Hyman G., Gebhardt, S., Guevara, E., Castro, M., Touval, J., Sotomayor, L. (2006). TNC Threats Assessment Version 1.1. Available online: http://conserveonline.org/workspaces/ersm.pilots/pilot/SACRThreats/view.html
- Lehner B, Verdin K, Jarvis A. 2006. HydroSHEDS: Technical Documentation Washington, DC: World Wildlife Fund US; 27 p. Available from: http://hydrosheds.cr.usgs.gov.
- Mcnab WH. 1989. Terrain Shape Index - Quantifying Effect of Minor Landforms on Tree Height. *Forest Science* 35(1):91-104.
- Parker A, Branner J. 1982. The topographic relative moisture index: an approach to soil-moisture assessment in mountain terrain. *Physical Geography* 3(2):160-8.
- Riley S, DeGloria S, Elliot R. 1999. A terrain ruggedness index that quantifies topographic heterogeneity. *Intermountain Journal of Sciences* 5(1-4).
- Rivas-Martínez S. 2005. Memoria del Mapa de Vegetación Potencial de España Available from: http://www.ucm.es/info/cif/book/publications.htm.
- Wilds S. 1996. Gradient analysis of the distribution of flowering dogwood(Cornus florida L.) and dogwood anthracnose (Discula destructiva Redlin.) in western Great Smoky Mountains National Park. M.Sc. Thesis. University of North Carolina, Chapel Hill. 151 p.