Executive Summary

Validation and diffusion of the GLOBIO methodology in the Andean region

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September 2008

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, 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 Main results from the case studies

2.1 Colombia

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.

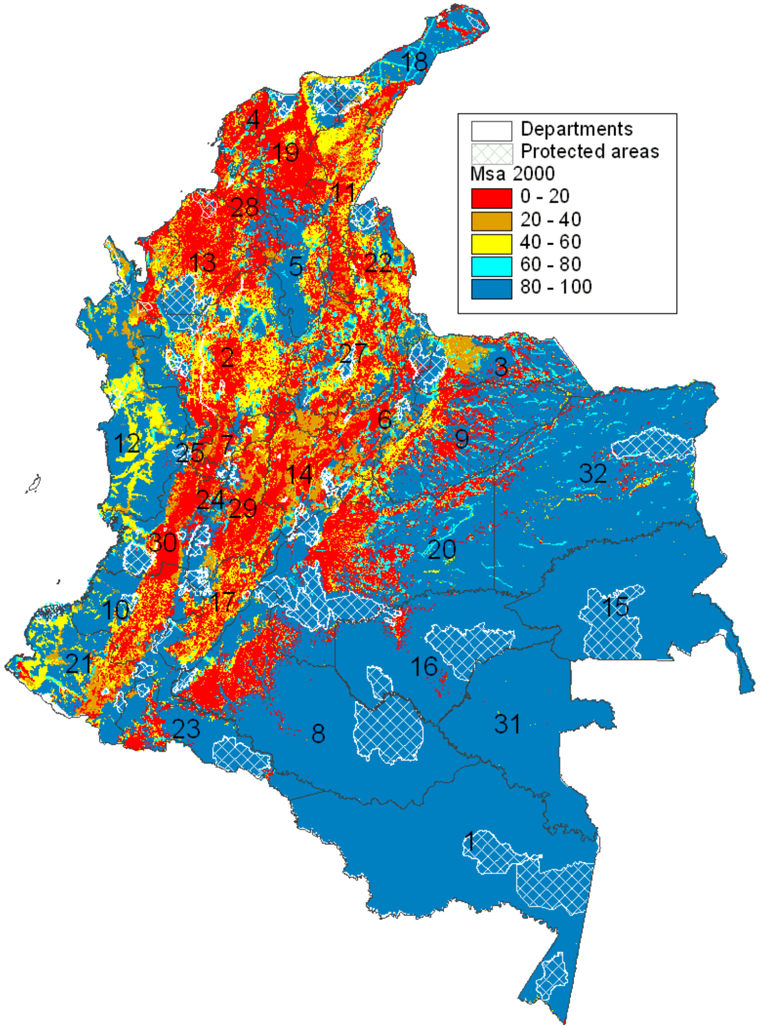
Foreign investment is increasing, thanks to a macroeconomic stability, increased security perception and policies that stimulate it. In 2007 it represented 27% of the countries GDP (DANE 2007), the commerce and mining sectors have received a lot of foreign capital, especially in the later for petroleum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



Departments

1	Amazonas
2	Antioquía
3	Arauca
4	Atlántico
5	Bolívar
6	Boyacá
7	Caldas
8	Caquetá
9	Casanare
10	Cauca
11	César
12	Chocó
13	Córdoba
14	Cundinamarca
15	Guainia
16	Guaviare
17	Huila
18	La Guajira
19	Magdalena
20	Meta
21	Narino
22	Norte Santander
23	Putumayo
24	Quindio
25	Risaralda
26	Santander
27	Sucre
28	Tolima
29	Valle Del Cauca
30	Vaupés
31	Vichada

Figure 1 Remaining MSA map of Colombia at year 2000

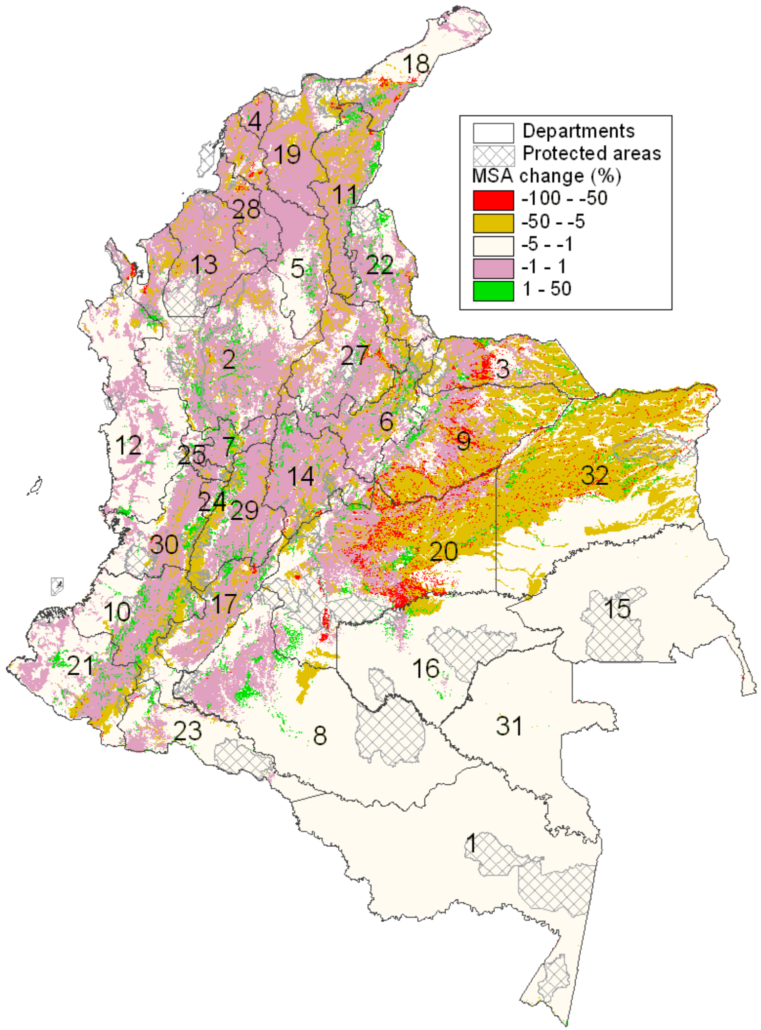


Figure 2 MSA change map for the scenario market forces on year 2030

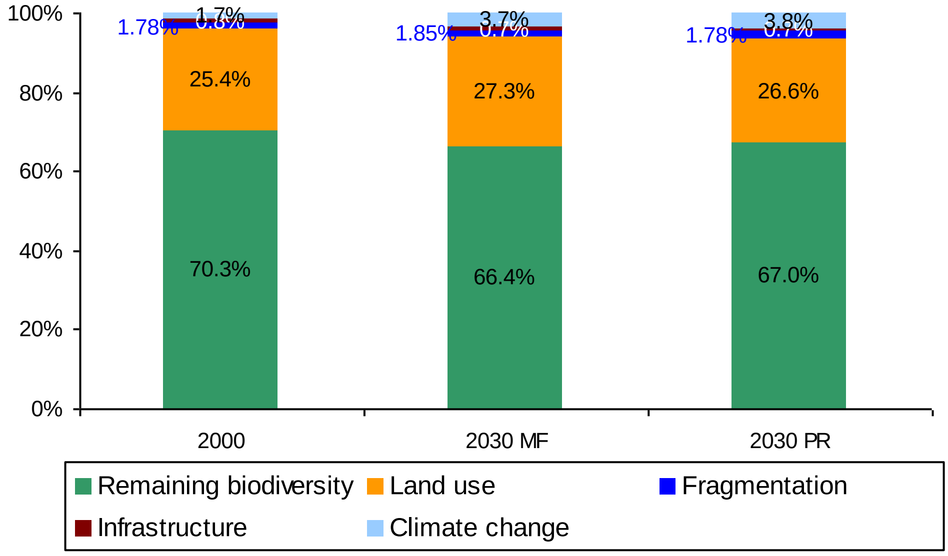


Figure 3 MSA of Colombia for year 2000 2030 scenario market forces (FM) and 2030 scenario policy reform (RP)

2.1.1 Results

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.

2.2 Ecuador

2.2.1 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.

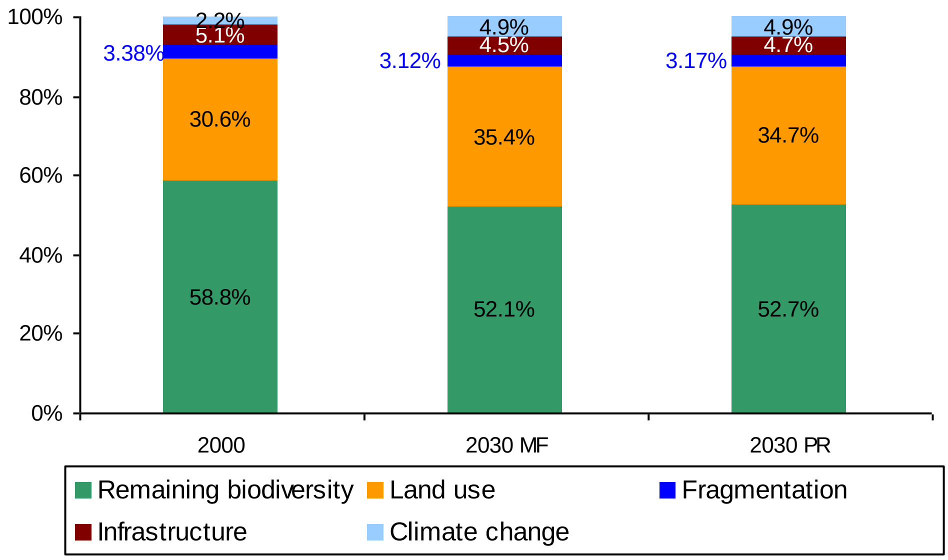


Figure 4 MSA of Ecuador for year 2000 2030 scenario market forces (FM) and 2030 scenario policy reform (RP)

2.2.2 Results

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.

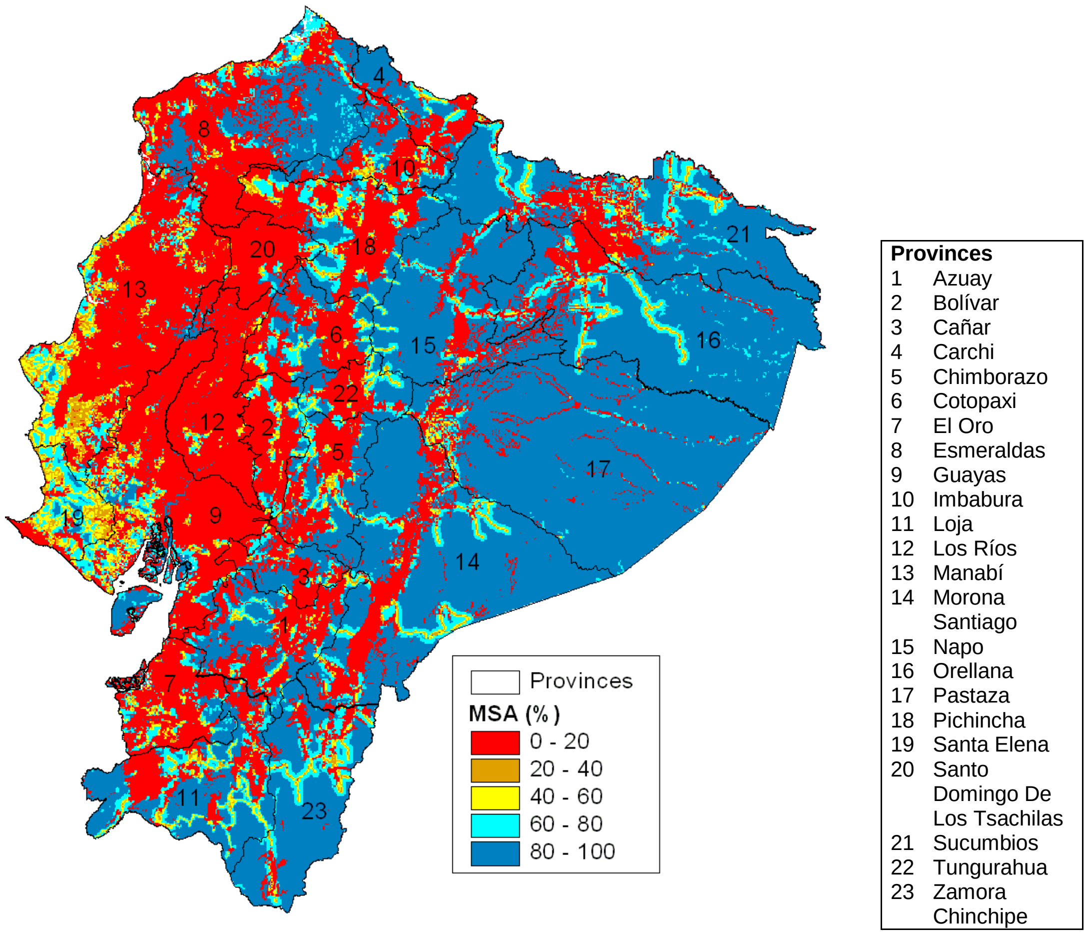


Figure 5 Remaining MSA map of Continental Ecuador at year 2000

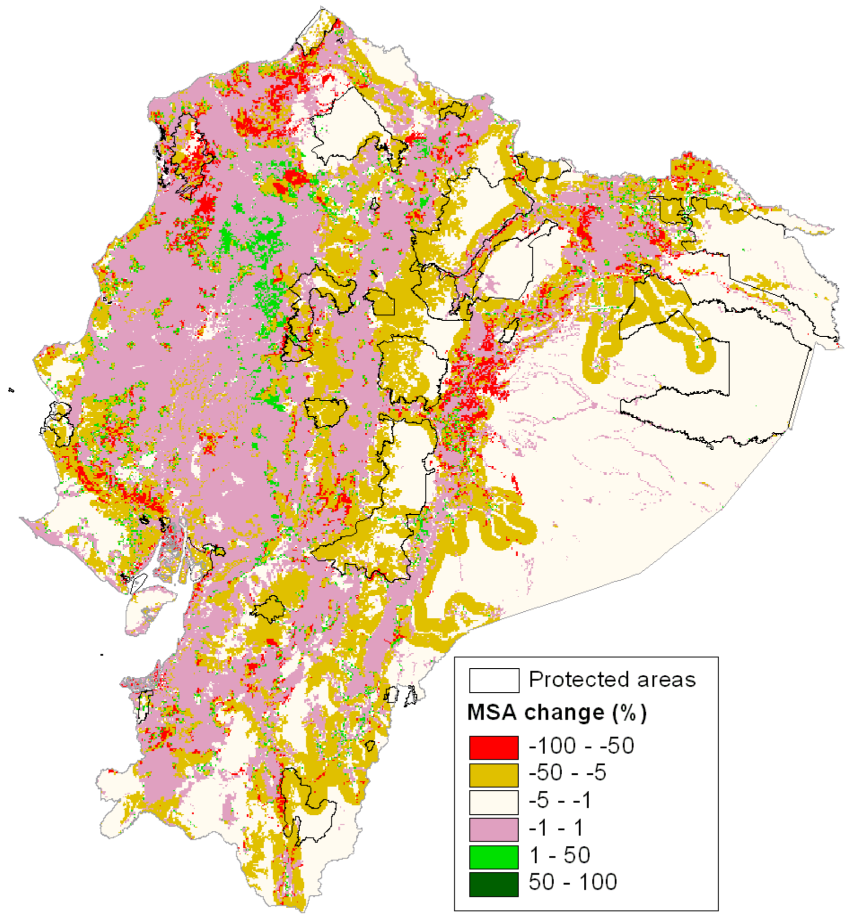


Figure 6 MSA change map of Ecuador for the scenario market forces comparing MSA lost between 2000 and 2030 with the national system of protected areas

2.3 Peru

2.3.1 National context

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.

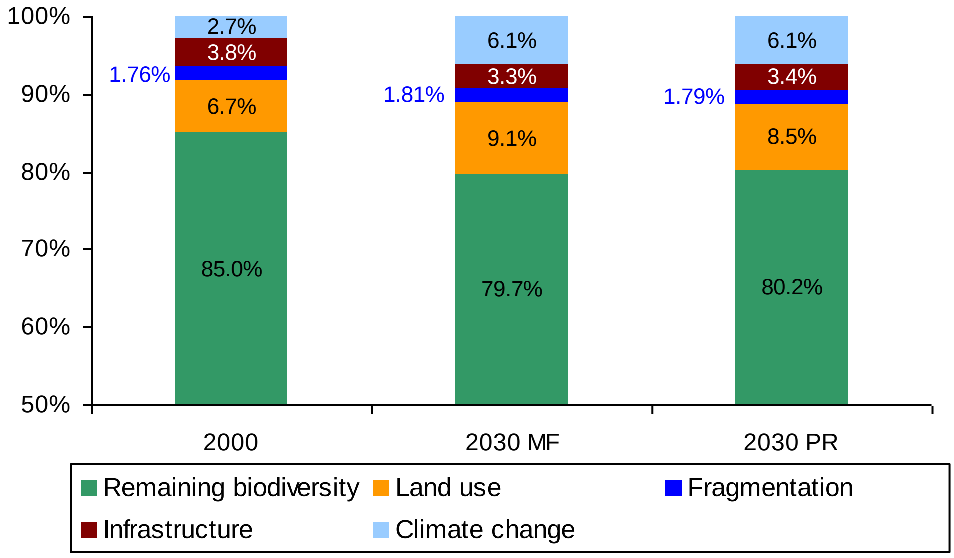


Figure 7 MSA of Peru for year 2000, 2030 scenario market forces (FM) and 2030 scenario policy reform (RP)

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.

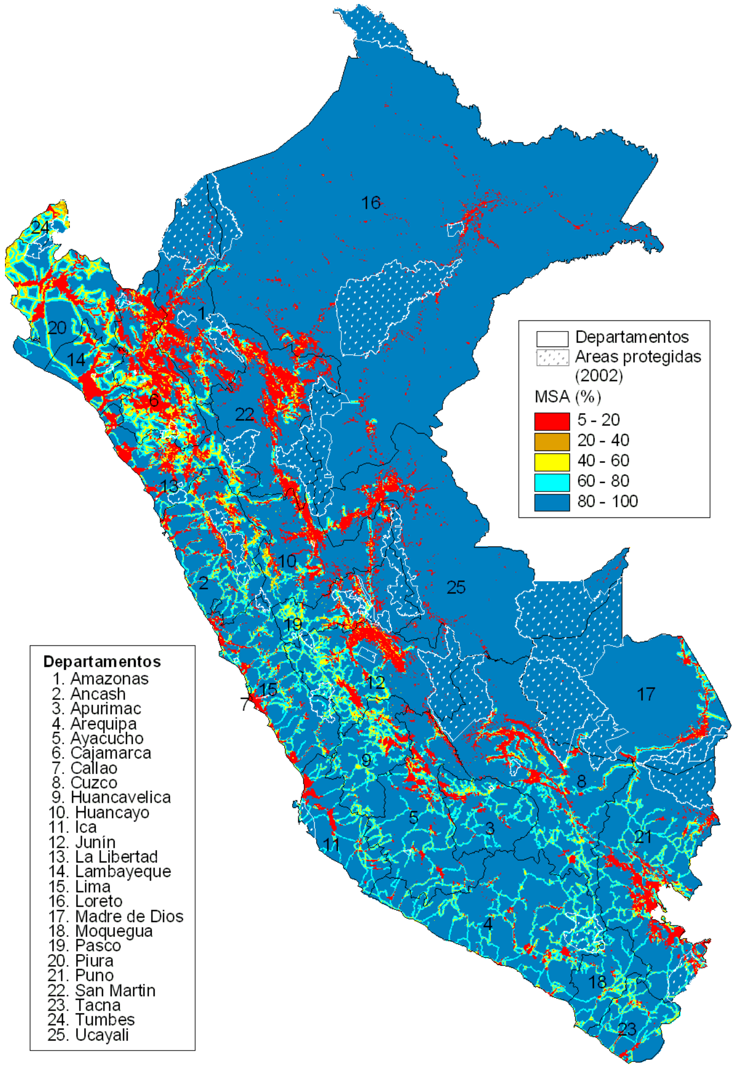


Figure 8 Remaining MSA map of Peru at year 2000

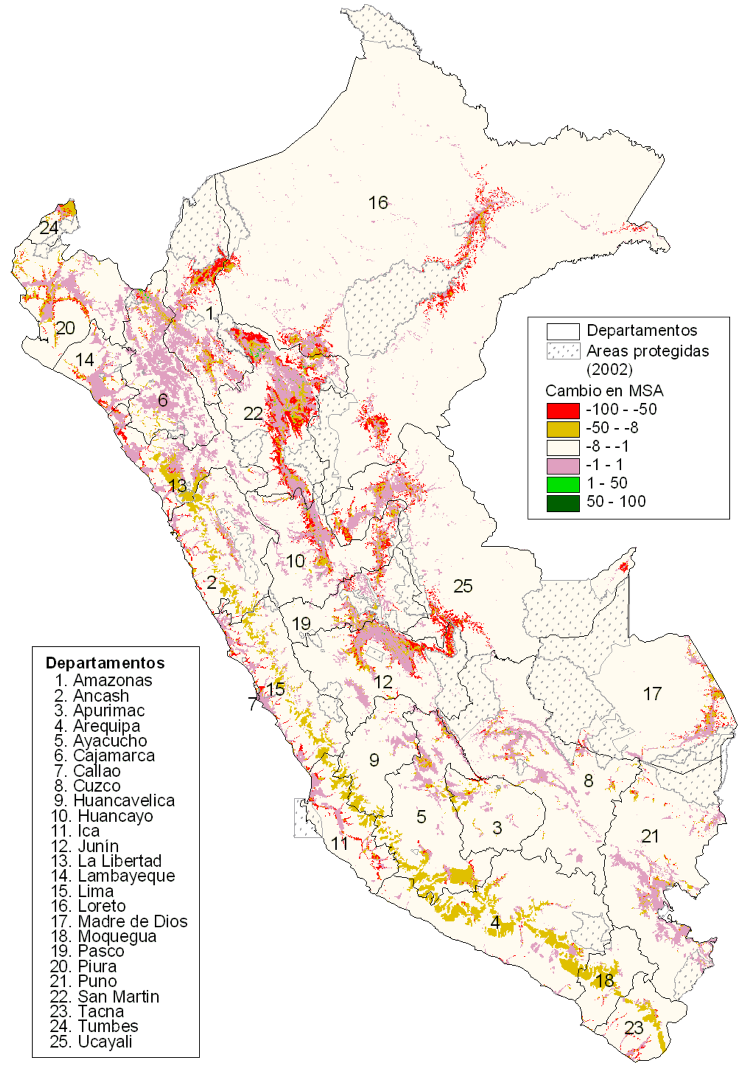


Figure 9 MSA change map for the scenario market forces of Peru comparing MSA lost with departments.

2.3.2 Results

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.

2.4 Peruvian Southeast Amazon forest

2.4.1 Local Context

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).

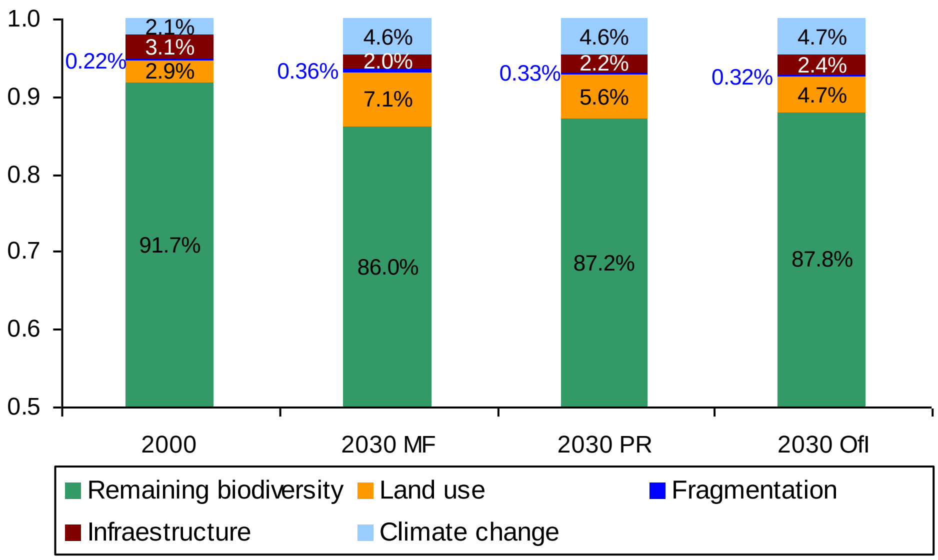


Figure 10 MSA of Peru for year 2000, 2030 scenario market forces (FM), 2030 order from inside (OdA) and 2030 scenario policy reform (RP)

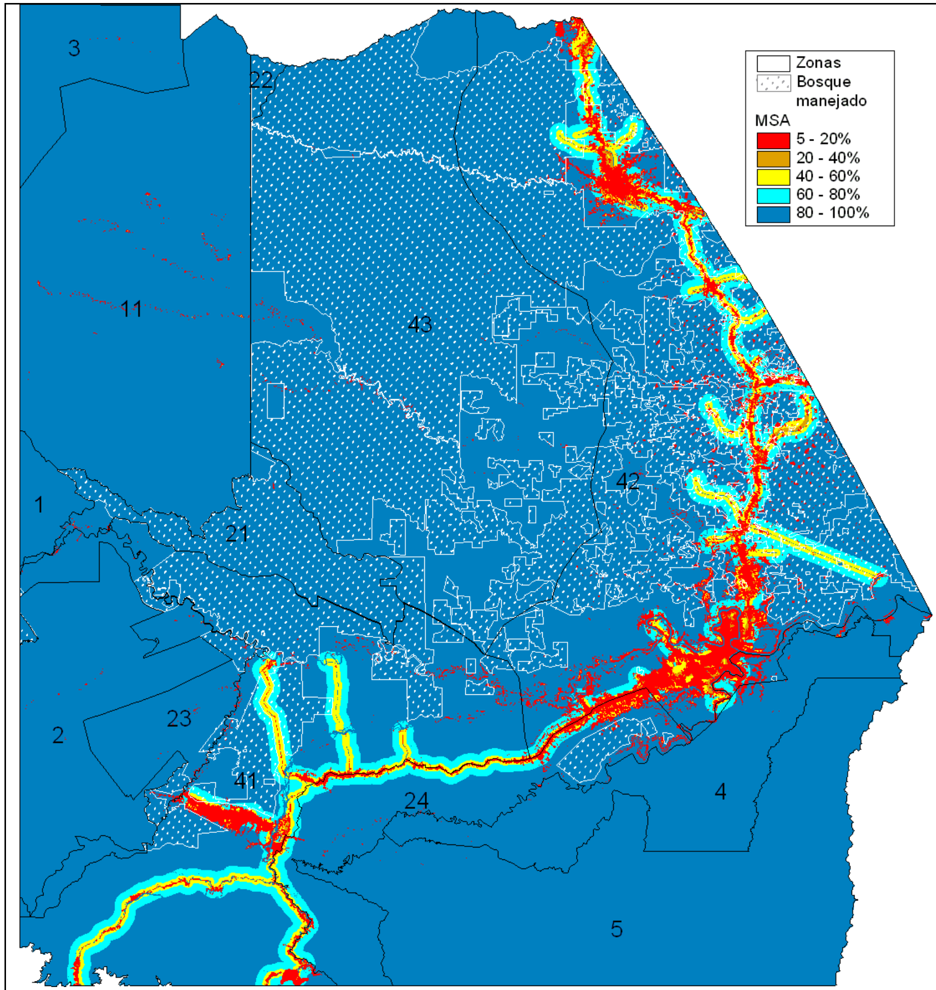


Figure 11 Remaining MSA map of Peruvian Southeast Amazon forest at year 2000

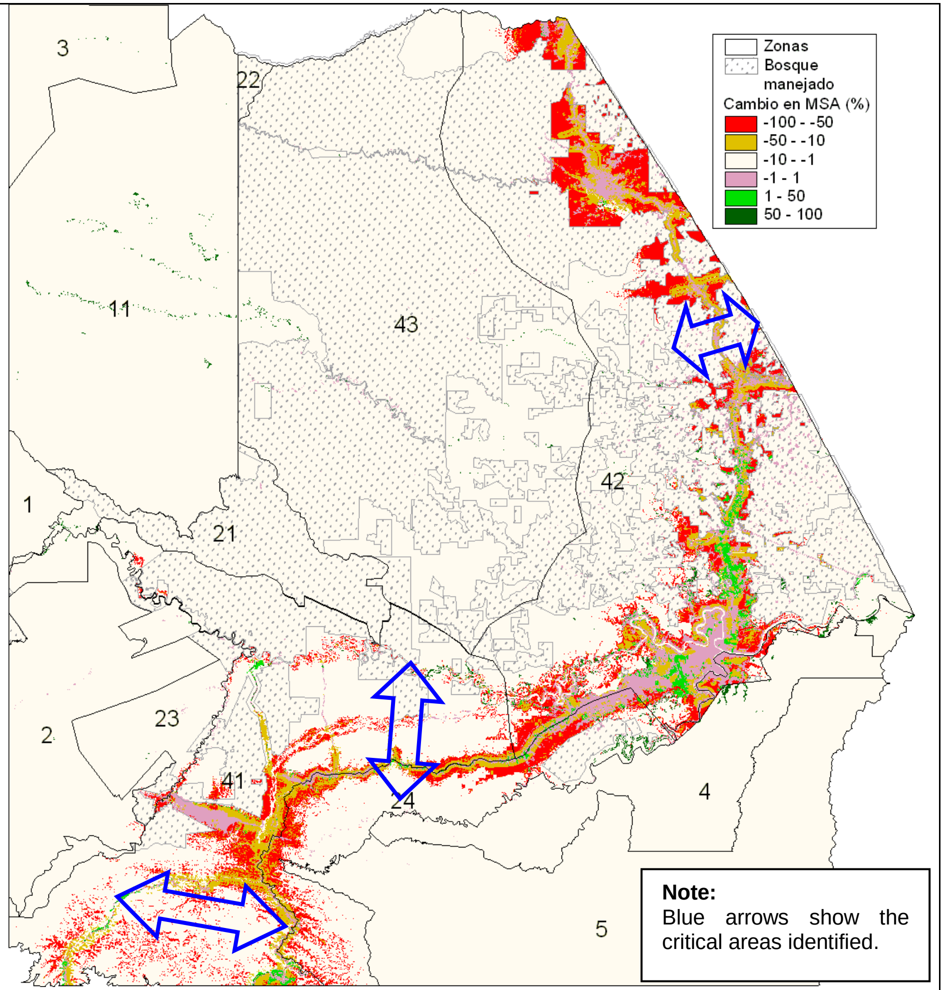


Figure 12 MSA change map for the scenario market forces of Peruvian Southeast Amazon forest comparing MSA lost with analysis zones and managed forests, and showing critical areas.

2.4.2 Main results

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.

3 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.

3.1 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).

3.2 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.

3.3 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.

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