UNIVERSITAT POLITÉCNICA DE CATALUNYA – BARCELONA TECH
SUSTAINABILITY MODELING AND MEASUREMENT LAB
PhD Program in Sustainability

THESIS PROPOSAL: BUILDING A DECISION – SUPPORT METHODOLOGY TO DEFINE ECOSYSTEM SERVICES BUNDLES AND TO ANALYZE TRADEOFFS IN DIVERSE LANDSCAPES. APPLICATION TO ECUADORIAN ECOSYSTEMS

Application to Ecuadorian Ecosystems.

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Abstract

Nowadays, the sustainability of ecosystems are in a debate on how should they be managed. It must be considered their management have to deal with a complex socio-ecological interactions that are formed with the surrounding landscape, affecting the availability and usage of ecosystem services (ES). The geographic dimension of this research involves characterization of the remaining ecosystems of mainland Ecuador. Our case study will be located in those Ecuadorian ecosystems where landscapes are experiencing serious environmental consequences and changes in their environmental services associated with the destination of LU and the various anthropogenic activities that have placed in the ecosystem boundaries, such as agricultural, livestock, industrial forestry and other agro-productive activities. There is evidence of ecosystems degradation (e.g. "Abras de Mantequilla" wetland) which belongs to Guayas River Basin (the largest tropical agricultural system in the Pacific coast of South America). This ecosystem has suffered loss of its native forests, due to the introduction of tree species like teak, African palm and banana cultivations. Due to socioeconomic and environmental relevance of our case study, this research has the objective of quantifying the provision of interactions between multiple ES of our interest. Thus it will be necessary to identify the exchanges/tradeoffs among environmental services and their synergies. The importance of identifying both exchanges and synergies of a fragile ecosystem as the case study is to enable a sustainable ecosystem management of the most important forest and lands in Ecuador and to enhance ecosystem's multi-functionality and real human being. We proposed a model that will contribute to the scaling and an adequate characterization of tree and LC distributions of ES in Ecuador. The model must span scales ranging from that of individual to that of the landscape. Large-scale plot studies, have proven to be extremely valuable for defining vegetation characteristics such as coverage gap distribution and specific ES pattern clustering.

Resumen

Hoy en día, la sostenibilidad de los ecosistemas están en un debate sobre cómo deben ser gestionados. Al momento de analizar su gestión se deben considerar las complejas interacciones socio-ecológicas que se forman con el paisaje circundante, afectando la disponibilidad y uso de los servicios ecosistémicos (SE). La dimensión geográfica de esta investigación consiste en la caracterización de los ecosistemas restantes del Ecuador continental. Nuestro caso de estudio son los ecosistemas ecuatorianos donde los paisajes están experimentando graves consecuencias ambientales y cambios en sus servicios ambientales relacionados con el uso de suelo y las diversas actividades antropogénicas que han colocado al límite las capacidad de resiliencia de los ecosistemas, tales como la agricultura, la ganadería, la silvicultura industrial y otras actividades agro-productivas. Existe evidencia de la degradación de los ecosistemas (por ejemplo el caso del Humedal "Abras de Mantequilla"), que pertenece a la cuenca del río Guayas (el más grande sistema de agricultura tropical en la costa del Pacífico de América del Sur). Este ecosistema ha sufrido la pérdida de sus bosques nativos, debido a la introducción de especies de árboles como la teca, palma africana y cultivos de plátano. Debido a la importancia socioeconómica y ambiental de nuestro caso de estudio, esta investigación tiene el objetivo de identificar los intercambios / compensaciones entre los servicios ambientales y sus sinergias. La importancia de identificar estas interacciones de un ecosistema frágil como el caso de estudio, es para permitir una gestión sostenible de los ecosistemas de bosques y de vegetación de mayor relevancia del Ecuador, y así mejorar la multifuncionalidad de estos. Hemos propuesto un modelo que contribuirá a una metodología apropiada de escala y una caracterización adecuada de los bosques y distribuciones de uso de suelo dentro de los ecosistemas. El modelo debe abarcar escalas que van desde el individuo hasta la dimensión de paisaje. Estudios similares, han demostrado ser de gran valor para la definición de características de la vegetación así como la distribución de la cobertura vegetal y la agrupación específica de patrones de SE.

1 Introduction

Ecosystem services (ES) are the goods and services that ecosystems provide to society and may be categorized as provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment [MA], 2005). Wherever humans live, complex socio-ecological interactions are formed with the surrounding landscape, affecting the availability and usage of ES. For example, social drivers such as urbanization, agriculture and associated deforestation influence the distribution of ecosystems and their services (Alberti, 2005; Geist & Lambin, 2002; Power, 2010).

Due to the growing interest in the science of ecosystem and landscape functions and services and especially since the release of the Millennium Ecosystem Assessment (MA, 2005), there are many researches in this field. Nevertheless, it is remarkable the fact of the need in continuing a profound investigation related to the integration of ES framework into landscape planning, management and decision-making.

In our field of interest, it is noticed that the main challenge of research exists at the landscape level, where there is no a clear optimal land management option in terms of many different land use (LU) options. Landscape functions (and services) have become an important concept in policy making, as decision makers have to deal with an explicit demand for landscape services from a broad range of stakeholders (FAO, 1999; OECD, 2001; Hollander, 2004; Wilson, 2004; Bills and Gross, 2005; Hein et al., 2006). However, landscape services are still lacking in most policy support tools (Pinto-Correia et al., 2006; Vejre et al., 2007), and current landscape models mostly deal with either land cover (LC) patterns (Geertman and Stillwell, 2004; Verburg et al., 2004) or are strongly sector-oriented (Heilig, 2003; Meyer and Grabaum, 2008).

In the case of Latin America, changes in LU scale continuously occur and they have important implications for the future of freshwater and coastal marine ecosystems and their management (Yanez - Arancibia and Lara - Domínguez, 1998). However, there is a lack of information about the potential of LU and biophysical alteration in the large-scale impact of tropical ecosystems. Rapid population growth and increasing international demand for tropical products have resulted in the conversion of vast areas of land for intensive agricultural production in Ecuador, as is typical of many other tropical developing regions of the world (Houghton, 1994). The economic benefit of exporting these products to meet international demands has driven deforestation and LU changes in the tropical forest located in the Ecuadorian coast and linked to the basin of the Guayas River.

The geographic dimension of this research involves characterization of the remaining ecosystems of mainland Ecuador. Our case study will be located in those Ecuadorian ecosystems where landscapes are experiencing serious environmental consequences and changes in their environmental services associated with the destination of LU and the various anthropogenic activities that have placed in the ecosystem boundaries, such as agricultural, livestock, industrial forestry and other agro-productive activities. There is evidence of ecosystems degradation (e.g. "Abras de Mantequilla" wetland) which belongs to Guayas River Basin (the largest tropical agricultural system in the Pacific coast of South America). This ecosystem has suffered loss of its native forests, due to the introduction of tree species like teak, African palm and banana cultivations. On the other hand, the estuary basin and coastal zone that are part of the same basin are also experiencing major problems such as eutrophication, sedimentation and pollution driven by urbanization, agriculture, aquaculture and deforestation.

For terrestrial ecosystems, the most important direct drivers of change in ES in the past 50 years have been LU and LC changes. Landscape-scale approaches to reducing loss of ES and biodiversity have therefore become increasingly important (Tengberg, et al., 2012).

On the other hand, the provision of ES depends not just on landscape composition but also on the landscape spatial configuration (i.e., the composition and organization of LC patches within the landscape). Therefore, this research is the basis for explaining the state of Ecuadorian ecosystem related to LU patterns in the last forty years in order to make better decisions regarding tradeoffs involved in LC and LU change, a systematic account of the relationships between ecosystem management and the ES and values that it generates. In this study, the potential to support native biodiversity will be assessed using available landscape shape metrics with the objective of making an analysis of landscape fragmentation and its potential impact on landscape capacity and ES.

LC mapping at multiple points in time provides a spatially-explicit time series of biophysical characteristics of landscapes that are relevant for ES. Also, the indirect information obtained from LC data can be used as a proxy for ecosystem service assessments. This is particularly important in remote mountainous regions that encompass ecosystems that are highly vulnerable to socioeconomic and climatic changes, and where land management is critical to the sustainability of communities living in and outside these regions (Millenium Ecosystem Assessment, 2005; Grêt Regamey et al., 2012). This is the case of Ecuador where its vegetation cover exhibits a clear demarcation between ecological units according to elevation, the latter being the source of variations in temperature, precipitation, atmospheric pressure, humidity and solar radiation.

However, the quantitative measurement of the relationship that exists between LU, ecosystem management and the provision of ES at national and more local scale in Ecuador is rare in terms of a widespread landscape functions analysis that will help to assess the quantifications and quality of ES in general and ES bundles in particular in order to identify their tradeoffs and synergies. Here we use the term ecosystem services bundles as sets of ecosystem services that repeatedly appear together across a landscape in terms of space or time (tradeoffs and synergies) (Raudsepp et al.). Therefore, it is important to determine the scale of the analysis, because it is the main factor in linking pattern and processes in the diverse landscapes functions that construct Ecuadorian ecosystems.

On the other hand, The Millennium Ecosystem Assessment, the Convention on Biological Diversity and PNUMA agree on the importance of ES for the support of life systems. This management is only feasible through the ongoing review of ES especially those at greatest risk of ecological fragility. Due to socioeconomic and environmental relevance of our case study, this research has also the objective of quantifying the provision of interactions between multiple ES of our interest. Thus it will be necessary to identify the exchanges/tradeoffs among environmental services and their synergies. The importance of identifying both exchanges and synergies of a fragile ecosystem as the case study is to enable a sustainable ecosystem management of the most important forest and lands in Ecuador and to enhance ecosystem's multi-functionality and real human being.

Scaling and an adequate characterization of tree and LC distributions must span scales ranging from that of individual to that of the landscape. Large-scale plot studies, have proven to be extremely valuable for defining vegetation characteristics such as canopy gap distribution and species-specific clustering (Scanlon et al., 2007). Consequently, policy makers can use this information to design spatial policies and evaluate the effect of their LU strategies on the capacity of the landscape to provide goods and services.

2 State of Art

2.1 ES and Landscape Functions interactions and potentials

The delivery of some of the ES is dependent on their spatial context (Kremen et al., 2007; Schröder and Seppelt, 2006) – pollinators, e.g. need different habitat characteristics for nesting and foraging. On the other hand, the demand and supply of some ES has shown a spatial dependency. For example: having suitable areas for organisms relevant for pest control or pollination somewhere in the landscape is not necessarily similar to having suitable areas for organisms relevant for pest control or pollination nearby arable fields. Consequently, the spatial configuration and spatial compositions of a landscape are key factors to be considered for the assessment of ecosystems, as well for regional or local scale.

Therefore, the interactions among ES and landscape functions are related to the potential of the landscape to provide (in the case of the pollination services and other interactive services) the assessment of the ES if the spatial pattern of nesting and foraging habitats is accessed. Similarly, the value of buffer strips for water quality regulation can only be estimated if the spatial pattern of diffuse emissions from agriculture is taken into account. Similarly, an assessment of outdoor recreation potential needs to consider patch size, effects of noise pollution and accessibility (Lautenbach et al, 2011).

The potential ES supply at regional and local landscapes in Latin America has become a challenge in the ES supply analyze. Even though, ES research in Latin America has been growing steadily but much more information is still needed. Further studies are needed to connect ecological processes, potential ES supply, actual ES delivery to societies, and ES values.

In the case of research on potential supply of ES in LA has primarily focused on timber (Guariguata et al., 2009), water provision (Blume et al., 2008), and carbon storage (Soto et al., 2010). On the other side, Pollination (Garibaldi et al., 2009) and pest regulation services (Avelino et al., 2012) have received much less attention.

2.2 Interactions between Landscape Patterns and ES

The study of vegetation and LU patterns has been an important approach in much of the ecological research in terms of landscape. Nevertheless, there is a lack of a correct determination of the factors that generate and maintain pattern in a specific landscape. The reason for this is the existence of multiple mechanisms that can give rise to commonly observed spatial measures. This diversified pattern analyze options has led to distinguished several types of landscape patterns evaluations.

For example, random patterns can be indicative of the absence of spatial interactions, but random patterns are also known to emerge from strong competitive interactions. Aggregated patterns, such as those routinely observed for woody tree species in natural communities, have been attributed to the disparate mechanisms of dispersal limitation and habitat differentiation. It has been suggested that the identification of dominant processes that lead to emergent vegetation pattern could benefit from a more thorough statistical measure of the vegetation spatial structure that implicitly considers the broad range of spatial scales over which aggregation occurs, rather than simply characterizes the average aggregation tendency of individuals. We adopt such an approach in applying cluster size analysis to tree canopy distributions and evaluate the consistency of the patterns over a range of environmental conditions (Scanlon et al., 2007).

When landscape pattern discussion is extrapolated in the Ecuadorian ecosystems, it is evident the major changes in LC are related to their composition. This issue is observable in the Andean region where the introduction of tree exotic species has arose to forest and LC fragmentation.

The change in LC composition goes along with change in LC configuration. The increase in landscape fragmentation resulted from the gradual clearing of native forests, and the introduction of patches of pine plantations in high alpine open grasslands of the Ecuadorian Andean region.

That is the case of Pangor watershed, which is located in the Western Andean Range of the country and it has an altitude between 1434 and 4333m. This watershed is a good example of rapid forest and lad cover fragmentation due to an increase in landscape changes, particularly since the second half of the 20th century. Changes in and cover pattern between 1963 and 2009 were characterized by an increase in the number of LC patches and a decrease in their mean size, by an order of magnitude in each case (Table 1). Forest fragmentation is particularly striking from 1991 onwards with a 5-fold increase in the number of LC patches (Table 1) (Balthazar et al., 2015)

The mentioned study made an analysis of landscape capacities between 1963 and 2009, considering a catchment-based approach to mapping the impact of forest cover change on ES in the Ecuadorian Andean region.

	Number of patches	Mean area of patches (ha)
1963	56	505
1977	63	449
1991	289	98
2001	544	52
2009	659	43

Table 1 Change in LC configuration between 1963 and 2009, as measured by two landscape metrics: the number of LC patches, and the mean area of the patches. (Balthazar et al., 2015)

The first exotic tree plantations were observed in 1977, but their expansion really started from the 1990s onwards, with an increase in area of 8.15km2 between 1991 and 2001. The first large pine plantations in 1991 were located in the upper part of the catchment. The increase in pine plantations continued during the 2000s, with an increase of 5.97% per year leading to a total surface covered by pines of about 15km2 in 2009. This trend continues until now as field observations in 2011 revealed large young pine tree plantations in *páramo* grasslands. From the 2000s onwards, patches of pines were located throughout the upper part of the catchment and, to a lesser extent, in the central and lower parts of the study area. Among the consequences of the native forest conversion to forest with an important population of exotic tree plantations like the pine trees, the Ecuadorian catchment case is a good example of the negative impacts of this forest pattern alteration on native biodiversity. The on-site effects are: deterioration of the esthetic quality of the landscape caused by the rapid turnover time between pine tree plantation and the waste resulting from harvesting it and the retard of natural regeneration of vegetation on-site. On the other hand: The off-site effects of the conversion of páramo grasslands to pine plantations are:

changes on the water balance and flow discharge. This means a strong decrease in the total water yield, a decrease in the water flow regulation capacity and a negative impact on slope stability (Balthazar et al., 2015).

The actual effects in landscape patterns changes are evident in the esthetic and recreational services of this type of forest, due to a decline in native forests, an increase in exotic tree plantations and extra pressure on LU from agricultural activities. The three drivers have led to a diminished forests resilience and capability to facilitate its vegetation recovery.

2.3 Other Interactions: Agricultural landscapes.

Pattern landscapes interact not only with LU or forest coverage changes caused by introduction of exotic tree species like the Pangor catchment case. They are also linked to one of the most common land conversion, which is agricultural landscapes.

As the Ecuadorian catchment case show its respective evidence, a rapid conversion in LU is driven mainly by agricultural landscapes introduction in the LU classifications. Agricultural landscape has an important influence on land conversion, which is attributable to its characterizations that are ruled by regular growth and harvest phases, reflected by related changes in their ecosystem service supply.

Of course, additional agricultural strategies and crops with various growing and harvesting rhythms exist. Better information on these variations is highly relevant for site-specific landscape management, i.e. to optimize additional inputs. Respective seasonal patterns can be found for regulating (e.g. during storm or rain seasons) and cultural ecosystem service (e.g. tourist season) supply (and demand) as well. Other provisioning ES, such as timber, show much longer rotation periods taking several decades to grow before being harvested rather suddenly. Therefore, the selection and definition of appropriate temporal assessment scales have to be carried out very carefully (Burkhard et al., 2014)

2.4 Temporal and spatial scales for landscape functions and ES.

The issue of the scale is a decisive feature to consider when landscape functions and ES are analyzed in terms of determining the positive or negative feedback of LU patterns that can occur in diverse regional and local scales. This is why is extremely important to define scales of our research, associated to time and space.

Scales can be defined by the extent and resolution: extent refers to the size of a dimension, for example, the size of the study area or the duration of time under consideration, whereas resolution refers to the precision used in measurement. There is increasing awareness of the importance of spatial and temporal scales for the analysis and valuation of ES (e.g. De Groot et al., 2002; MA, 2003).

The importance of scales has been widely recognized in both economics and ecology. However, to date, few ecosystem valuation studies have explicitly considered the implications of scales for the analysis and valuation of ES. There are two key scales (economic and ecological scales) proposed by De Groot el al., 2010; that need to take into account in ecosystem management issues:

- Economic Scales: Some examples are described in De Groot et al., 2010 work: (1) Distances to urban centers have been widely used as an explanatory variable for economic activity; (2) Spatial dimensions have been included in economic optimization models for resource harvesting.

- Ecological scales: Commonly, ecological processes operate at specific spatial and temporal scales (Limburg et al., 2002; Holling et al., 2002). Ecological and institutional boundaries seldom coincide, and stakeholders in ES often cut across a range of institutional zones and scales (Cash and Moser, 1998). The supply of ES depends on the functioning of ecosystems, which, in turn, is driven by ecological processes operating across a range of scales (MA, 2003; Hein et al., 2006). Nevertheless, De Groot et al., 2010 offers a specific ecological scale can be identified at which an ecosystem service is generated (Table 2).

Ecological scale	Dimensions	Regulation services
Global	>1,000,000 km^2	Carbon sequestration Climate regulation through regulation of albedo, temperature and rainfall patterns
Biome–landscape	10,000–1000,000 km^2	Regulation of the timing and volume of river and ground water flows Protection against floods by coastal or riparian ecosystems Regulation of erosion and sedimentation Regulation of species reproduction (nursery service)
Ecosystem	1–10,000 km^2	Breakdown of excess nutrients and pollution Pollination (for most plants) Regulation of pests and pathogens Protection against storms
Plot plant	<1 km^2	Protection against noise and dust Control of run-off Biological nitrogen fixation (BNF)

Table 2. Most relevant ecological scales for the regulation services. De Groot et al. 2010.

For instance, a local forest patch may provide pollination service to nearby cropland. The supply of the hydrological service depends on a range of ecological processes that operate, in particular, at the scale of the watershed. At the global scale, ecosystems may provide a carbon sink or support the conservation of biodiversity. Analyses of the dynamics of ES supply requires consideration of drivers and processes at scales relevant for the ES at stake (De Groot et al., 2010)

2.5 Socio-economical, ecological and Lande characterization of Ecuador.

2.5.1 Socio-economical diagnosis of Ecuador

The Ecuadorian economy is relatively small and is mainly dedicated to export primary products. Its structural economy is highly sensitive to international environment, which is reflected in the following facts: a) the average GDP (2007-2010): USD 108.4 billion. This amount represents 0.15% of the world economy; b) the international opening rate[1] is 57%, which places the country at a disadvantage position in international markets in relation to the dynamics of foreign trade picture in region. Some examples like Argentina (57.6%) and Brazil (28.5%) are the evidence of these highly inequality among countries in the

[1] Tasa de apertura internacional: (Exportaciones + importaciones)/PIB

region in terms of international commerce; c) When discussion is related to primary products exports (It is referred to the products without any added value and are mostly agricultural products), during the period 2007-2010, these type of exports represented 76.2% of total exports

In other words, Ecuador's economy is highly dependent on international trade and to the global commerce behaviors as well. It is especially highly dependent to the economy of the United States, its main trading partner, since the American country buys 39.1% of Ecuadorian exports[2].

It is important to note that the Ecuadorian economy reflects a turning from dollarization as a result of the bankruptcy in the national banking system (1999). Since dollarization event (2000) Figure 1 shows that even though, all the components of GDP grew, each of them did it at different rates. On the whole, imports and exports progressed more rapidly than the rest of the variables, which can be interpreted as a steady increase in the national opening up trade.

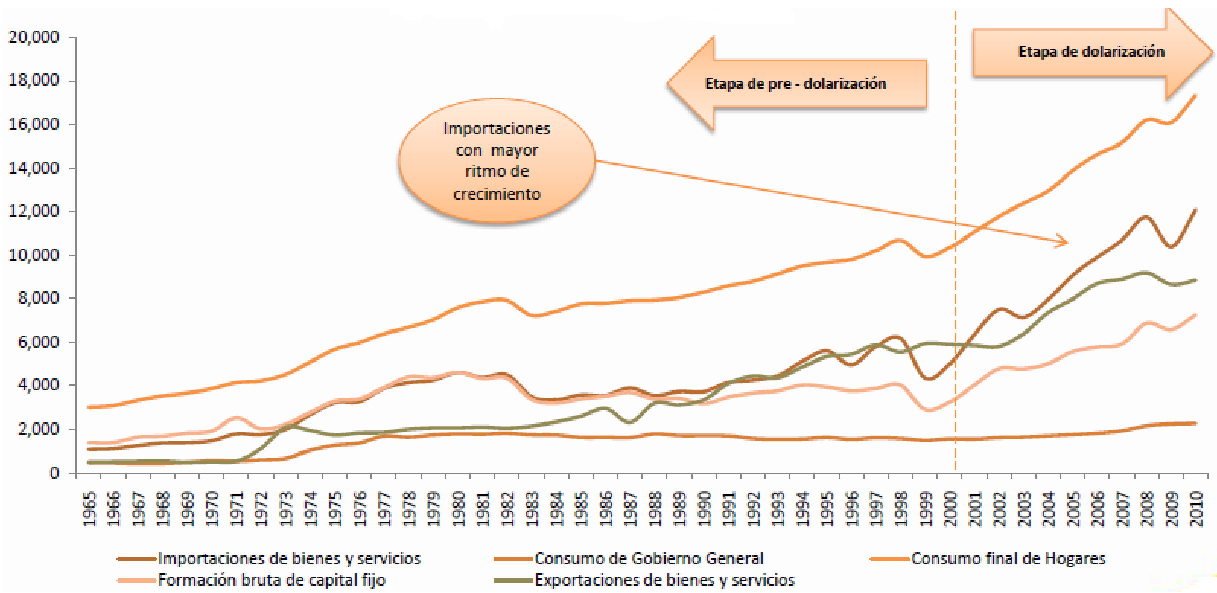

Figure 1 Evolution of the main components of GDP. (USD 000) (Period time: 1965-2010). Banco Central del Ecuador (BCE).

Nowadays, after having recovered from the effects of the global crisis, Ecuador's economy reached a robust growth. In 2012, 2013 and 2014 growth decelerated moderately yet it maintained strong with rates of 5.2%, 4.6% and 3.8%, respectively. The government of President Rafael Correa Delgado—who was re-elected for a new 4-year mandate in February by an ample margin of votes —maintains the double priority of eradicating poverty and amending the productive matrix for changing, thus, the country's productive structure and to generate an economy sustainable and diversified oriented to knowledge and innovation. With this double priority, the public sector's expense and investment have increased from 21% of the GDP in 2006 to 44% in 2013. A vast part of these resources was destined to both investment programs and projects in energy, infrastructure, and transportation, as well as in social sectors. Economic growth in Ecuador has been inclusive, which has directly reduced poverty and inequality levels and increased the middle class. Between 2006 and 2014, poverty measured by income (using the national

[2] Banco Central del Ecuador (BCE), Promedio Período: 2007-2010.

poverty line) decreased from 37.6% to 22.5%, whilst extreme poverty was reduced from 16.9% to 7.7%. In addition, the inequality reduction has been quicker than in the region's average: The Gini's coefficient was reduced from 54 to 48.7 between 2006 and June 2014, since growth benefitted more the poorest. Between 2000 and 2011 a more pronounced increase of the income took place in the two poorest quintiles. In fact, the income of the poorest 40% of the population increased in 8.8%, compared with the average 5.8% of the country. Despite these remarkable outcomes, there is still a lot to be done to sustain and to enlarge the achievements reached in poverty reduction and inequality, as well as of the economic growth. These challenges are associated with the overreliance of the economy on the oil sector. In recent months, the sharp decline in oil prices and the appreciation of the U.S. dollar have severely affected the trade balance and the financing of public investment, as well as the competitiveness of Ecuadorian exports. In this context, consolidating the reduction in inequality and poverty poses a major challenge. This is especially critical given that despite a significant decline in recent years, poverty rates remain high, particularly in rural areas (Wold Bank, 2015).

2.5.2 LU in Ecuador

Land use refers to its category in the rural sector. Thus, we find the following categories provided by the National Agricultural Statistical System (SEAN): permanent crops, temporary/transitory crops and fallow land, break crop, cultivated pastures, natural pastures, woodlands and forests, moors and other uses.

It must be emphasized that the main land categories are the permanent and temporary crops. Therefore, for permanent crops the annual growth rate it is 6.25% (in reference to 2012), which also represent 12.49% of the total national land usage by 2013. On the other hand, temporary crops represented 8.53% of the total LU in the country at the same year and showed a reduction of 1.72% (in reference to 2012). At geographic regional level, it seems that the Coast has the largest presence of permanent crops with 67.12%, followed by the Sierra (Andean region) with 23.94% and the East (Rainforest region) with 8.94%. In the case of temporary crops the trend is the same, so the Coast region has 59.24% of this land category, the Sierra has 35.99% and East Regions hast a participation of 4.77%

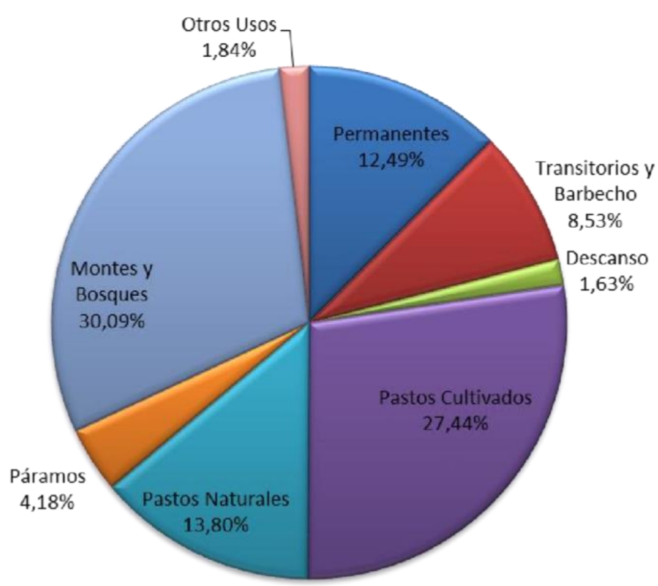

Figure 2 Total National LU, Year 2013. ESPAC 2013

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2.5.3 LU structural analysis

At a national level, the largest area of arable land is devoted to cultivated pasture with 29.85%, followed by natural pastures with 11.96% natural pastures, permanent crops represent 11.62% and temporary crops and fallow are 8.58% of total arable land. In addition, we can see that a high percentage of land is dedicated to mountains and forests with 30.10%, which percentage trend is presented in all regions with more than 20% each (Table 3).

When we analyze LU structure by region, it is determined that 34.88% of the land in the Coast Region is dedicated to cultivated pastures, as well 20.99% to permanent crops and 13.57% to temporary crops and fallow. This region is highlighted by the production of banana, coffee, cocoa and rice. These crops dominate the LU in the region because of the favorable climate and soil conditions.

In the Andean region, it is observed that 22.75% and 22.56% of the arable land is devoted to natural pastures and cultivated pastures respectively; followed by 7.43% of temporary/ transitory crops and 6.12% of permanent crops. Although farmers in this area are dedicated to the cultivation of variety of short-cycle crops, the vast terrain occupied by natural and cultivated pastures show livestock activity is highly predominant in the region.

In the Eastern (Rainforest-Amazon) Region, because of its land properties, is observed woodlands and forests account for 52.77% of the total land, followed by 34.25% of cultivated pastures and 4.88% of area dedicated to permanent crops. A high percentage of land designated to cultivated pastures is also due to an important livestock activity in the region. This LU behavior is similar to the Andean region, which is also dominated by livestock activities.

LAND USE	NATIONAL		COAST REGION		ANDEAN REGION		RAINFOREST REGION	
	Area ha	Use Percentage	Area ha.	Use Percentage	Area ha.	Use Percentage	Area ha	Use Percentage
Permanent Crops	1 .382.918	11, 62%	968.607	20, 99%	289.529	6, 1 2%	1 24.782	4, 88%
Transitory crops and fallow land	1 .020.870	8, 58%	626.431	13, 57%	351 .533	7, 43%	42.905	1, 68%
Break Crop	1 26.982	1, 07%	63.959	1, 39%	50.801	1, 07%	1 2.222	0, 48%
Cultivated Pastures	3.553.008	29, 85%	1 .609.695	34, 88%	1 .067.061	22, 56%	876.252	34, 25%
Natural Pastures	1 .423.1 1 4	11, 96%	244.025	5, 29%	1 .076.1 86	22, 75%	1 02.903	4, 02%
Páramos	608.272	5, 11 %	6.524	0, 14%	567.251	11, 99%	34.497	1, 35%
Woodlands and Forests	3.583.056	30, 10%	991 .083	21, 47%	1 .242.099	26, 26%	1 .349.874	52, 77%
Other Uses	205.657	1, 73%	1 05.1 99	2, 28%	85.642	1, 81 %	1 4.81 7	0, 58%
TOTAL	1 1 .903.878	1 00,00%	4.61 5.522	1 00,00%	4.730.1 04	1 00,00%	2.558.252	1 00,00%

Table 3 LU area categories, Year 2013. ESPAC 2013.

2.5.4 Ecological characterization of Ecuador

In terms of vegetation cover classification in Ecuador, most of them are determined by the biome categories of the country. The vegetation cover exhibits a clear demarcation between ecological units according to elevation, the latter being the source of variations in temperature, precipitation, atmospheric pressure, humidity and solar radiation. As a result of this model, Ecuador has four bioclimatic: desert, pluvial, pluviseasonal and xeric categories.

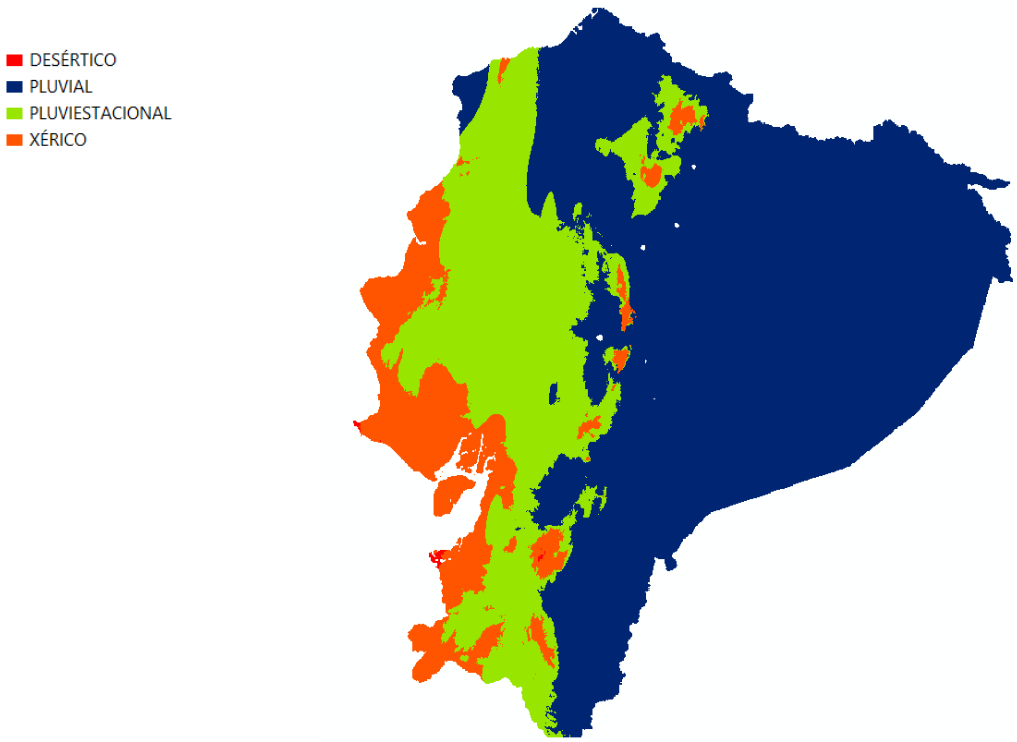

Figure 3 Bioclimatic categories in mainland Ecuador. MAE, 2008.

Additionally, according to the report of the Ministry of Environment (2000), the rapid grow of the Ecuadorian primary industry led alarming subnational annual deforestation rates between 1.7 (238,000 hectares) to 2.4 (340,000 hectares), which numbers are increasing (SENPLADES, 2009). Similarly, according to the National Coalition for the Defense of Mangrove and the National Plan for Good Living, 70% of mangrove areas and saline areas disappeared between 1969 and 1999. Thus, the lack of investment, the lack of incentives for the restoration and protection of water sources, among others, are responsible for the indiscriminate expansion of the agricultural production at the expense of the remaining ecosystems (Mentefactura, Ecolex, SCL Econometrics, 2006).

This situation worsens due to the high concentration of land and water in few hands, the lawlessness in the land tenure and rural poverty. A study by Blankstein and Zuvekas (1973) at the national scale indicated that about 1% of the farms owned more than 55% of the land in 1954, while 73% of land holdings represented less than 7% of the total land area. The agrarian land reforms of the 1960s and 1970s led to a redistribution of the land ownership, but also promoted rapid colonization of so-called vacant lands, which were often covered by native forests. This fact was the beginning of the LU changes the country has suffered.

Among other drivers that has influenced in the loss of native forest land were mentioned by Vanacker et al. (2003), who emphasized that deforestation and forest degradation were caused by: 1) rapid population growth; 2) The agrarian land reforms of the 1960s and 1970s already mentioned in this document and; 3) From the 1980s onwards, exotic tree species (mostly eucalyptus and pine) were increasingly used for plantation forests that now cover extensive areas. These change factors caused the expansion of the agricultural frontiers into the primary and secondary native forests. It is important to mention, that the conversion of native forests to agricultural lands is associated with the most negative ecosystem impacts. The only positive impact of the establishment of agricultural land was the provision and valuation of food products.

Nowadays, the effects of intensive LU change in the Ecuadorian landscape overview are the modifications of landscape compositions in cases like the Andean region were the introduction of exotic tree species might its main driver. The change in LC composition goes along with change in LC configuration. On the other hand, other important effect is land fragmentation resulted from the gradual clearing of native forests, and the introduction of patches of pine plantations in high alpine open grasslands like the Pangor's catchment case. In the mentioned case, changes in LC pattern between 1963 and 2009 were characterized by an increase in the number of LC patches and a decrease in their mean size, by an order of magnitude in each case.

3 PhD Thesis Proposal

The particular social and environmental dynamics that act in the territory has put on the debate which planning directions and environmental management should be executed taking into account the livelihoods of thousands of small family producers, the conservation policies, and the agrochemical and agricultural export companies in the area. This dichotomy shows the importance of trend analysis (including projection of resilient scenarios) of ES of tropical forests in coastal areas and question whether the actual model of land management, based on exogenous development, depending on banana production and similar crops and on the agrochemical industry, is convenient. It is also necessary to question if the actual model is putting on risk food sovereignty and security and diminishing the quality of life of small farmers and theirs communities. Given the previous state of the art, the aim of this research is to answer the following questions

(1) Are there distinct spatial patterns of ES across Ecuador?
(2) Are there specific relationships (spatial trade-offs and synergies) between ecosystem and landscape functions and services?
(3) Do multiple ES form spatial ecosystem bundles and bring new social and ecological dynamic conditions (changes in temporal and spatial terms) into the Ecuadorian landscape functions on services, in terms of sustainability and resilience)?
(4) Are there possible critical thresholds?

(5) Is it possible to build a decision - support methodology to define which services are beneficial and how these benefits are affected by synergies or tradeoffs among these services?

3.1 Methodology

In order to answer these questions, we will integrate more than one specific methodological framework to our analysis. This has been considered because ES definitions and theirs respective analysis is a research field that responds to different nature and social-geographic contexts and has to be adapted to the inputs availabilities, data access and liability and landscape compositions.

3.1.1 Historical dynamics and patterns

In order to understand the impacts of LC changes on the provision of ES in Ecuador over a relatively long time period and to identify social- economic and ecological effects related to land coverage and use patterns in Ecuadorian ecosystems over a 40 year- time period, time series of LC maps can be derived from satellite remote sensing data. However, the image availability is limited to the last 40 years at best in our case study. Therefore, satellite data have to be combined with other data sources such as historical topographic. This issue will be taken into account where mapping assessment arises. Landsat images are also an important input for our research because they will help us to identify large-scale spatial patterns, detect and analyze possible landscape distribution clustering of sustainable ES management across ecosystems of mainland Ecuador.

3.1.2 Decision-support methodology approach

In order to develop a sound and robust decision-support methodology, the main framework that has been considered is that of De Groot et al., 2010 and 2012 proposal which is the Cascade Framework for integrated assessment of ecosystem and landscape services. Additionally, we will consider that of Burkhard et al. 2012 and Koschke et al. 2012 approach, that will combined with De Groot et al. 2010 and 2012 framework in order to have a suitable method for the Ecuadorian landscapes and ES. This is because of the heterogeneity of ecological systems like Ecuador´s case, which have been identified by several studies. However, as stated by De Groot et al. (2010): “Empirical information on the quantitative relationship between LU and ecosystem management and the provision of ES at the local and regional scale is however still scarce…”

De Groot et al. (2002, 2010, and 2012) presented its conceptual framework and typology for describing, classifying and valuing ecosystem functions, goods and services in a clear and consistent manner.

As Figure 4 shows, the first step towards a comprehensive assessment of ecosystem goods and services involves the translation of ecological complexity (structures and processes) into a more limited number of ecosystem functions. These functions, in turn, provide the goods and services that are valued by humans.

On the other hand, the same figure shows ecosystem functions concept, that are best conceived as a subset of ecological processes and ecosystem structures. Each function is the result of the natural processes of the total ecological sub-system of which it is a part. Natural processes, in turn, are the result of complex interactions between biotic (living organisms) and abiotic (chemical and physical) components of ecosystems through the universal driving forces of matter and energy.

The ecosystem function concept thus provides the empirical basis for the classification of (potentially) useful aspects of natural ecosystems to humans: observed ecosystem functions are re conceptualized as 'ecosystem goods or services' when human values are implied. The primary insight here is that the concept of ecosystem goods and services is inherently anthropocentric: it is the presence of human beings as valuing agents that enables the translation of basic ecological structures and processes into value-laden entities. As Figure 4 shows, in our proposed framework, the form of this translation is not restricted to economic terms of 'consumption' but may also be ecological and/or socio-cultural.

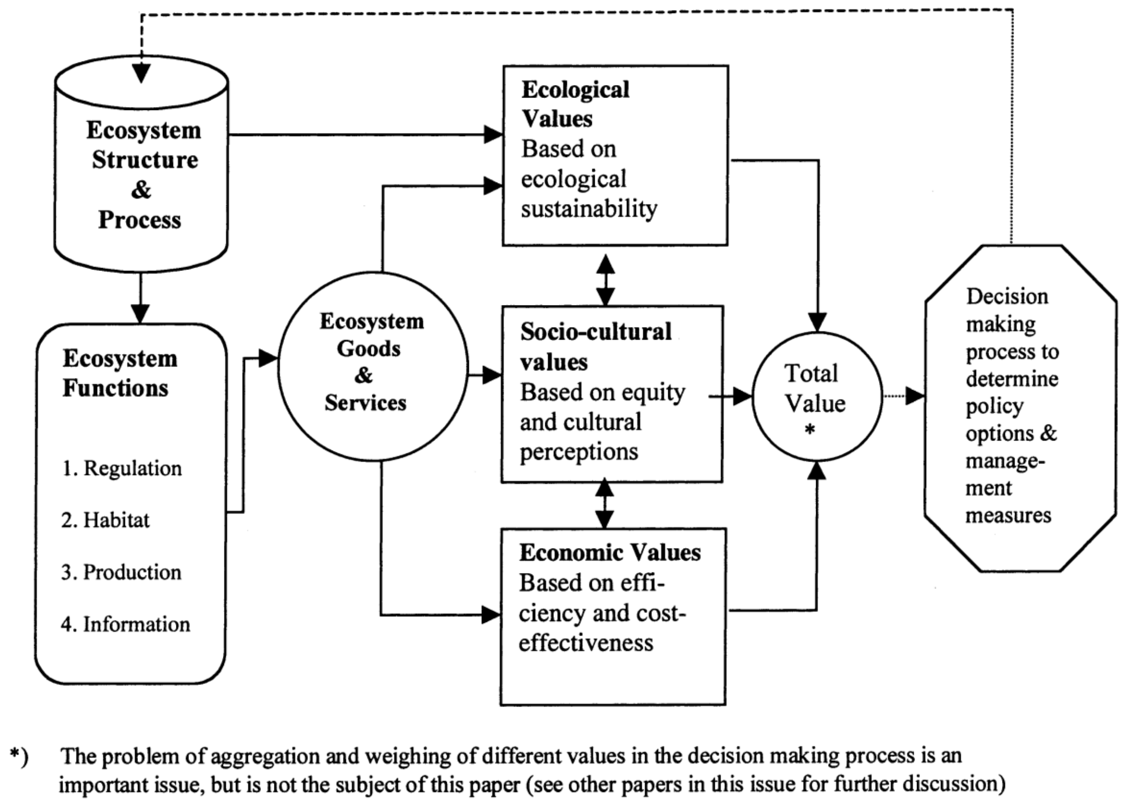

Figure 4 Cascade Framework. Framework for integrated assessment of ecosystem and landscape services. De Groot et al., 2002

De Groot et al. (2010, 2012) method can be used in combination with socio-ecological approach (stakeholders and community participation. One of the reasons for combining these approaches is the fact of the heterogeneity of ecological systems in most of Latin America. On the other hand, it is known that natural resources are the basis of subsistence in many poor communities and that their livelihood in developing countries is directly dependent on ecosystems (UNEP, 2011; Delgado et al, 2013).

Given the objectives of our work (i.e., to analyze the relation between landscape functions and services patterns and their positive or critical feedback in social and ecological systems), we pretend to use an eco-social approach oriented to gather as much information as possible about the rural population of the most important Ecuadorian ecosystems, and how they use provisioning ES in relation to its livelihood and its awareness (Figure 5). In this context, we think this type of approach is a contribution to local studies of ES in Ecuador.

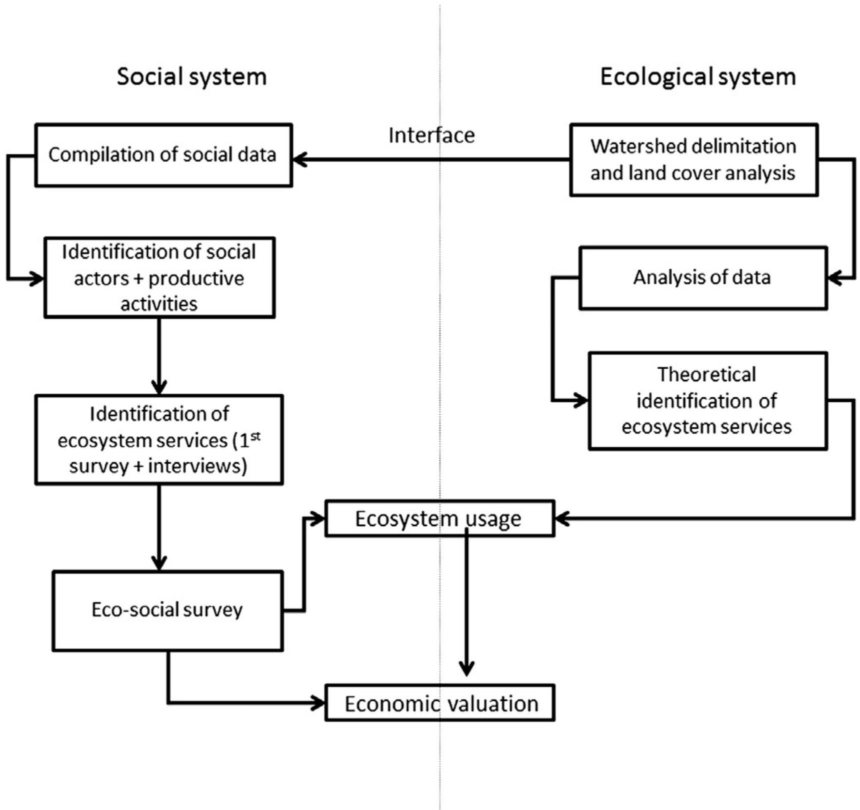

Figure 5 Schematic representation of the eco-social approach used to analyze the provision ES by the watershed and their contribution to the wellbeing of rural populations. Delgado et al., 2013.

Some inputs required for the combining both methods are: 1) National proxy data in order to identify rural settlements, social actors. 2) National proxy data for characterizing the productive activities within the mapping unit that will be used (e.g. watershed units or others). 3) The information resulting from these first two steps will be used to design a first survey oriented to identify the ES recognized by the population within our mapping unit. This first survey will corresponded to a semi structured interview with questions including all four types (De Groot et al., 2010) of ES.

3.1.2.1 Multi-criteria assessment

The objective of this framework is to understand the impacts of LC changes on the provision of ES over a relatively long time period. It is pretended to analyze around 40-year time series of LC data to map landscape changes and their respective patterns.

Through a multi-criteria assessment and the benefit transfer method, the concept of landscape capacities was used for ES assessment (Burkhard et al., 2009; Koschke et al., 2012). These methods were tested on European CORINE LC maps, and are based on a benefit transfer method where the data assessed on smaller spatial units are up-scaled to larger areas assumed to be homogeneous (Koschke et al., 2012). This multi-criteria assessment framework offers an alternative to the monetary accounting obtained through a costly, time-consuming and data-intensive survey of each ecosystem function at the landscape scale.

When using quantitative data on specific ecosystem functions from local scale studies to develop a normalized scoring, a multi criteria assessment is not subject to qualitative expert judgment.

By analyzing multi-temporal LC data of Ecuador for the period 1977–20008, we will specifically try to test: 1) the feasibility and added value of extending LC change analyses to longer time periods, and 2) the potential impact of LC change trajectories on the provision of ES.

3.1.3 Inputs

The massive amount of manual sampling required to compile these data sets, however, places a practical limitation on their widespread collection. High resolution remote sensing is an alternative for detecting landscape level vegetation pattern, and one that is particularly well suited for monitoring sparse vegetation in which individual tree coverages can be distinguished. The ease by which these data can be acquired allows for a more geographically widespread detection of large-scale spatial pattern (Scanlon et al., 2007)

Some of the inputs that will be considered in our research are explained below:

I. Vector Data: The Ecuadorian Military Geographical Institute and other public institutions like The Ministry of Environment, Tourism, and Agriculture and others, have vector data of the country related to basic information, human settlements, mobility and connectivity, environmental, economic and socio-cultural information.

II. Satellite images: Landsat data will be used for LC mapping of the recent decades. It is important to take into consideration that image availability in the region is limited because of high cloud-coverage (i.e., only 6 images have no more than 30% cloud coverage for the entire period). Five scenes (1977–1982 -1990–2000-2008, from the same season) will be acquired with the 1T level of pre-processing (orthorectified images with a root mean-square (RMS) positional accuracy of <50m, Tucker et al., 2004). Scenes were then atmospherically and topographically corrected with ATCOR3, following the calibration procedure from Balthazar et al. (2012).

    a. LC Classification: LC type will need to be defined with the purpose of the optimization and common classification of the geographical images use.

III. Statistical Information: The secondary information will be taken from the Census of 2010 of the National Institute of Statistics and Census of Ecuador (INEC). The temporal data related to crops and agriculture context will be obtained from the National Agricultural Statistical System.

IV. National Environmental Indicators: These are measures that describe qualitatively or quantitatively the states of environmental dynamics and phenomenon and its social and economic relations across Ecuador. Through the National System of Environmental Indicators SNIA, indicators are presented as efficient and systemic inputs for the evaluation and validation of the progress of goals set in the environmental field, facilitating decision-making through the development of environmental public policies. These Indicators produce information on the following topics and subtopics: atmosphere and climate, soils, ecosystems, marine and coastal resources, environmental social dynamics. These indicators will be contrasted with those obtained in this research and also check the status of the functions and services of Ecuadorian landscapes

V. Survey Information: The application of the social-ecological approach will be executed in following manner: 1) National proxy data in order to identify rural settlements, social actors. 2) National proxy data for characterizing the productive activities within the mapping unit that will be used (e.g. watershed units or others). 3) The information resulting from these first two steps will be used to design a first survey oriented to identify the ES recognized by the population within our mapping unit. This first survey will corresponded to a semi structured interview with questions including all four types (De Groot et al., 2010) of ES.

3.1.4 Indicators

We propose three different methods for calculating landscape functions and their ES and be capable to compare their spatial and quantitative results with the objective to propose the best decision-making methodology inputs.

Based on Cascade Framework, De Groot et al. (2010) presented an overview of indicators for the assessment of the location and quantity of the (potentially) provided landscape services. These indicators, representing biophysical and social properties of the landscape, and they can be used to map the presence of landscape functions and their capacity to provide goods and services. The following classification evidences 23 ecosystem functions that provide a much larger number of goods and services and they can be used in the Ecuadorian case, as we are gathering statistical and research data that will help to define bio-physical and categorical indicators (Table 4).

Table 4 Potential indicators for determining (sustainable) use of ES. Adapted from De Groot et al. 2010.

Service comments and examples		STATE INDICATOR (how much of the service is present) / PERFORMANCE INDICATOR (how much can be used or provided in sustainable way)
Provisioning Services	Food	Total or average stock in kg/ha / Net Productivity (in kcal/ha/year or other unit)
	Water	Total amount of water (m3/ha) / Max sust. water-extraction (m3/ha/year)
	Fiber & Fuel & other raw materials	Total biomass (kg/ha) / Net productivity (kg/ha/year)
	Genetic Materials: genes for resistance to plant pathogens	Total "gene bank" value (e.g. number of species & sub-species) / Maximum sustainable harvest
	Biochemical products and medicinal resources	Total amount of useful substances that can be extracted (kg/ha) / Maximum sustainable harvest (in unit mass/area/time)
	Ornamental species and/or resources	Total biomass (kg/ha) / Maximum sustainable harvest
Regulating Services	Air quality regulation: (e.g. capturing dust particles)	Leaf area index, NOx-fixation, etc. / Amount of aerosols or chemicals "extracted"—effect on air quality
	Climate Regulation	Greenhouse gas-balance (esp. C-sequestration); Land cover characteristics, etc. / Quantity of Greenhouse gases, etc. fixed and/or emitted = effect on climate parameters
	Natural Hazard mitigation	Water-storage (buffer), capacity in m3 / Reduction of flood-danger and prevented damage to infrastructure
	Water regulation	Water retention capacity in soils, etc. or at the surface / Quantity of water retention and influence of hydro-logical regime (e.g. irrigation)
	Waste treatment	Denitrification (kg N/ha/y); Immobilization in plants and soil / Max amount of chemicals that can be recycled or immobilized on a sustainable basis.
	Soil formation and regeneration	E.g. bio-turbation / Amount of topsoil (re)generated per ha/year
	Pollination	Number & impact of pollinating species / Dependence of crops on natural pollination
	Biological Regulation	Number & impact of pest-control species / Reduction of human diseases, live-stock pests, etc.
Habitat or supporting services	Nursery habitat	Number of transient species & individuals (esp. with commercial value) / Dependence of other ecosystems (or "economies") on nursery service
	Genepool protection	Natural biodiversity (esp. endemic species); Habitat integrity (irt min. critical size) / "Ecological Value" (i.e. difference between actual and potential biodiversity value)
Cultural & amenity services	Aesthetic: appreciation of natural scenery (other than through deliberate recreational activities)	Number or area of landscape features with stated appreciation / Expressed aesthetic value, e.g.: Number of houses bordering natural areas # users of "scenic routes"
	Recreational: opportunities for tourism and recreational activities	Numberor area of landscape & wildlife features with stated recreational value / Maximum sustainable number of people & facilities Actual use
	Inspiration for culture, art and design	Number or area of Landscape features or species with inspirational value / #books, paintings, etc. using ecosystems as inspiration
	Cultural heritage and identity: sense of place and belonging	Number or area of culturally important landscape features or species / Number of people "using" forests for cultural heritage and identity
	Spiritual & religious inspiration	Presence of Landscape features or species with spiritual value / Number of people who attach spiritual or religious significance to ecosystems
	Education & science opportunities for formal and informal education & training	Presence of features with special educational and scientific value or interest / Number of classes visiting, Number of scientific studies, etc.

3.1.5 Landscape Capacities: an approach to define ES.

Ecosystem functions can be defined by the aptitude of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly (De Groot, 1992). This concept is used as a powerful tool to assess the potential of ecosystems in changing environments (Bollige and Kienast, 2010).

For land management decisions, the concept of landscape (functions and services) is often used instead of the concept of ecosystem (Hermann et al., 2011). The concept of landscape capacity enables integration of LC data for evaluating ecosystem functions and services in a spatially-explicit manner (Burkhard et al., 2009; Hermann et al., 2011).

Therefore, taking into account the impact of the forest cover changes on ecosystem service provision at the landscape scale, It will be assessed the following indicators (Table 5) using the concept of landscape capacities. This concept is used as a proxy for ecosystem service and is incorporated within the Cascade Framework and Multi-criteria assessment, which was previously reviewed in this document.

Table 5 Selected indicators, indicator values, source and scale of local scale studies for the different analyzed mountain ES. Balthazar et al. (2015)

LAND COVER	INDICATORS	SOURCE	SCALES
On-site functions			
Biodiversity (floristic species)	Potential to support native biodiversity (relative scale)	Hall et al. (2012)	Ecuadorian Andes
Soil structure and composition	OM content (%)	Hofstede et al. (2002)	Ecuadorian Andes
Protection against water erosion	C-factor (%)	Molina et al. (2008)	Ecuadorian Andes
Above ground carbon storage (biomass)	Mature biomass: (kg/m2)	Lieth (1973) Hall et al. (2012)	World -Ecuadorian Andes
Soil carbon storage	Carbon content: (MgC/ha)	Hall et al. (2012)	Ecuadorian Andes
Esthetic quality of the landscape	Relative scale	Burkhard et al. (2009)	Europe
Off-site functions			
Water yield (provision and regulation)	Discharge (mm/year)	Buytaert et al. (2007)	Ecuadorian Andes
Erosion regulation	Soil 137Cs mass activities	Henry et al. (2012)	Ecuadorian Andes
Provision of food/fodder	Monetary prices (US$)	Kocian et al. (2011)	World - Ecuador
Provision of wood/timber	Monetary prices (US$/m3)	PROFAFOR (2007)	Ecuadorian Andes

3.2 Definition of the modeling approach

Increasingly, studies are showing that multi-functional use of natural and semi-natural ecosystems and landscapes is not only ecologically more sustainable, and socio-culturally preferable but frequently also economically more beneficial than converted systems. These studies has shown that main ecosystems like tropical forests, *páramos*, wetlands and mangroves provide more benefits to society when they stay in their native composition instead of converting them into intensive economic use (De Groot et al., 2010).

However, new studies are needed in order to develop a method for LU planning and decision- making, above all in countries that show evidence of rapid LU conversion and its collateral effects like deforestation and degradation, like the Ecuadorian case.

A good example of the relationships between the levels of ES and the degree of loss of biodiversity related to different management systems were developed by Braat and ten Brink (2008). They suggest a simplified set (Figure 6) that explain the need to analyze, and quantify these relationships among ES that we can find in a specific area and determine their most suitable management method.

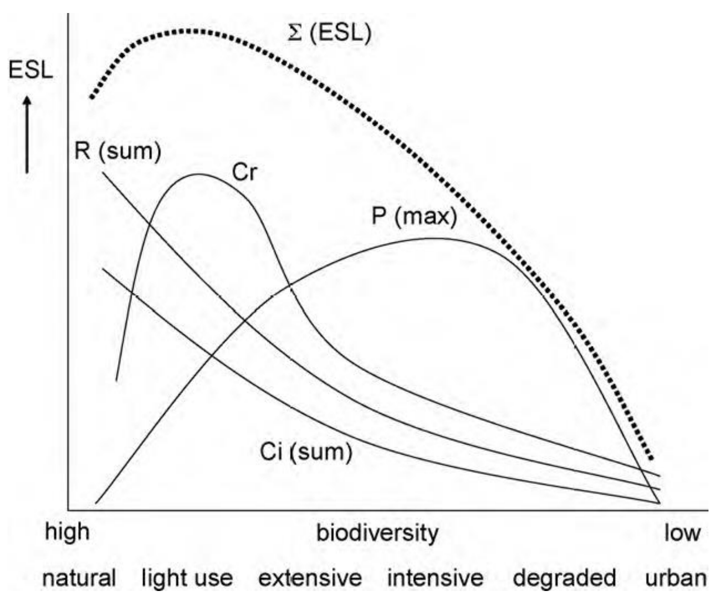

Figure 6 Generalized functional relationships between the levels of ES provision (Y-axis) and the degree of loss of biodiversity related to different LU intensities (X-axis). Adapted from Braat et al. (2008).

Therefore, an important challenge of this research is to investigate the relationship between provisions of the total bundle of ES and analyze the impact of changes in management state on ES and possible positive feedbacks and (critical) thresholds in landscape patterns.

Consequently, this research will take into account as its key concept that local-scale interactions are the main drivers for large-scale pattern formation (Scanlon et al., 2007). It is remarkable that nature has its own self-organization models in order to suggest the existence of characteristic patterns among the several interactions in nature. These models of self-organization suggest that characteristic patterns should exist across a broad range of environmental conditions provided that local interactions do indeed dominate the development of community structure.

The modeling methodology that will applied is the cellular automata model, which consists of a regular grid of cells, each in one of a finite number of states, such as on and off (in contrast to a coupled map lattice). The grid can be in any finite number of dimensions. For each cell, a set of cells called its neighborhood is defined relative to the specified cell. An initial state (time t = 0) is selected by assigning a state for each cell. A new generation is created (advancing t by 1), according to some fixed rule (generally, a mathematical function) that determines the new state of each cell in terms of the current state of the cell and the states of the cells in its neighborhood. Typically, the rule for updating the state of cells is the same for each cell and does not change over time, and is applied to the whole grid simultaneously. The cellular automata model will let us to observe the probability of power-law distributions related to forests, vegetation and landscape patterns that clusters due to the interaction of effects of global-scale resource constraints (for example, water availability) and local-scale facilitation. The interactions could be led to power-law distribution caused by positive local feedbacks or critical thresholds.

The input information required for documenting any suggestion of prevalence of self-organized vegetation patterns across Ecuadorian ecosystems and theirs landscape functions will be detailed and assessed later.

It is important to emphasize that from the assumption of self-organized vegetation patterns identification in the Ecuadorian ecosystems, the temporal analysis (40 year- time period) is expected to detect the ecological and social effects as a result of LU pattern transformation. For the several ecosystems that are going to be analyzed in the Ecuadorian context, their classified lands will be analyzed in 10 km x 10 km grid cell size and for each of the areas the probability distribution will be defined.

Notably, the identification of the mentioned patterns also goes hand in hand with the quantification of spatial bundles that enables geographic representation and analyses of related ES without the double counting that would result if they were treated as unrelated entities. These approaches will help to identify that landscape distribution of ES may correspond to predictable social and ecological subsystems and associated LU types.

Scalon et al., (2007) applied the cellular automata model in Kalahari Transect located in southern Africa. This area is considered number one in a number of worldwide International Geosphere- Biosphere Programme transects that spans a mean annual rainfall gradient from approximately 1,200 to 200mm per year. The results of this case show that the identified positive spatial feedbacks and critical thresholds related to the increases or mortality of tree density, respectively; were highly correlated to water availability in the area. The outcomes led to stable power-law cluster size distributions over a wide range of vegetation densities in Kalahari region.

The results of approaches to visualize landscape function are two-fold. First, relations between service provision and spatial process indicators are identified and quantified and second, the spatial distribution of landscape functions is made explicit. Therefore, we will use the cellular automata model with the purpose to visualize the spatial distribution of landscape functions but considering local and global effects on transition between different states. The application and implementation of lattice-based cellular automata models have permitted the evaluation of patter-formation processes in several nature interactions and at the same time power-law clustering has been observed as result of these complex system dynamics (presented by simple rules of interaction).

4 Proposed Timeline

Task	2014	2015				2016				2017				2018	
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Thesis Proposal	■	■	■												
Define Thesis Objectives	■														
Define Thesis Title		■													
Document Preparation		■	■												
Thesis Proposal Presentation			■												
First Article				■	■	■	■	■							
Formulate research questions				■											
Bibliographic research and definition of a topic				■											
Definition of therotical framework, write review of					■	■									
Methodology definition							■								
Results								■							
Publish article								■							
Second Article								■	■	■	■	■			
Formulate research questions								■							
Bibliographic research and definition of a topic								■							
Definition of therotical framework, write review of									■	■					
Methodology definition											■				
Results												■			
Publish article												■			
Third Article									■	■	■	■	■		
Formulate research questions									■						
Bibliographic research and definition of a topic									■						
Definition of therotical framework, write review of										■	■				
Methodology definition												■			
Results													■		
Publish article													■		
Thesis Defense												■	■	■	■
State of Art												■			
Methodology												■	■		
Results													■		
Conclusions														■	
Presentarion Preparation															■
PhD Thesis Defense															■

Table 6 Timeline Diagram for Thesis Tasks

5 Research Stays

It has been proposed two research stays in Ecuador, during the Ph.D. research plan. These stays have the purpose to gather inputs data and coordinate research collaborations for the development and writing of the planned articles according to the proposed timeline. These stays are scheduled during 2016 and 2017, from November to January, respectively.

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