Challenges to Managing Ecosystems Sustainably for Poverty Alleviation:

Securing Well-Being in the Andes/Amazon

Final Report

May, 2008

Iniciativa Amazónica · WWF · King's College London, University of London · Universidad Nacional de Colombia Sede Palmira · The Nature Conservancy, Protecting nature. Preserving life. · CIAT, An Alliance Center Supported by the CGIAR, Partners in Research Cultivating the Future

ESPA-AA Authors and Contributors

Lead authors and coordination
Roberto Porro[1,2,3]
Jan Börner[1,2,4]
Andy Jarvis[2,5]

Co-authors
Mark Mulligan[6], Silvia Benitez[7], Maria Ximena Barrera Rey[8], Luis German Naranjo[8], Marcela Quintero[2], Ruben-Dario Estrada[2], Jorge Rubiano[9], Sergio Camilo Ortega[8], Stephen A. Vosti[10], Samuel Fujisaka[2], Ana Milena Piñero Quiceno[8], Cesar Suarez[8], Leonardo Saenz Cruz[6], Edwin Keizer[6], Manuel Peralvo[11], Eric Nelson[12], Heather Tallis[12], Guillermo Mendoza[12]

Contributors
Gilberto Schittini, Maren Hohnwald, Silvia-Elena Castano

Correct citation:

ESPA-AA 2008: Challenges to Managing Ecosystems Sustainably for Poverty Alleviation: Securing Well-Being in the Andes/Amazon. Situation Analysis prepared for the ESPA Program. Amazon Initiative Consortium, Belém, Brazil.

[1] Amazon Initiative Consortium, [2] International Center for Tropical Agriculture, [3] World Agroforestry Centre, [4] Centrum für Internationale Migration und Entwickung (Germany), [5] Bioversity International, [6] King's College London (United Kingdom), [7] The Nature Conservancy, [8] World Wildlife Fund For Nature, [9] Universidad Nacional de Colombia (Colombia), [10] University of California at Davis (United States of America), [11] Seearth (Ecuador), [12] Stanford University (United States of America)

Acknowledgements

This report is a product of research and an extensive consultation of stakeholders (researchers, civil society organizations, government and non-governmental organizations) from six countries in the Andes/Amazon region. We sincerely thank all participants of national and regional stakeholder consultations whose names are listed in the respective reports that can be downloaded from our project website www.ecosystemsandpoverty.org. Apart from stakeholder contributions, the final version of this report has greatly benefited from the constructive and extensive comments of Dr. Gretchen Daily (Stanford University, USA), Dr. Susan Poats (Corporación Grupo Randi Randi, Ecuador), and Dr. Donald Sawyer (Universidade de Brasília and Instituto Sociedade, População e Natureza, Brazil). Finally, we would like to thank the institutions that coordinate the ESPA Program for funding this situation analysis and for their valuable contribution to improve preliminary versions of this report.

List of Acronyms

ACTO	Amazon Cooperation Treaty Organization
AECI	Agencia Española de Cooperación Internacional
AI	Amazon Initiative Consortium
ARPA	Program for Protected Areas of the Amazon Region, Brazil
BAU	Business as usual scenario
BOLFOR	Bolivian Sustainable Forest Management Project
CAF	Corporación Andina de Fomento (Andean Development Corporation)
CAN	Andean Community of Nations
CBD	Convention on Biological Diversity
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
CI	Conservation International
CIF	Certificate of Forest Incentive for Reforestation, Colombia
CRES	Compensation and rewards for environmental services
CYTED	Iberoamerican Program on Science and Technology
DFID	Department for International Development, UK
EDA	Extrapolation Domain Analysis
ENSO	El Niño-Southern Oscillation
ES	Ecosystem service
ESPA	Ecosystem Services and Poverty Alleviation Programme
ESPA-AA	Ecosystem Services and Poverty Alleviation Programme, Andes-Amazon
ESRC	Economic and Social Research Council, UK
FAO	Food and Agriculture Organization of the United Nations
FF	Fossil fuel
FONAG	Fund for the Protection of Water, Ecuador
GCM	General Circulation Models
GEF	Global Environment Facility
GIS	Geographic Information System
GTZ	German Agency of Technical Cooperation
HDI	Human Development Index
HEP	Hydroelectric power
IAI	Inter-American Institute for Global Change Research
ICMS-E	Ecological Tax on the Circulation of Goods and Services, Brazil
IDB	Inter-American Development Bank
IICA	Inter-American Institute for Cooperation on Agriculture
IIRSA	Initiative for Integration of Regional Infrastructure in South
IPAM	Instituto de Pesquisa Ambiental da Amazonia
IUCN	International Union for Conservation of Nature
LBA	Large-scale Biosphere-Atmosphere Experiment in Amazonia
MEA	Millennium Ecosystem Assessment
MO	Management option
NERC	Natural Environment Research Council, UK
NGO	Non-governmental organization

NRM	Natural resource management
NTFP	Non-timber forest products
PA	Protected area
PES	Payment for Ecosystem/Environmental Services
PROAMBIENTE	Socio-Environmental Development Program for Smallholder Production
PV	Present value
R&D	Research and development
REDD	Reduced Emissions from Deforestation and Degradation
TCO	Tierra Comunitaria de Origen (Indigenous Communal Land Holding), Bolivia
TNC	The Nature Conservancy
UBN	Unsatisfied basic needs
UN	United Nations
UNAMAZ	Association of Amazonian Universities
UNCCD	United Nations Convention to Combat Desertification
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
WofE	Weights of evidence algorithm
WWF	World Wide Fund for Nature

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Executive Summary

The Ecosystem Services and Poverty Alleviation Program (ESPA) was initiated in 2007 by the Natural Environment Research Council (NERC), the Department for International Development (DFID), and the Economic and Social Research Council (ESRC) of the UK. ESPA is a global program in its initial stages that will promote research and capacity-building to achieve sustainable ecosystem management and increased well-being in developing countries.

This report focuses on the Amazon basin and the eastern Andean slopes (herein referred to as the Andes/Amazon ecosystem or region). The Amazon is the largest fresh water system and tropical forest in the world. Large portions of the region are still covered by relatively intact primary forests that provide substantial locally and globally valuable ecosystem services (ES). Rural population densities in the region are among the lowest in the world. As such, the Andes/Amazon is a contrast to other ESPA target areas that are characterized by scarce and degraded resources used by often overwhelming numbers of the poor. Hence, in the Andes/Amazon, ESPA should focus on promoting resource conservation *before* valuable ES are irreversibly lost due to actions by resource users ranging from poor slash-and-burn farmers to large timber and commodity farming interests. A rationale for this approach is that rebuilding ecosystem services in ecologically degraded areas is generally much more costly than preventing their loss in the first place. As an agricultural colonization frontier, the Amazon has lost some 84 million ha of native forests over the last few decades – a loss accompanied by losses of locally and globally valuable ES.

A "situation analysis" of ES and poverty in the Andes/Amazon was conducted September 2007 - March 2008. Findings are intended to help guide ESPA in terms of research and capacity-building priorities. A macro-scale approach was taken to examine ES, well-being, and management needs. The work was accompanied by an extensive consultation with local, national and regional stakeholders.

The introductory chapter sets out the objectives of the situation analysis, and the approach of the study. It also briefly discusses the relationships among ES and poverty in the context of this situation analysis. The discussion settles on key findings of a recent study that has reviewed the literature on this relationship on a global scale. The situation analysis adopts existing definitions of ES, which are understood to be the "processes and conditions through which ecosystems support human life" or, more generally, the "benefits that people obtain from ecosystems". No single poverty definition is adopted throughout the report. Depending on data availability and analytical approaches it employs different poverty concepts and explores implications if necessary. Stakeholder consultations reinforced the need to adjust standard poverty measures to better capture the ES dimensions of well-being in the Andes/Amazon. Moreover, the concept of poverty itself was challenged in favour of a well-being oriented approach.

The report focuses on key issues: Paramount ES provided by the Andes/Amazon ecosystem to local populations and to the global society, and the main threats and challenges to the provision of these services are identified (Chapter 2). The benefits that local populations derive from using ES are characterized (Chapters 2 and 5). Promising options to manage ES provision in ways that also prevent or help to alleviate poverty are identified and characterized (Chapters 3 and 4). Key results of stakeholder consultations and related priorities for research and capacity building are summarized in Chapter 5. Chapter 6 summarizes the key messages of all chapters and proposes three core areas to be addressed by research and capacity-building in the ESPA program. Prototype research projects and promising impact pathways are proposed.

Chapter 2 provides a spatial assessment of ES and poverty in the Andes/Amazon. The literature review and the stakeholder consultation allowed for the identification of the most important ES.

However, not all ES could be quantified and assessed spatially due to data limitations. Attempts to quantify services included direct measures or measures of the natural resource base for any particular service provision. Services examined were water quantity and quality, local climate regulation, carbon as an indicator for global climate regulation services, soil related services, and a set of services associated with terrestrial and aquatic biodiversity. The spatial assessment confirms that rural inhabitants are most vulnerable to changes in ES provision. Particularly traditional and indigenous populations have developed strong dependencies on locally abundant ES and goods. Hence, relative resource abundance does not mean low vulnerability. Especially, ES that are subject to natural variability and human pressures (e.g. water flow and quality, local climate, forest products) introduce an important source of uncertainty even into relatively well adapted livelihood strategies. A key contribution of Chapter 2 is to illustrate some of the spatial and long-term temporal dimensions of ES provision, which may help to better target future ESPA program activities.

Chapter 3 reviews the diverse options available to manage ES and their potential effects on the poor. Management options (MO) are classed as enabling (e.g., technologies, property rights, environmental education, public-private partnerships, credit, and insurance), incentives (e.g., payments for environmental services, subsidies, inputs, and certification or eco-labeling), and disincentives (e.g., taxes, regulations, fines, and imprisonment). It becomes clear that the MO of choice in the past have been disincentive-based. In large and sparsely populated areas, where few actors can have large impacts, the need to constantly enforce disincentive MO may make them less cost-effective than incentive-based MO. Research is needed to support the current trend in favour of such MO to determine where and under what conditions they represent true alternatives. Options to manage ES should not be understood as substitutes for social policies and basic public services. The lack of the latter is often the root cause of poverty in the Andes/Amazon. What is needed is a better understanding of how to combine enabling and incentive MO for ES management in order to allow for the poor to capture benefits.

Chapter 4 reviews factors underlying successful programmes and projects that have implemented management options in the Andes/Amazon. Lessons learned are discussed. Reviewed projects dealt with conservation and recuperation of ES and ecosystems; impacts on well-being; and innovative approaches. Project impacts are discussed in terms of economic benefits, reversal of environmental degradation or ES conservation, local added value, redistribution of benefits, empowerment of communities, and potential of resources' transfer from wealthier to poorer sectors. Again, incentive-based MO, such as certification and incentives from ecotourism, seem to have more potential to benefit the poor. Pilot experiences need to be replicated and scaled out.

Chapter 5 summarizes the main outcomes of the stakeholder consultation and discusses environmental policy approaches in the Andes/Amazon. Recommendations include: better definition, assessment, and valuation of ES; assessment of contributions of ES to well-being; development of management options that contribute to well-being; development and support of pilot studies; and improving capacities of institutions dealing with ES and poverty alleviation.

Chapter 6 recommends three core areas to be included in the ESPA Program agenda for the Andes/Amazon. The first area involves primarily biophysical, the second interdisciplinary, and the third primarily socio-economic and policy research:

1. Understanding and predicting spatial and temporal dynamics of key locally and globally valued ES (especially, forest products and fish resources, local and regional climate regulation, water quality/quantity, and carbon sequestration) with a special focus on:

    a. Integrating traditional spatial scales of study (individual sites) to policy relevant regional scales such as the one addressed in this situation analysis. Also taking into account the important implications of geographic and environmental differences throughout the region on the development of *locally adaptive and effective* regional policies. Recognizing the impact of trans-frontier and trans-continental linkages especially for climate and water.

   b. Identifying critical thresholds of change in the provision of ES due to human impacts (such as deforestation), climate change, and their interaction, and devising monitoring, prevention, adaptation, and mitigation measures to ensure that significant thresholds that would lead to increased poverty and vulnerability are not crossed through ecosystem mismanagement.

   c. Developing and disseminating practical methods to monitor and document local changes in ES provision and spatial-temporal management support systems to identify the agents and processes driving such changes, as well as testing *in silico* preventative policy measures.

2. Understanding, measuring and valuing the contribution of locally important ES to generate well-being among heterogeneous local stakeholder groups, with a special focus on:

   a. Developing and testing comparative frameworks to integrate ES-related welfare into region-wide index-based poverty measures.

   b. Identifying and mapping location and stakeholder specific vulnerability, based on indicators of the state of ES provision, and threats' assessment.

   c. Developing and disseminating methods and tools to forecast natural and policy-induced changes in ES provision and their likely impacts for local well-being, as well as to predict the effect of alternative management options to mitigate such impacts.

   d. Establish and institutionalize a regional knowledge management platform on ES and well-being to support prioritization of local and regional policy initiatives through interdisciplinary research for development outputs.

3. Promote innovative approaches to reduce the transaction costs and strengthen the incipient implementation of incentive based management options for enhanced ES provision (e.g. certification/ecolabelling, payments for environmental services, ecotourism; as well as other novel MO) and conduct comparative research to extract lessons learned with a special focus on:

   a. Globally and locally valued ES which are affected by externalities of local income generating activities.

   b. How, where and for whom incentive-based management options need to be combined with enabling management options in order to maximize benefits for the poor.

   c. Developing and disseminating decision-frame works and related tools for policy makers to decide where and under what conditions incentive-based management options will work and what can be done if minimum conditions are not in place.

Chapter 6 ends with a series of prototype projects to address key research questions in each of these areas, suggests promising impact pathways and capacity-building components.

1. Introduction

In 2007, the Ecosystem Services and Poverty Alleviation Programme (ESPA)[1] was launched by the Natural Environment Research Council (NERC), the Department for International Development (DFID), and the Economic and Social Research Council (ESRC) of the British Government. Still in its planning phase, ESPA is a global programme that intents to promote research and capacity-building to achieve sustainable ecosystem management and well-being in developing countries.

We might first ask why the Andes/Amazon ecosystems should be among the priorities of such a program. The Andes/Amazon region, defined here as the Amazon biome and the Eastern Andes slopes representing the Amazon basin catchment zones (Figure 1.1), is in many ways different from the regions and contexts studied by the other ESPA situation analyses (e.g., China, India/Hindu Kush/Himalaya, rural/urban interactions, semiarid sub-Saharan Africa, marine and coastal regions).

First, large parts of the region are still covered by relatively intact primary forests, thus providing ecosystem services much closer to natural ecosystem capacity than in most of the other ESPA pilot regions. Second, rural population densities are among the lowest in the world, and although income-based poverty prevails, rural dwellers are arguably not affected by such levels of resource scarcity as, for example, their sub-Saharan counterparts. As a consequence, more international attention has been paid to alleviating poverty and rebuilding ecosystem services in resource poor and overpopulated regions. Yet, are natural resource (and, hence, ecosystem service) scarcity in combination with high levels and density of poverty the only necessary conditions for research and capacity-building interventions? There are three reasons for answering no:

1. Continuous resource degradation and constant levels of poverty in large parts of the rural tropical world indicate that a common believe regarding rural development can be misleading. There is little reason to expect that temporarily compromising natural resources eventually leads to higher levels of rural well-being, which, in turn, stimulates increasing resource conservation *before* valuable ecosystem services are irreversibly lost.

2. Rebuilding ecosystem services in ecologically degraded areas is arguably much more costly than preventing their loss in the first place. Moreover, the rural poor often loose out in attempts to rebuild ecosystem services through conventional policy instruments.

3. The Amazon region is probably the youngest among the remaining large human colonization frontiers. As a consequence, modern technologies have contributed to its expansion at rates historically without precedence, i.e. over the last few decades, 84 million ha of natural ecosystems have been lost (Malhi et al. 2008) As an overwhelming amount of research has shown in the past three decades, this expansion is associated with losses of regionally and globally valuable ecosystem services. As such, the Amazon clearly contrasts with resource poor – high population ESPA areas in that even relatively few and poor settlers can exert considerable and increasing pressure on natural resources. That said, ecosystem service loss in the Amazon region is also driven by large-scale commercial interests that compromise livelihoods of low-income and traditional rural populations.

These three arguments and the evidence presented in this report make a clear case in favour of a prevention-oriented research and capacity-building intervention to support integrated and sustainable management options for the Andes/Amazon ecosystems with the stated objective of

[1] www.nerc.ac.uk/research/programmes/espa/

maintaining ecosystem service provision and prevent aspects of poverty associated with their loss.

Indeed, negative effects of land use change in the Andes/Amazon are related to convoluted political processes, clearly expressed in Amazonian socioeconomic contexts. The Amazon is home to some 380 ethnic groups that have been drastically affected by frontier expansion and biodiversity loss resulting from land use transformations. Likewise, riverine, peasant and other traditional rural populations throughout the region rely on food, fibre, fodder, fuel, and medicinal plants locally extracted. Both transitions and clashes occur between indigenous production systems and market-driven systems, jeopardizing the existence of several of these groups. Skyrocketing land prices and concentration of wealth and land ownership further exacerbate this situation, increasing rural-urban migration and augmenting social stress in the region's urban and peri-urban areas. Moreover, the regions' unique socio-cultural setting and the diverse forms in which local livelihoods depend on its ecosystem services (in both sustainable and unsustainable ways), makes it a particular valuable case for examining the nexus between ecosystem services and poverty alleviation.

Figure 1.1 The study region as defined by the Amazonian biome and the contributing catchment in the eastern slopes of the Andes

This report presents the results of a situation analysis of ecosystem services and poverty in the Amazon and Eastern Andes, carried out between September 2007 and March 2008. It intends to provide guidance to the ESPA program as regards the definition of research and capacity-building priorities for the Andes/Amazon. As such, the report necessarily takes a macro-scale approach to examine the state of knowledge on ecosystem services, well-being and related management needs in the region. To reduce the inherent caveats of such an approach, the situation analysis was embedded in an extensive stakeholder consultation process, in which local, national and regional stakeholders contributed to improving and validating its outcomes.

In the remainder of this introductory chapter we lay out our general understanding of the relationship between ecosystem services and poverty, the specific objectives of the situation analysis and the methodological approaches taken.

1.1. Ecosystem services and poverty in the Andes/Amazon

"Ecosystem service" has become a widely used term in both the scientific literature and policy debates. According to the Millennium Ecosystem Assessment (MEA 2005), ecosystem services are the "benefits that people obtain from ecosystems". Another definition separates ecosystem services, "the processes and conditions through which ecosystems support human life", from ecosystem goods, i.e. products provided by ecosystems that generate benefits through consumption (Daily 1997).

Thinking of the benefits nature provides in terms of goods and services suggests an analogy with economic goods and services. This analogy helps to better understand the complex relationship between human well-being and the environment by breaking down the environment - well-being relationship into manageable pieces. One of the best-known, although heavily contested, global environmental valuation studies employed the ecosystem service concept to provide a first rough estimate of the value of the benefits that nature provides to human beings (Constanza et al. 1997). The study contended that tropical rainforests such as the Amazon provide high value services such as climate regulation, nutrient cycling, erosion control, waste treatment, food and raw material production, genetic resources, and recreation. Research has estimated that the amount of carbon retained in the Amazon corresponds to 1.5 decades of anthropogenic greenhouse gas emissions (Soares-Filho 2006); and that the Amazon and eastern Andes slopes together represent the world's largest continuous area of global biodiversity priorities (Turner et al. 2007). The Amazon Basin supported by its Andean catchment zones form the largest freshwater system in the world (Muller-Karger et al. 1988) with benefits in terms of, among others, local livelihoods, transport, and electricity generation.

Given that both the provision of some types of ecosystem services and the way in which humans benefit from them are complex and not well understood, the MEA developed a qualitative conceptual framework linking categories, such as provisioning and regulating services to components of well-being, e.g. health, security, and autonomy. This qualitative conceptual framework helped to identify those dimensions of the nature - well-being relationship that are particularly hard to quantify and have therefore received less attention by both environmental regulatory policies and by the research that supports such policy formulation.

Although human well-being - environment relationships are widely recognized, the extent to which poverty is both consequence and cause of reduced ecosystem service provision remains subject to debate (Gray and Moseley 2005; Ravnborg 2003). Much of this debate relates to what actually constitutes poverty or well-being. In a component of a recent global scoping study on compensation and rewards for environmental services (CRES), Iftikhar et al. (2007) reviewed a variety of poverty concepts in terms of how they may be linked to environmental dimensions. As they point out, conventional poverty measures, such as the poverty-line and the dollar-a-day concepts, fail to incorporate non-market goods and services as well as non-material dimensions of poverty (e.g. vulnerability to shocks). This limits the usefulness of these poverty measures to analyse well-being – environment relationships. Both Vosti and Reardon (1997) and DFID's (1999) livelihood framework highlight asset-based poverty measures, which has helped to name and measure the contributions of ecosystems to human well-being. The CRES scoping study indicates that such broader poverty concepts also tend to emerge from self-assessment of poverty (Iftikhar et al. 2007). This notion could be confirmed in various national stakeholder consultations, especially with traditional populations in Brazil, which highlighted other than income-based dimensions of well-being. In these meetings it was not always possible to reach a consensus on what ultimately constitutes poverty in the Andes/Amazon context.

The bottom line of the debate on poverty, or lack of well-being, is that these concepts are both multidimensional and context specific. Some of the stakeholders consulted for this situation analysis even suggested that well-being may be, to some extent, a subjective experience. Although income-based measures such as one-dollar-per-day or poverty-line approaches may capture a fair range of dimensions, they often fail to capture differences between the poor in natural resource-abundant areas vs. their counterparts in resource-scarce areas. The United Nations Development Programme (UNDP) map of the Human Development Index (HDI)[2] in Brazil reveals that even a more comprehensive measure of well-being does not capture distinctions thought to be important by stakeholders, e.g., between tropical forest areas in the western Amazon and semi-arid savannas in north-eastern Brazilian areas. In these cases, poor health conditions, low levels of education, and limited access to other basic services clearly contribute to the incidence of poverty. Yet, humans adapt to ecosystem conditions and changes in them (e.g. through climate change, infrastructure development, or expansion of commercial agriculture) may have completely different implications for well-being in the different contexts.

First, livelihoods in tropical rainforests are possibly more dependent on (and thus more vulnerable to changes in) what nature provides at relatively low cost than those in the higher Andes. Second, abundance of a given ecosystem good or service (e.g., rapid regrowth of fallow vegetation after slash-and-burn agriculture in forest ecosystems) may be seen as a benefit by a native community; but as a cost factor by immigrants interested in extensive cattle production. Third, depending on socio-cultural background as well as economic and political settings, a given group of natural resource users may use and modify ecosystem service provision in ways that prevent other groups from reaping its benefits. Fourth, although changes in the provision of some ecosystem services may take place quickly, adaptation generally takes time and may require policy action.

Hence, understanding environment-poverty relationships requires knowledge about the spatial and temporal dimensions of ecosystem service supply and use, and the specific contexts in which benefits are derived. As a consequence, it may be that no globally comparable measure can meaningfully reflect the share that ecosystem services hold in the portfolio of factors that makeup human well-being at local scales.

Nonetheless, faced with the task of providing a regional scale overview of the situation of ecosystem services and poverty in the Andes/Amazon, we also have to rely on sources of information with consistent regional coverage. Hence, some analyses presented below employ standard poverty measures such as the dollar-a-day approach to identify and locate the incidence of low-income groups, but without necessarily proposing a causal relationship between low-income poverty and ecosystem service provision. That said, empirical evidence across the world does show that environmental degradation and consequent losses to ecosystem service provision are likely to affect low-income populations the most and thereby increase poverty because:

First, low-income households generally have little or no access to substitutes for basic goods and services they receive from particular natural resources (e.g. clean water, soil quality, forest products). And second, they also typically do not have a choice between alternative technologies

[2] The HDI is a compound indicator based on income, education and life expectancy

(for improved provision or use efficiency) to offset the impact of deterioration of service provision.

A comprehensive answer with respect to which of the two reasons applies in specific contexts and to what extent this may lead to poverty is beyond the scope of this report. Nonetheless, based on a careful selection of case studies, an extensive literature review, and consultation with local stakeholders we intend to shed some light on how ecosystem services and their conservation could contribute to both preventing and alleviating poverty in the Andes/Amazon region. On this basis we define the general and specific objectives of this report in the following section.

1.2. Objectives and approach of the situation analysis

The ultimate objective of this situation analysis is to define a series of priorities for research and capacity-building to be addressed by follow-up activities in the implementation phase of the ESPA program. As such, it has to identify knowledge and capacity needs that, if properly addressed, can contribute to preventing and alleviating poverty through the maintenance of ecosystem services provision in the Andes/Amazon region. To achieve this principal objective, we defined a series of milestones to be addressed by different components of the analysis (see Figure 1.2 below):

1. Identification of the key ecosystem services provided by the Andes/Amazon ecosystem to local populations and to the global society (Chapter 2 of this report)
2. Identification of the main threats and challenges to these ecosystems and their provision of services (Chapter 2 of this report).
3. Characterization of the benefits that local populations derive from using these ecosystem services (Chapters 2 and 5 of this report).
4. Identification and characterization of promising options to manage ecosystem service provision in ways that could contribute to the prevention and alleviation of poverty in different contexts (Chapters 3 and 4 of this report).
5. Participation of local and regional stakeholders in achieving objectives 1 through 4, and defining research and capacity-building priorities related to implementing sustainable ecosystem service management options with benefits for the poor.

Figure 1.2 shows how the five components are embedded in continuous stakeholder engagement.

Five operational components of the study were defined: a spatial analysis of ecosystem services and poverty in the Andes/Amazon region (C1), a literature based analysis of options to manage ecosystem services and their impact on poverty (C2), an analysis of selected case studies of projects and programs to manage ecosystem services to alleviate poverty (C3), a review of research and capacity-building needs linked to all other components (C4), and (C5) a systematic process of stakeholder engagement feeding into all components throughout the project (yellow and orange areas in Figure 1.2).

The macro-scale spatial analysis of ecosystem services and their linkages with poverty is a key component of this situation analysis. Maps and models of ecosystem service stocks and flows are used to describe spatial and temporal characteristics of ecosystem services for which regional data are available. Component 1 integrates secondary data and spatial models of ecosystem service flows to assess some of the main drivers of ecosystem services loss, such as deforestation and climate change. Where possible, ecosystem service provision is overlaid with poverty and other socioeconomic indicators, which helps to characterize interactions between the two.

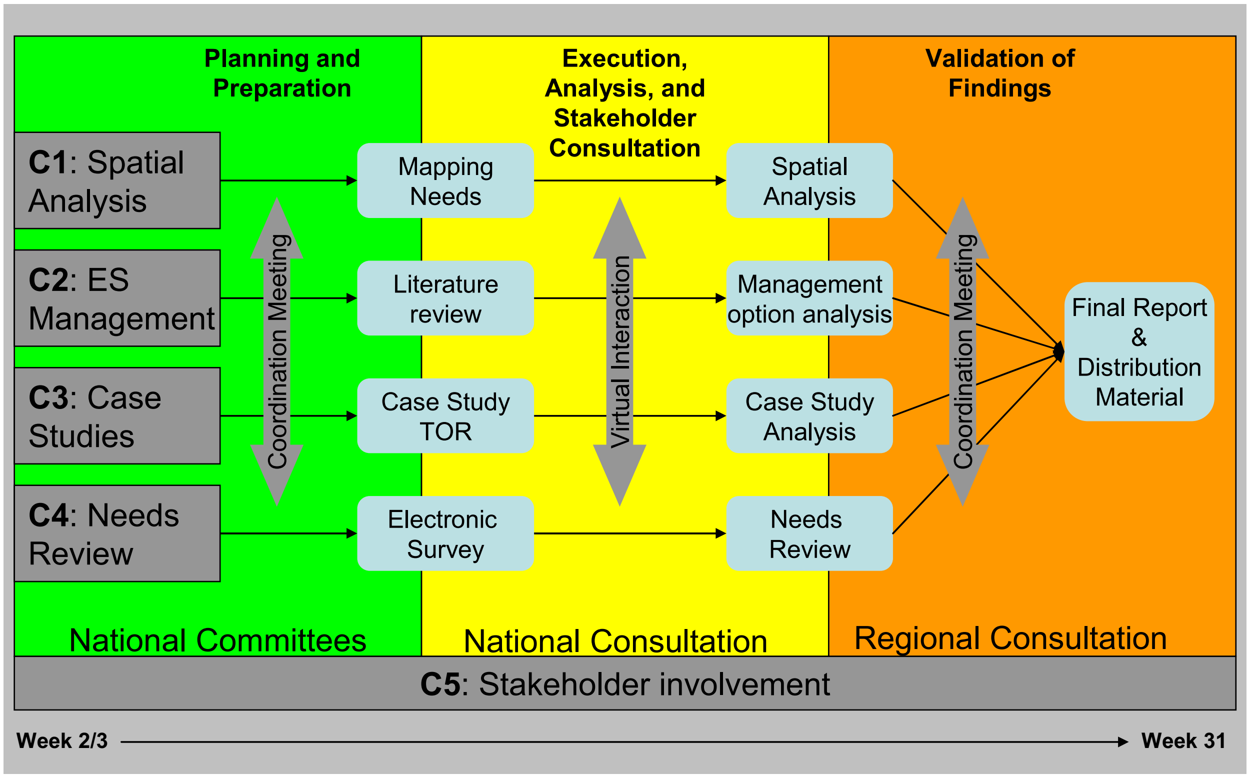


Figure 1.2 Components of the situation analysis and their linkages

Based on a review of regional and international literature, Component 2 identifies and characterizes existing and promising options to manage ecosystem service provision and their implications for poverty prevention and alleviation. Key characteristics of ecosystem services and how they are modified and/or benefits are derived from them are identified. A set of criteria to make informed choices among ecosystem service management options is proposed; and, on the basis of this, future research and capacity-building needs are proposed.

Component 3--which builds on Component 2--looks at how some of these management options actually perform in different contexts in the Andes/Amazon region. Cases from the Andes/Amazon region are reviewed in which programs or projects have addressed environmental problems in different ways and with varying success, while simultaneously attempting to improve human welfare. A more comprehensive set of evaluation criteria using environmental and welfare indicators was developed to help assess the performance of management options and related implementation strategies.

Component 4 draws on the other components, contributions from local and regional stakeholders, and a review of environmental policies of the six major Andes/Amazon countries. This component was designed to extract, from all project components, key elements of a potential research and capacity-building agenda for the ESPA program.

The involvement of local and regional stakeholders throughout project execution was coordinated through Component 5 in three different stages. After a project preparation phase, key stakeholder organizations such as government and research institutions, civil society organizations, and NGOs were contacted in Brazil, Bolivia, Peru, Ecuador, Colombia, and Venezuela. This first contact involved presentation of the ESPA program and identification of key contact persons. These key collaborators were invited to participate in national stakeholder consultation workshops to identify the most relevant ecosystem services in each country and how these services are related to the well-being of local populations. Participants also identified research and capacity building priorities for more effective ecosystem service management with positive welfare effects. Hence, this component is complementary in that it was designed to discover those ecosystem services, and their well-being implications, that Component 1 cannot cover due to data limitations.

With preliminary results available from all components, two regional stakeholder workshops were organized in the Andes and the Amazon region. Workshop participants evaluated preliminary results in order to then define key research and capacity needs at regional and local levels. Outcomes of the regional stakeholder workshops were analyzed in Component 4 and integrated into the proposed research and capacity-building agenda.

1.3. Concepts and Definitions

We developed a simple conceptual framework for this situation analysis based on Swallow et al. (2007) and the Millennium Ecosystem Assessment (Figure 1.3).

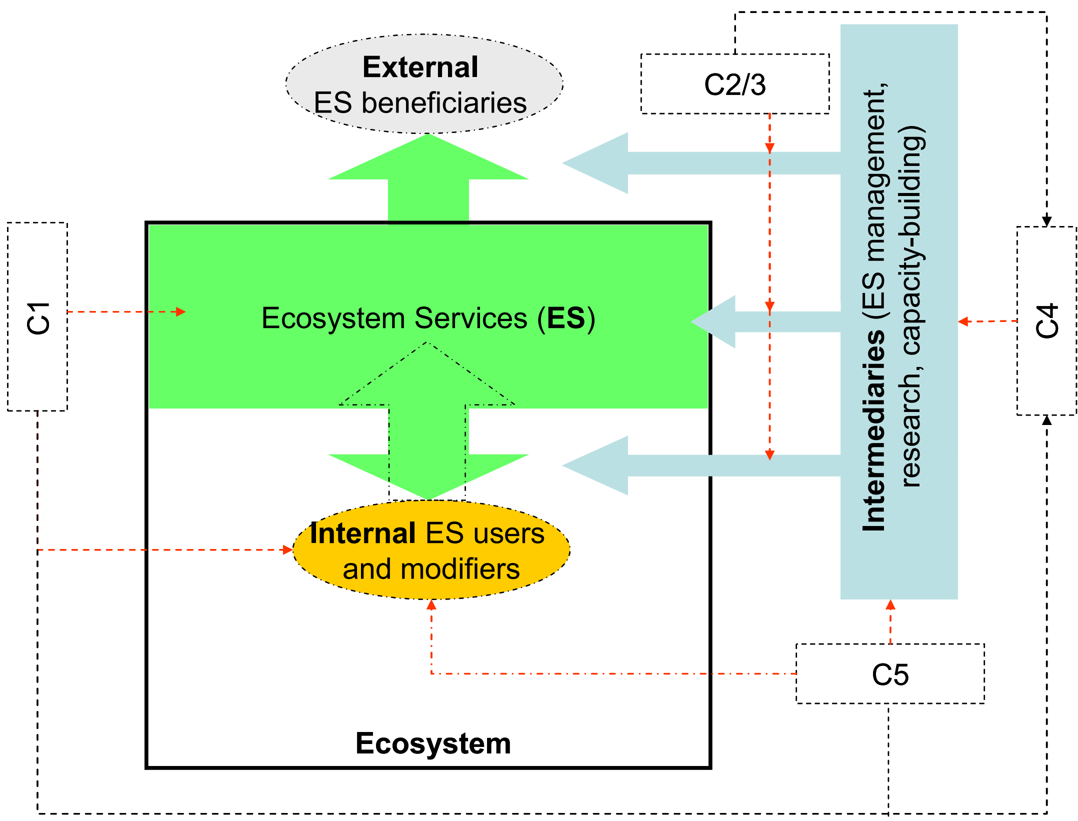


Figure 1.3 Conceptual framework of ecosystem services and stakeholders

According to Figure 1.3, a given ecosystem provides services (ES) to users and modifiers inside the ecosystem and to external ES users (e.g., global society). The conditions of ES use, access, and human driven modification are influenced by intermediaries (i.e., policy makers, local user groups, civil society organizations, and research, education and training organizations).

Dotted lines in Figure 1.3 illustrate how the components of our analysis examine and describe this system and help to derive recommendations for the ESPA program. Component 1 analyses ES and the conditions of ES use and modification inside the ecosystem. Components 2 and 3 assess how intermediaries, ES modifiers and users can influence the performance of the system though management interventions. Component 5 interacts with ES users, modifiers, and intermediaries and, together with previous components, feeds results into Component 4, the definition of research and capacity-building priorities.

We adopt the most inclusive of definitions of ecosystems services set out at the beginning of this introduction, i.e. the benefits that people obtain from ecosystems (MEA 2005). This is because a comprehensive analysis of ES and poverty needs to account for all potentially relevant contributions of the environment to human well-being regardless of whether these are in the form of goods or services. Nonetheless, we show, for example, in Chapters 3 and 4 of this report that more restrictive definitions of ES eventually need to be adopted to evaluate ES management options or analyze specific aspects of the environment-well-being relationship.

It was not possible to adopt a single concept or definition of poverty that equally satisfied the different analytical approaches and stakeholder perceptions. Stakeholders challenged the use of the term “poverty” in the context of the Andes/Amazon region--a region in which many traditional and native communities deemed poor by most standard poverty measures actually do not consider themselves poor.

In an attempt to align stakeholder perceptions with the needs of analytical approaches, poverty could be defined as “unacceptable conditions of well-being”, where “acceptability” refers to the subjective dimension of poverty and “conditions” comprise more objective dimensions such as the lack of access to basic public services and natural resources, income and asset endowment, education, and health among others. In this report, some of these measurable dimensions of poverty are used to characterize well-being of ES users and modifiers in spatially explicit ways. Other more complex concepts of poverty, such as “conservation investment poverty” are introduced--albeit not measured--as useful tools in the evaluation of management intervention options.

Finally, ecosystem services can be managed in several ways with and without the involvement of public policy. All potentially involved stakeholders--e.g., governmental, non-governmental, and civil society organizations and local communities--can and should benefit from research and capacity-building to improve ecosystem service management and well-being. To account for all potentially relevant approaches to ecosystem service management, we introduce the term “management option”. As opposed to frequently used terms such as policy instruments or interventions, management options (MO) comprise the whole range of alternatives through which stakeholders can engage in the management of linkages between well-being and the environment--i.e., from community-based management approaches to government induced market interventions or command-and-control policies.

1.4. Structure of the report

The report is structured as follows. Chapter 2 provides a spatial assessment of ecosystem services and poverty in the Andes/Amazon region. Data availability at the regional level constrained the services included in the spatial analysis. Considering the above assumption, we focused on the types of services that are deemed most relevant at local and global level by both the reviewed literature and the stakeholders consulted throughout the consultation process.

We start off with the analysis of water quantity and quality, followed by local climate regulation services and carbon as an indicator for global climate regulation services. Next come soil related services and a set of ecosystem services that we group under services related to ecosystem functioning, such as those associated with terrestrial and aquatic biodiversity, e.g. fish and forest products. Note that, whenever services could not be measured directly, the natural resource basis for service provision was analysed as an indicator for service provision.

Following the spatial assessment, Chapter 3 critically reviews the diverse options available to manage ecosystem services and their potential effects on the poor based on a literature review. Chapter 4 puts this into practice by presenting a systematic review of the success factors of programmes and projects that have implemented selected management options in the Andes/Amazon region. Lessons learned are extracted.

Chapter 5 summarizes the main outcomes of the stakeholder consultation process and a review of the environmental policy settings in the Andes/Amazon countries in order to develop an agenda for research and capacity-building interventions in the ESPA programme.

At the end of each chapter key research questions are extracted that are summarized together with the main messages of this report in Chapter 6.

2. Spatial assessment of ecosystem services and poverty in the Andes/Amazon

2.1. *Approach of the spatial assessment*

To provide a baseline analysis of the distribution of ecosystem services in the study region, our pragmatic approach has depended on data quality and availability. The aim was to: (1) quantify environmental service provision under current conditions, (2) examine impacts of scenarios for change and management options (climate and land use impacts) to understand how the provision of services may change, and (3) identify potential impacts of these changes on the region's capacity to meet human needs for ecosystem services.

Ecosystem services selected for inclusion in the spatial assessment were:

- Provision of water quality and quantity
- Climate Regulation
- Sequestration and storage of carbon and biomass
- Provision of forest products and other terrestrial biodiversity products
- Commercial fisheries production
- Other aquatic biodiversity products
- Conservation of plant genetic resources for food and agriculture

These services do not represent all possible ecosystem services, but do represent some of the most important to the poor and potentially affected by ecosystem (mis)management. They were also selected on the basis of data availability for spatial mapping of provision, consumption, and threat. The first two services are critical services to agricultural production, hydroelectric power (HEP) generation, transport and human health in the region. Carbon and biomass are critical global services with the potential to open up new sustainable livelihoods for poor landowners, based on payments for environmental services (PES) with markets nationally and globally. The following four biodiversity related services are critical to diet (in particular the provision of protein through fisheries) and climate-change stable agriculture through the use of plant genetic resources. The relative importance of these services varies across the region with the provision of the services but also between social groups according to the need for services. Terrestrial biodiversity and forest products for example (including bush meat) are much more significant services to indigenous communities than to urban dwellers, whilst the provision of high quality and reliable water resources are more critical to urban dwellers dependent on potable supplies and HEP generation. There are other services that are also important to the poor but these are ones with such limited data that a spatial assessment was not possible, hence these are discussed further in subsequent chapters. We also map the distribution of poverty and population in order to characterise the study region for comparison with the assessment of individual ecosystem services.

We use an evidence based approach bringing together the best available datasets for analysis at the continental scale. Where analysis needs to be informed by our current understanding of processes we combine the spatial data with process based models capable of simulating the behaviour of aspects of the system. Most scientific endeavour is some form of modelling: theories are conceptual models of the real world; data are empirical models of the real world. Mathematical models are no different: when they are used properly they are a formalization of scientific reasoning and assumptions in an experimental/exploratory form with no room for ambiguity and less room for bias and obfuscation than the traditional analytical approach. Where our work relies on a single model scenario, we use a sensitivity approach to understand the range of potential responses in the face of the uncertainty. Robust spatial modelling and remote sensing is important for the region-wide assessment of environmental services and for the development of better policy to use ecosystem management for poverty alleviation. Although an in-depth understanding of processes related to ecosystem services and well-being can only be achieved through case studies, modelling is the only tool in the scientists' toolbox that can deliver region-wide assessment in an open and transparent way and in a way that can be more scientifically robust than taking the outcomes from a limited number of case studies and assuming they hold for the entire Andes and Amazon. Whilst characterisation of this kind at the Amazon scale is a significant challenge, it has been engaged with here on the one hand to provide the regional focus required for the review and secondly to highlight the significant gaps and questions which remain as one moves from plot scale studies to studies at policy relevant scales. The accuracy of this situation analysis is strengthened by combining and comparing spatial modelling results with the analysis of case-studies (Chapter 4), as well as validating it through a broad stakeholders' consultation (Chapter 5).

These analyses are not intended to be definitive statements on the total services provided, rather they are a situation analysis of our knowledge of these services and the gaps in that knowledge: for example we have not accounted for greenhouse gases other than carbon in our analysis of services relating to global atmospheric chemistry related services. We have done this not because methane for example is unimportant but rather because the data for spatial assessment of methane is not available to us as it is for carbon and we thus conclude that further data are required by ESPA or other programmes before a more realistic assessment can be made.

2.2. Population and poverty in the study region

Population: The study region covers almost ten million km^2, of which 92% is a part of the Amazon biome. Population was 44 million in 2000, and on average has grown over 250% since 1960 (Table 2.1). Most rapid growth has been in Colombia, French Guiana, and Venezuela, although collectively these countries represent only 8% of total population. Nearly half of the Amazon population in 2000 is found in Brazil, where the population has grown at a fairly steady 30-50% per decade since 1970. According to the data, most growth has occurred in rural areas (300-350% from 1960-2000), although this is more likely an artefact of the scale of analysis rather than a true demographic (Table 2.2). Nearly 50% of population is concentrated in moist forest ecosystems, although *várzea* (seasonally flooded forest) ecosystems and savannah are undergoing high growth rates in recent decades (Table 2.3). Detailed tables on population distribution in the study region are available in Annex 1.

Table 2.1 Population 1960 – 2000 in the study region grouped by country based on the GRUMP gridded population of the world from CIESIN (http://sedac.ciesin.columbia.edu/gpw/)

	1960	*1970*	*1980*	*1990*	*2000*	*% Growth*
Bolivia	2,254,239	2,938,516	3,791,760	5,044,365	6,551,865	291
Brazil	5,914,232	6,431,362	10,022,472	14,482,984	18,841,137	319
Colombia	250,239	485,528	683,064	1,024,494	1,429,488	571
Ecuador	1,560,097	1,441,982	1,802,324	2,329,175	2,710,316	174
French Guiana	29,349	48,398	69,456	124,368	175,263	597
Guyana	646,148	800,848	853,792	825,818	841,015	130
Peru	3,826,553	5,225,969	6,987,118	8,901,382	10,933,121	286
Surinam	295,402	380,598	636,894	419,752	459,059	155
Venezuela	423,571	436,232	884,844	1,388,211	1,750,050	413
Total	***15,199,830***	***18,189,433***	***25,458,724***	***34,.540,549***	***43,691,314***	***287***

Table 2.2 Population in urban areas, indigenous lands and other rural areas

	1960	*1970*	*1980*	*1990*	*2000*	% Growth
Urban	3,839,136	4,393,730	5,881,405	7,887,020	10,026,922	261
Rural colonizer	10,830,045	13,210,869	18,633,130	25,252,923	31,802,582	294
Indigenous	530,649	584,834	944,189	1,400,606	1,861,810	351
Total	***15,199,830***	***18,189,433***	***25,458,724***	***34,.540,549***	***43,691,314***	***287***

Table 2.3 Population in different major ecosystems across the study region

	1960	*1970*	*1980*	*1990*	*2000*	*% Growth*
Dry forest	1,756,206	2,319,276	3,128,718	4,321,858	5,738,405	327
Guayanan ecosystems	12,289	10,795	55,767	83,838	122,138	994
Mangroves	228,220	269,402	308,142	403,177	475,858	209
Moist forest	5,616,624	6,148,737	9,310,246	13,206,691	17,391,081	310
Montane Forest	2,789,888	3,533,346	4,674,768	5,862,553	7,039,474	252
Montane Grasslands	2,538,852	2,961,243	3,599,053	4,343,382	4,997,123	197
Savanna	1,511,421	2,068,081	3,094,377	4,450,590	5,478,176	362
Swamp Forest	122,041	156,944	150,307	169,103	181,705	149
Várzea	624,289	721,609	1,137,346	1,699,357	2,267,384	363
Total	***15,199,830***	***18,189,433***	***25,458,724***	***34540,549***	***43,691,314***	***287***

Poverty: Measures of poverty such as per capita income, unsatisfied basic needs, human development index, and others are commonly used by development agencies. Stakeholders during the consultation process often pointed out that these measures of poverty say little about the conditions in which people are living, especially in the Amazon, and that any real measure in the Andes and Amazon must consider the quality of life. There is a growing field that attempts to capture more subjective measures of poverty akin to quality of life, such as life satisfaction (Abdallah et al. 2008) and happiness (NEF 2006). An astonishing 4,300 articles have been published on these topics, although adoption of such ideas in the broader development community has been slow. Future ESPA projects should contextualise poverty beyond the classic socio-economic indicators and take an approach that includes concepts of quality of life and life satisfaction, and preferably include measures of natural capital in examining the link between ecosystem services and poverty.

Despite the stakeholder preference for a quality of life focus in the poverty analysis, the data to do this is simply not available across broad regions of the study area. Consistent sub-national level census data for the period 1993-2003 was available for 5 countries (Brazil, Bolivia, Colombia, Ecuador and Peru) and used in this assessment. We used two poverty indicators--unsatisfied basic needs (UBN--expressed as a percentage of population lacking one basic need) and infant mortality (number per 1000 population). Whilst data on the Human Development Index exists for Brazil at the municipality level, this was not available for other countries.

The poverty maps are shown in Figure 2.1, and summary tables are provided for each country (Table 2.4), for each major ecosystem (Table 2.5) and for each community type (Table 2.6). For both indices, Bolivia is highlighted as the poverty hotspot in the region with 56% of the population in the study region suffering from a lack of at least one basic need and infant mortality at 61 per 1000. Inequality in Brazil is reflected in the data for the study region, with a significant coefficient of variation in both unsatisfied basic needs and infant mortality within the country (53% and 34% respectively). Percentage population with unsatisfied basic needs in the Brazilian Amazon appears to be concentrated in the western Amazon and areas surrounding Belém, although it is important to note that there is little correlation between UBN and infant mortality across all areas. Both poverty measures appear to be fairly evenly spread across different ecosystems, although dry forests and montane grasslands have marginally higher levels of unsatisfied basic needs. There is no evidence in the data of greater poverty in lowlands (Amazon biome) versus highlands (Andean ecosystems), nor is there any evidence of differing levels of poverty in urban areas compared with rural areas (regions undergoing colonisation and indigenous lands). The latter may however be a sampling issue due to the scale of the poverty data being analysed.

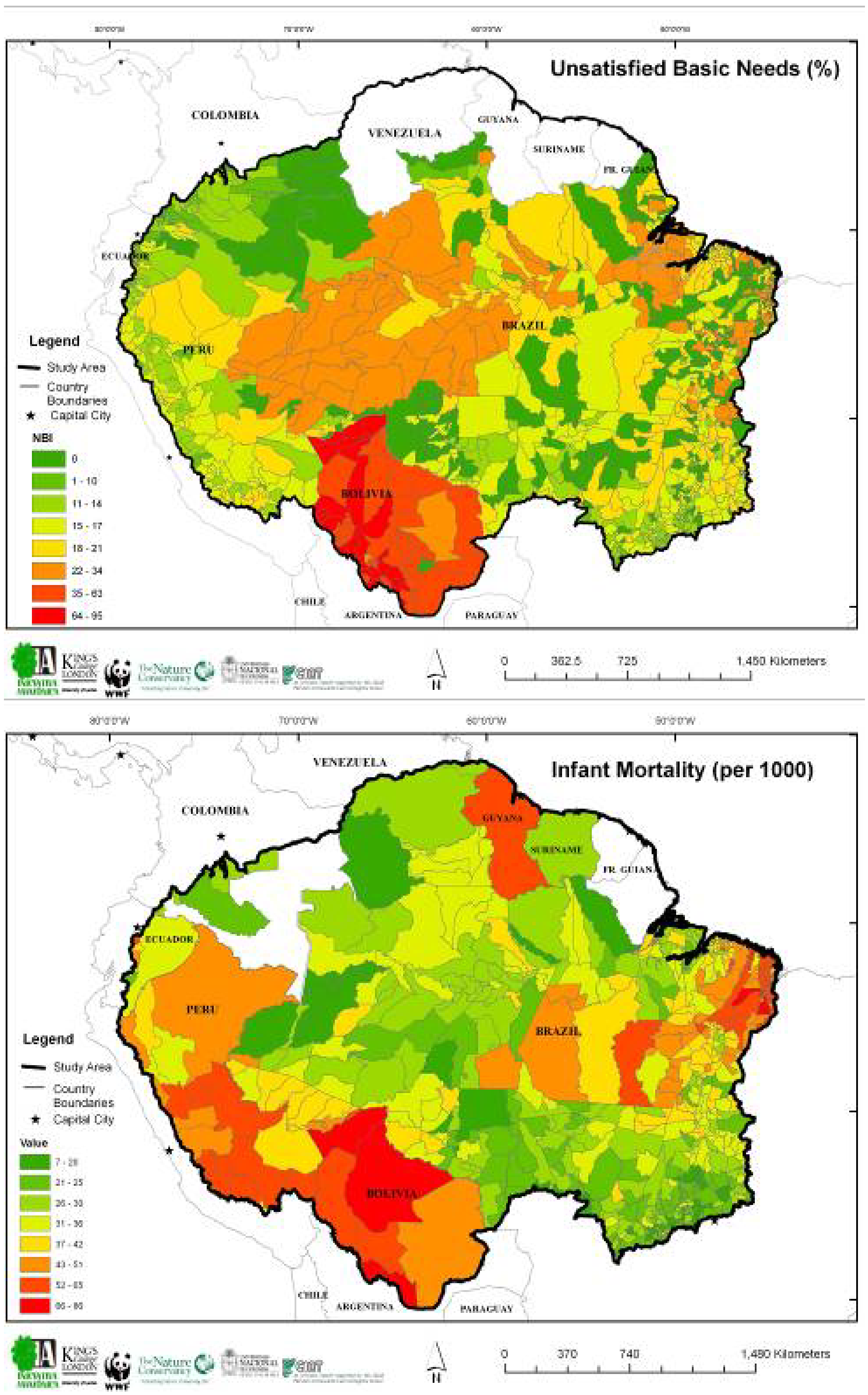


Figure 2.1 Distribution of poverty in the study region using unsatisfied basic needs (UBN) (top) and infant mortality (bottom)

Table 2.4 Average poverty indicators for each country in the study region, based on national level census data from 1995-2005.

	Unsatisfied Basic Needs (%)				***Infant Mortality (per 1000)***			
	Mean	Std	Min	Max	Mean	Std	Min	Max
Bolivia	56.9	23.1	0	95	61.8	10.5	36	86
Brazil	14.3	7.7	0	66	33.3	11.4	12	80
Colombia	9.6	2.8	0	18	25.3	5	18	47
Ecuador	10.9	3.8	0	18	34.8	8.2	18	52
Peru	13.9	2.9	0	88	49.4	8.7	14	67
Total	***18.1***	***15.9***	***0***	***95***	***39.9***	***14.5***	***12***	***86***

Table 2.5 Average poverty indicators for each ecosystem in the study region

	Unsatisfied Basic Needs (%)				***Infant Mortality (per 1000)***			
	Mean	Std	Min	Max	Mean	Std	Min	Max
Savanna	14.6	10.6	0	70	29.7	11.8	12	70
Dry forest	25.5	23.8	0	95	43.3	13.7	20	86
Montane grasslands	23.5	23.6	4	95	51.5	13.6	18	86
Montane forests	18.4	15.9	0	92	49.1	11.1	21	70
Mangroves	16.6	8.4	0	24	45.2	13.2	22	80
Várzea	17.9	7.2	0	66	31.8	8.5	14	57
Moist Forest	15.7	11.4	0	80	37.6	13.2	12	80
Guyanan ecosystems	4.5	5.6	0	11	33	0	33	33
Total	***18.1***	***15.9***	***0***	***95***	***39.9***	***14.5***	***12***	***86***

Table 2.6 Average poverty indicators for each community type (urban, rural coloniser, indigenous) in the study region

	Unsatisfied Basic Needs (%)				**Infant Mortality (per 1000)**			
	Mean	***Std***	***Min***	***Max***	***Mean***	***Std***	***Min***	***Max***
Urban	17.5	14.1	0	95	39.1	14.4	12	86
Rural	18.1	15.9	0	95	39.9	14.5	12	86
Indigenous	17.0	14.4	0	88	39.5	12.9	14	71
Total	***18.0***	***15.7***	***0***	***95***	***39.8***	***14.4***	***12***	***86***

Regional data generally does not allow for in-depth and formal analyses of the interrelationships of these poverty indicators with the ES described below. However, given that the livelihood conditions of many low-income groups are known from case studies, some general conclusions can be drawn on the implications of the state of knowledge about each ES category for such groups. Table 2.6 groups average poverty indicators according to three broad stakeholder groups (urban, rural, indigenous). Below we qualitatively evaluate the implications of findings on ES for these groups at the end of each section.

2.3. Water quality and quantity

Water is a readily quantifiable environmental service with key impacts on human health and welfare, agricultural productivity, energy generation, transport, and environmental health. Links between water poverty and human well-being are usually clear in arid and semiarid areas where water is highly limiting: these relationships are less readily defined in areas with plenty of water such as much of the Andes and the Amazon. Nevertheless, the provision of high quality and dependable water flows is a critical environmental service provided by ecosystems in the Andes and Amazon. There is much evidence that land use change can have impacts (both positive and negative) on the provision of these services (Bonell and Bruijnzeel 2004; DFID 2005; CIFOR 2005; and Chapter 4). Available water at any point is rainfall minus evaporation plus inputs from upstream minus losses to downstream. In spite of catchment scale models and calculations of the water balance, there has been little detailed water balance modelling at the continental scale (i.e., the focus of this study). To quantify provision of water based services, we used global and regional databases for climatic and surface characteristics that determine water balance (i.e., rainfall, cloud cover, solar radiation, temperature, humidity, vegetation cover, topography, and drainage characteristics). These surfaces were used to parameterise the FIESTA water balance model (http://www.ambiotek.com/fiesta) at a spatial resolution of 1km and using a diurnal-within-monthly time step for the entire Amazon watershed. We present results on the water balance (rainfall – evapotranspiration) at a point and on runoff (water balance accumulated downstream). The key maps are presented in a Google Earth interface at www.ambiotek.com/ESPA, but Figure 2.2 shows the map of flow sensitivity to land-use change derived from the results of the FIESTA model.

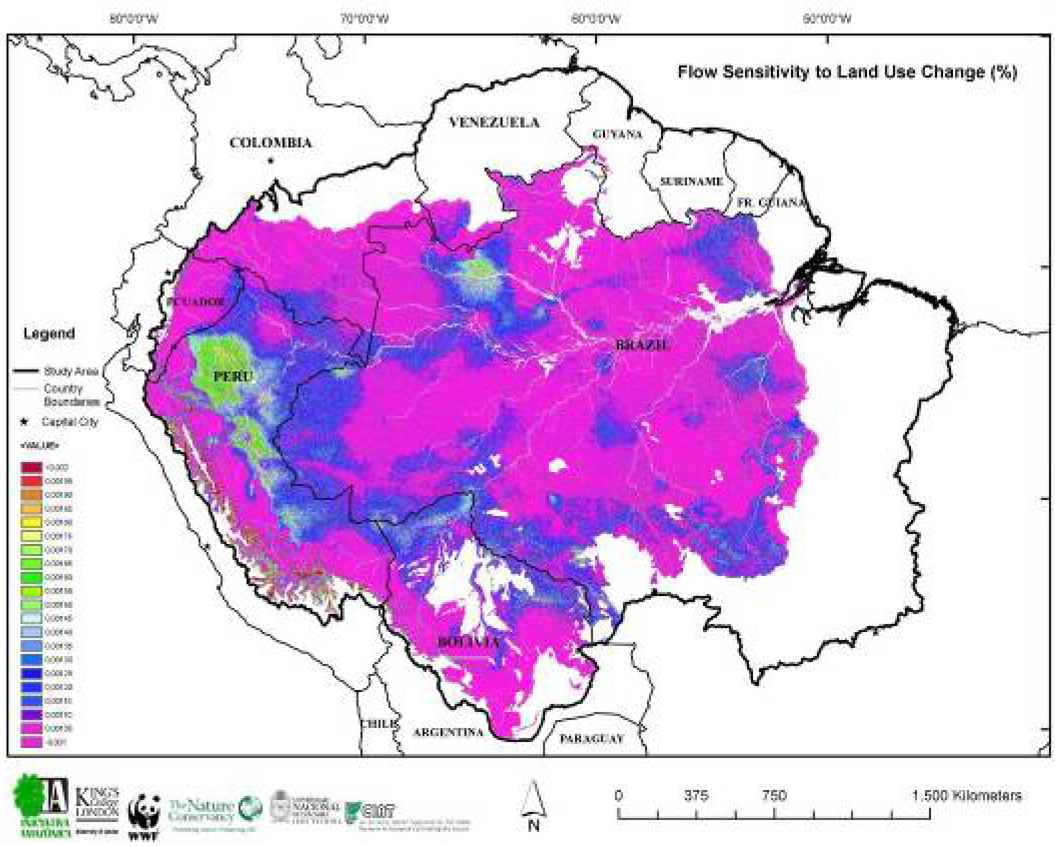


Figure 2.2 Flow sensitivity to land-use change derived from the FIESTA model

Key results indicate that:

- There is a great deal of uncertainty concerning the Amazon water balance based on the input data used (especially rainfall inputs which are still highly uncertain across the basin).

- Although the Andes may have highest water balance per unit area, their small extent means that their inputs are dwarfed by rainfall falling on the Amazon.
- The wettest catchments are in the North (N) and West (W) and the driest in the South (S) and East (E).
- Seasonal deficits in the S and E (and locally in the N+W) mean that inputs from upstream are significant to the seasonal water balance in these areas and that most of the catchment is seasonally dependent on seepage and base flow.
- Most deforestation historically has taken place along the main channel and primary tributaries of the Amazon River, along the flanks of the Andes (especially in the N and S) and throughout the "Arc of deforestation" in the S and E.
- Deforestation has had a minimum impact on water balances, with local increases in runoff of the order of a few mm/year in deforested areas.
- Runoff has lead to small increases (<1%) in flow of the major rivers draining these areas. Localised responses based on historic measurements and paired catchment studies are much more complex and uncertain (see Annex 2).
- Different General Circulation Models produce broadly the same pattern but different magnitudes of temperature change for the Amazon. Different GCMs produce different patterns as well as magnitudes of rainfall change.
- Impacts of climate change on water balance are much greater than those of historic land use change. The HADCM3 GCM says that: a) evaporation increases throughout the basin but especially in the E; and b) water balance decreases throughout much of the N and central Basin; but increases throughout the Andes, N and E. These factors lead to increases in runoff over the Andes (by 100% in the south) and decreases of up to 100% in the N and central Amazon. Neighbouring rivers can show an opposite trend in terms of change in water balance. Under the ECHAM GCM, evaporation increases throughout the basin, but especially in the E; and water balance increases in the W (500mm/yr) and decreases in the E (600mm/yr). These changes lead to increased runoff in the Andes and western Amazon (30-100%) and decreased runoff in the NE (-30 to -50%) of the basin.
- Regarding hazards (high and low flows), forest loss has led to small increases in low flows especially in the N and W of the basin and small decreases in high flows especially in the E of the Basin. Climate change scenarios lead to much greater changes in minimum and maximum flows. Under the ECHAM scenario minimum, flows increase especially in the W of the Basin while they decrease under HADCM3 everywhere except the extreme west.
- In summary, the Amazon basin has a generally plentiful provision of quality water that is relatively reliable seasonally and inter-annually. Although land use change effects have been minimal so far, according to the data available, climate change impacts are likely to be much more significant. There are areas of poor water accessibility (for infrastructural reasons) or for reasons of local aridity or water contamination and these are locally significant even though they do not appear at the continental scale. Better data resolution and availability along with more detailed research would improve the certainty of these analyses.

2.3.1. Implications for poor local stakeholders

Dependence on water quality and quantity is generally high for all local stakeholders. The relative abundance of water in the Amazon basin does not necessarily imply low well-being impacts of changes in water related ES provision. Local economies in the Amazon are highly adapted to (and, hence, dependent on) abundant water services, be it for transportation, energy generation, fishing or direct uses (drinking water, etc.). Seasonal water shortages are likely to especially affect fishery based livelihood strategies for traditional populations (*riberinhos*) alongside rivers. They also increase fire susceptibility on forests and may, hence, indirectly affect extractivism. Both excess rain and longer and more intense dry season are likely to negatively affect agriculture-based livelihood strategies of colonists and farmers. While waterways are of less importance for transportation in the Andes, excess rain and intensive droughts may increase erosion and runoff from steep slopes and affect downstream water users access to water quality.

Table 2.7 Stakeholder groups and water related ES implications

Local stakeholder groups	Dependence on water quantity/quality	Well-being implications of key results
Urban	High, but urban water distribution systems can substitute for ES. In the Amazon, some informal urban settlements may depend more on natural water related services. In the Andes, poor downstream urban settlements depend on water quality affected by upstream modifiers.	Climate change related droughts may negatively affect access to good quality water in informal urban settlements. Climate change and land use may reduce both water quality and quantity for downstream water users in the Andes.
Colonists/farmers	High ES dependence, for direct uses, transportation and agriculture	More extreme seasonal water shortages may reduce agricultural productivity and increase erosion and runoff. Remote communities may experience reduced mobility during dry seasons
Traditional/Indigenous	Same as previous	Same as previous

Key research issues and questions for ESPA: Water quality and quantity

1. Development and unhindered distribution of satellite-based climate datasets for improved continental scale hydrological analyses and modelling.
2. Assessment of the relative impacts of land use and climate change on water availability and flow within the Amazon Basin, including feedback processes and assessment of potential land cover or climatic thresholds that can generate significant hydrological change.
3. Assessment of the hydrological sensitivity of the basin to climate change that moves beyond the standard scenario application approach in which the results are highly dependent on the scenario used; and in which different scenarios can produce very different outcomes towards an approach that recognises sensitivity to climate change. Assessment can include use of ensemble simulations.
4. A more detailed treatment of spatial (geographical) variability across the Amazon and its implications for scaling up of site studies.
5. Better understanding of the relationships between water and poverty in water-rich environments and the extent to which these are mediated by water access and quality as much as quantity, including analysis of the issues of dams for HEP generation.

2.4. Local climate regulation

Local climate regulation is a key environmental service related to land cover manifested in rainfall and cloud generation, and, thus, water balance, humidity, and temperature. Even if impacts of forest cover on runoff generation are low and positive for the terrestrial component of the hydrological cycle, it may be that feedbacks among land cover, cloud cover, and rainfall increase precipitation and reduce evaporation through generation of cloud cover. Such an effect would clearly impact on regional climates. There is evidence both for and against this (Charney 1975; Xue and Shukla 1993; D'Almeida et al. 2007; Leopoldo et al. 1995; Salati and Nobre 1991; Annex 3). Reviewing the literature dealing with the impact of land use change (ecosystem management) on climate regulation we found that:

1. Macroscale grid models suggest an overall decrease in water resources associated with deforestation at the Amazon scale attributed to reduced evapotranspiration affecting the basin's rainfall recycling.

2. Mesoscale grid models with greater detail predict changes in the intensity and distribution of precipitation and an increase in the seasonality of cloudiness in areas of high deforestation (Chu et al. 1994; Avissar and Liu 1996; D'Almeida et al. 2007). Results vary spatially, however, depending on climatic conditions and topography. Single column models (as opposed to spatial grid models) indicate greater precipitation over forested areas due to greater evapotranspiration flux from them.

Past analyses have a number of limitations including: coarse scales that are unable to resolve local and regional effects, a reliance on models rather than data, poor quality or limited period rainfall datasets, and the localised application of single column models or data based approaches that cannot resolve spatial variability across the basin, resulting in conflicting, location-dependent results.

In addition to the literature review summarised above, a GIS analysis used the best available current rainfall, cloud cover, and forest cover datasets covering the entire basin (from http://www.kcl.ac.uk/geodata) to better understand the role of forest cover on climate regulation. Although much was carried out before ESPA, the analysis, refocused for this purpose, calculated the difference in mean annual seasonal and diurnal cloud cover (2000-2006) and rainfall (1997-2006) between 1km pixels and their westernmost neighbour, and compared these differences with differences in tree cover (Hansen et al. 2003) between the same 1km cells (Hansen et al. 2003).

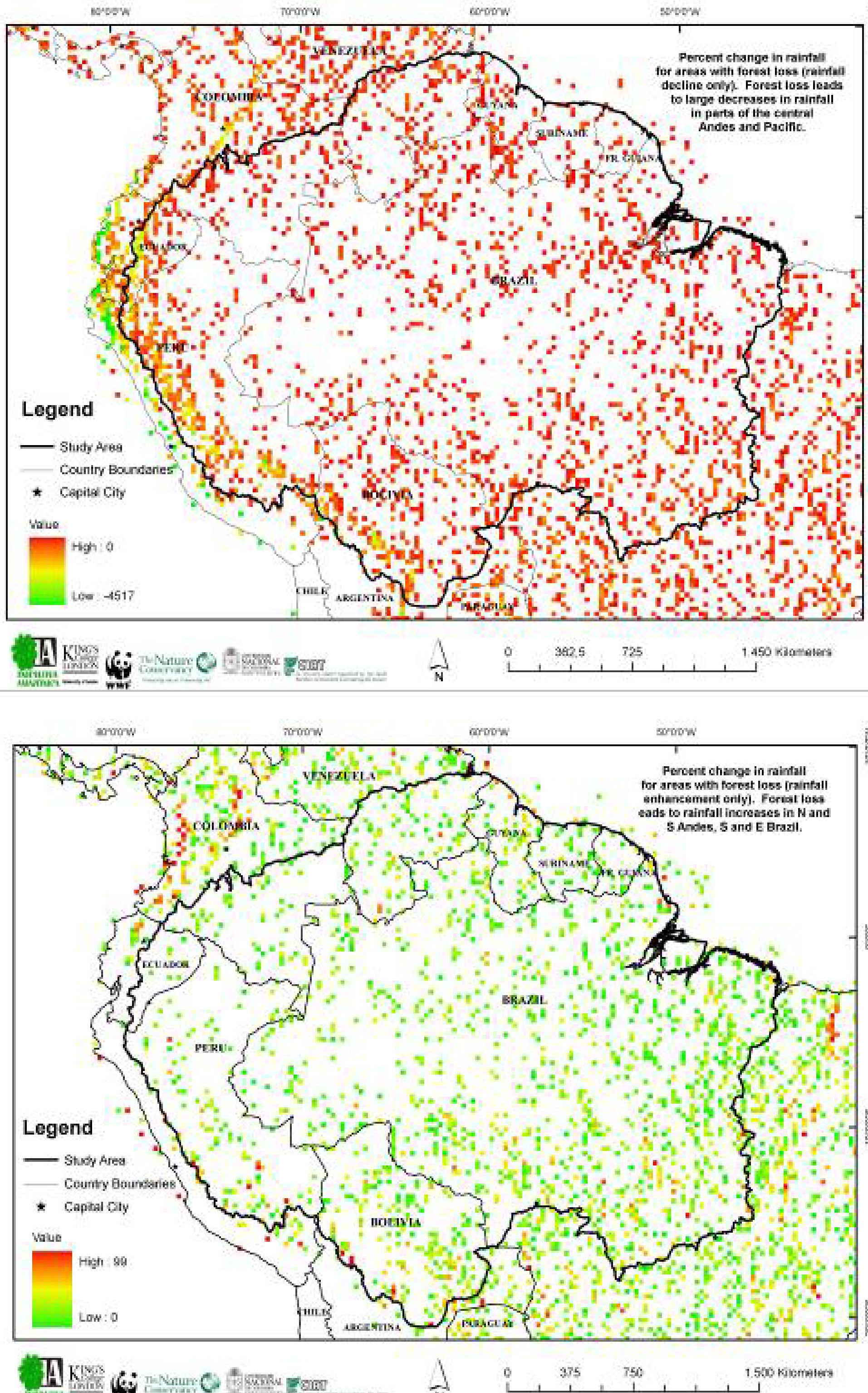


Figure 2.3 Percent change in rainfall for areas with forest loss with rainfall decline only (top) and rainfall enhancement only (bottom)

Results indicate that:

- There is no consistent relationship between difference in forest cover and rainfall of neighbouring cells. Forest loss can be associated with increases or decreases in rainfall.
- Spatial variation with forest loss led to rainfall increases of +10% in N and S Andes, S and E Brazil, but declines in rainfall in the central Andes and Pacific.
- Similarly, change in cloud frequency shows no relationship with change in forest cover.
- Spatially, cloud frequency increases significantly with forest loss in some parts of SE Amazon and E Amazon; but decreases significantly with forest loss throughout the central and S Andes and E Amazon.

In summary, there remains a great deal of uncertainty in quantifying the provision of the regional climate regulation services by different land cover types. This reflects the complexity of mesoscale meteorological situations, which exist from the Andes to the eastern Amazon.

2.4.1. Present and future need for climate regulation

Given current climate change negotiations, the need for climate regulation services is impossible to quantify. Perhaps the need is for the maximum regulation possible because this will sustain current levels of rainfall, cloud cover, temperature, and humidity.

2.4.2. Implications for poor rural stakeholders

As with water related ES, all stakeholders are highly dependent on ES that regulate local climate. Since the direction of impact is hard to quantify based on existing data, stakeholder specific implications would be extremely speculative. Specific local climate conditions may favour (or not) vectors for infectious diseases in both rural and urban environments. Changes in rainfall, locally, are likely to have similar effects as changes caused by a globally changing climate.

Key research issues and questions to be addressed by ESPA: Local Climate Regulation

1. Deeper analysis of the impacts of forest cover change on cloud and rainfall generation, and application of these feedbacks in hydrological models (that look at the impacts of forest cover on evaporation and runoff while ignoring the feedback of evaporation to cloud cover and rainfall). Although most models (as the one used here) indicate that deforestation leads to increases in runoff, deforestation may lead to decreases in runoff, with impacts on rainfall generation and recycling at the continental scale, though evidence presented in the Amazon wide precipitation analysis indicates that forest loss can lead to either increases or decreases in rainfall, depending on the context. Questions: What are the full cycle impacts of large scale land use change on water resources in the Amazon and how will these impacts interact with regional climate change and human well-being?
2. More data based analysis of rainfall recycling processes and response to land cover change at the basin scale. Question: What is the role of rainfall recycling in the provision of water at the Amazon scale and how is this mechanism sensitive to land use and climate change?
3. Need for climate regulation services is much less developed than the provision side. Although there are local needs for the maintenance of the climatic status quo, there are also global needs such as the role of the Amazon in global climate regulation. Further research should focus on questions such as: What is the resilience of Amazon livelihoods to changes in climate, and the nature of livelihood responses (positive and negative) to climate change?

2.5. Carbon and biomass

The Amazon forest provides the global ecosystem service of carbon storage and sequestration. Biomass in the Amazon basin has been mapped (Brown and Lugo 1992; Fearnside 1997; Malhi et al. 2006; Saatchi et al. 2007). Coupling the Saatchi et al. 2007 map with the TNC map of ecosystem classes shows that some 92% of the Amazon biomass is tied up in forests. Assuming that carbon is 50% of biomass means that some 80 Pg (billion metric tons) of carbon are currently tied up in the Amazon basin forests (86 Pg of carbon for all Amazon ecosystems). The Amazon thus represents 21% of all carbon in the world's tropical forests. Since 1751 roughly 315 Pg of carbon have been released to the atmosphere from the consumption of fossil fuels (FF) and cement production (Marland et al. 2007). The carbon in Amazon forests is thus equivalent to some 25% of all post Industrial Revolution FF emissions. Annual average FF emissions from 1970-2004 are some 5.8 Pg. Using the modelled land cover changes of Soares-Filho et al. 2006 (business as usual--BAU scenario) and considering only deforestation (not regeneration), some 30% of the existing carbon stocks in the Amazon will be lost by 2050 (*Figure 2.4*). This loss would place a further 24 Pg of carbon into the atmosphere (equivalent to four years of total global emissions at current rates).

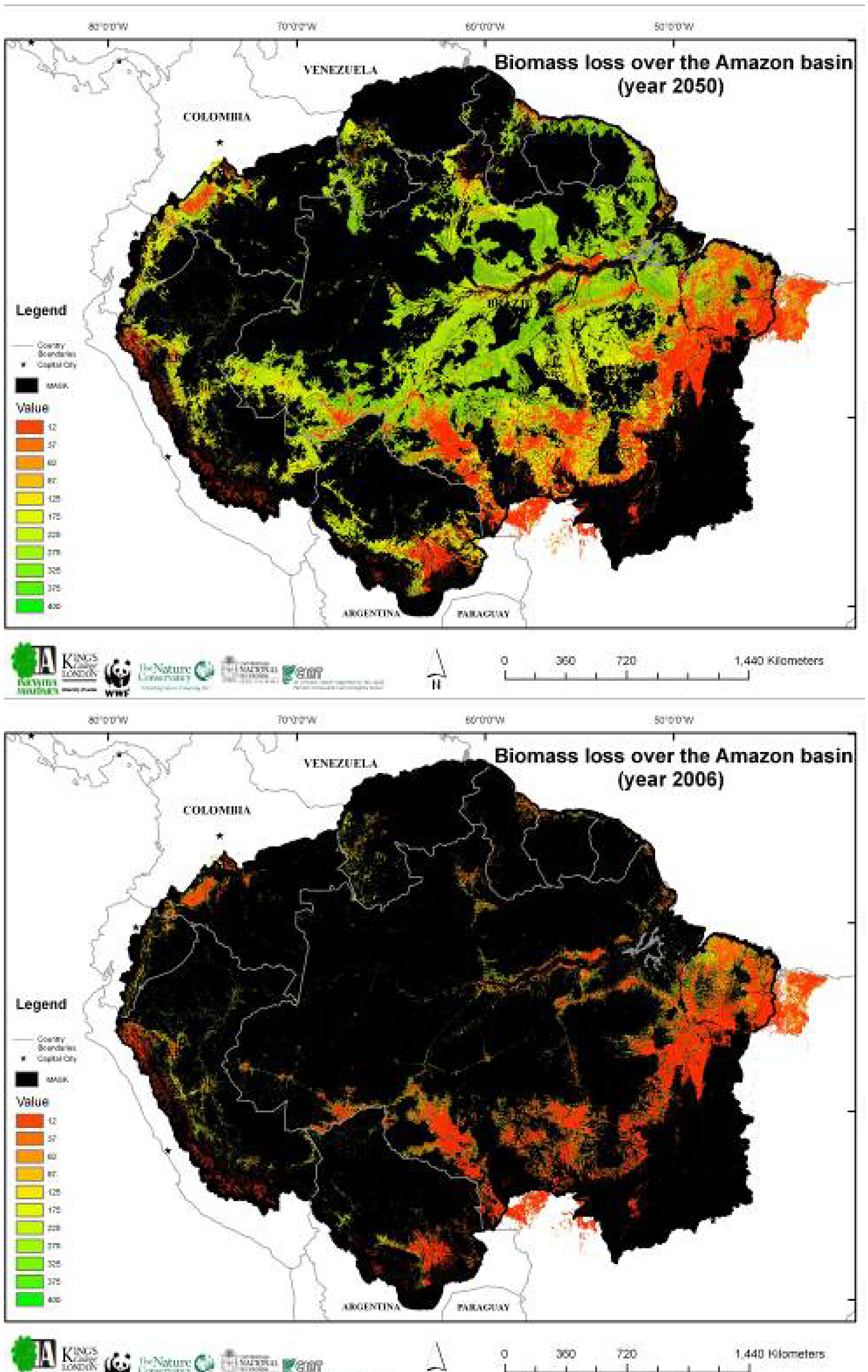


Figure 2.4 Biomass loss over the Amazon basin, year 2006 (top) and year 2050 (bottom).

Carbon sequestration rates for Amazon ecosystems vary from 1.1 to 3.7 Mg/ha/yr for *terra firme* forest (Chambers et al. 2001; Mahli et al. 2004). This produces total annual added stocks of 2.3 Pg for the Amazon, most of which (2.2) is from the forest ecosystem. This total would be reduced by 30% by 2050 under the Soares-Filho business as usual scenario. The Amazon thus currently sequesters the equivalent of 40% of current annual FF emissions. Combining the loss in Amazon carbon stocks (in addition to the atmospheric carbon stocks) with the loss of sequestration under the BAU scenario gives an overall net contribution to atmospheric carbon dioxide of 24 Pg (stock losses) plus 116.5 Pg (loss of sequestration potential over the 50 years--assuming that forest replacement crops do not grow significant standing biomass as secondary forest does, but rather have most of their biomass returned to the atmosphere through annual burns or decomposition). This represents an additional 48% on current annual FF emissions as a result of deforestation. Carbon sequestration by the Amazon is clearly a significant global environmental service.

2.5.1. Present and future need for carbon and biomass

How much additional carbon could be sequestered in the Amazon if the objective was to maximize its contribution to climate change? The literature indicates that greatest sequestration rates are obtained under forest plantation (6.6 Mg/ha/yr), *várzea* forest (5.4 Mg/ha/yr) and particularly forest regeneration (9.3 Mg/ha/yr). In terms of maximising carbon sequestration, the replacement of old growth forest (which sequesters 2.2 Mg/ha/yr on average) with plantation or regenerating forest would increase the sequestration rate, but if much of the old growth forest carbon were returned to the atmosphere in the process, the 7 Mg/ha/yr of extra sequestration under regenerating forest would take 20 years of sequestration to offset the carbon released into the atmosphere on conversion from old growth forest to regenerating. Over those 20 years, sequestration rates of the regenerating forest will have fallen closer to the levels for old growth forest. The net long-term carbon gains from regenerating forest are thus low if the carbon stocks have been released for the purpose of replacement with regenerating forest: avoiding deforestation in the first place is a more effective approach, especially because of the positive benefits for other environmental services (especially the hydrological and biodiversity related ones).

2.5.2. Implications for poor local stakeholders

ES related to carbon and biomass in both the Andes and the Amazon are clearly global. Local stakeholders derive little or no benefits from the carbon content in vegetation and soils, if not in the form of other local ES that are examined (e.g. soil productivity, forest products). What remains is the perspective of deriving benefits from the increasing international demand for reduced carbon emissions through direct transfers to local ES modifiers. Such benefits depend on the design of new mechanisms to make such transfers happen, e.g. through payments for environmental services (PES) schemes. Even if such mechanisms were in place, benefits are likely to accrue only to those local stakeholders that can demonstrate additionality (of ES) on land with secure property rights. Stakeholders living in remote areas with little or no pressure on forests are unlikely to benefit.

Table 2.8 Stakeholder groups and carbon related ES implications

Local stakeholder groups	Well-being implications of key results
Urban	Few or no opportunities to participate in carbon markets exist for urban poor.
Colonists/farmers	Landowners and communities with use rights living on public land can sell carbon related ES in the areas threatened by deforestation with high carbon content (see green areas in right panel of *Figure 2.4*) or in areas where additional carbon can be sequestered at competitive costs.
Traditional/Indigenous	Indigenous people living in demarcated indigenous territories have sufficient property rights to sell carbon related ES. Yet, few indigenous territories are located in high pressure areas.

Key research issues and questions to be addressed by ESPA: Carbon and biomass

1. Most studies of the impact of land use change do not consider the impact of changes in sequestration, only of carbon stock losses. There is still much debate as to the role of the Amazon as a global carbon sink (Houghton et al. 2000; Clark 2002; Laurance et al. 2001). More research is needed to scale up the plot and tower scale studies to Amazon-wide estimates capable of tackling the issue of the overall contribution of the basin. Question: How will the carbon budget of the entire Amazon respond to environmental change and what are the implications for reduced emissions from deforestation and degradation (REDD) in developing countries?
2. Given the potential incorporation of avoided deforestation in the post Kyoto climate change treaty through REDD, a mechanism now exists for payments for carbon services. Key questions concerning how to ensure that this mechanism works for the poor include: how much carbon is sequestered by different ecosystems; and how does this vary spatially, seasonally and inter-annually? How can areas at risk of deforestation be assessed? And how could PES (payments for environmental services) schemes contribute?
3. The global need for carbon sequestration services is apparent; but there remains a great deal of uncertainty as to the long-term carbon balance implications of particular carbon management strategies (avoided deforestation, plantation forest, protection, conservation, regeneration, tree planting and biofuel cultivation). Critical questions include full cycle impacts (i.e., all aspects considered from production through consumption). Moreover these studies need to take into account the changing ecology of Amazon forests under climate change and CO_2 fertilisation effects and must be carried out at the Amazon scale.

Further information: Baseline datasets in Google Earth (www.ambiotek.com/ESPA); project presentations (www.ambiotek.com/ESPA); Forest and climate interactions: a bibliography (http://www.ambiotek.com/ESPA); Literature review on water quality and quantity provision in the face of climate and land use change in the Amazon (www.ambiotek.com/ESPA), Annex 4.

2.6. Status of erosion and soils productivity losses in the Amazon Basin

Soil is an environmental resource critical to hydrological and ecological systems and the basis of agriculture. There are a number of important soil-related ecosystem services, including soil quality, soil biodiversity and soil carbon. However, consistent spatial data on soil-related services is scarce, hence this analysis focuses only on soil erosion, and acknowledges that other important services are missing. This analysis has made an initial effort at mapping soil erosion and the likelihood of soil productivity losses, but it should be noted that this is only an initial approach to generating spatial maps of soil-related ES, and further work in this area is merited.

Soil erosion can lead to local reductions in soil fertility and productivity and to contamination and sedimentation of rivers. Soils have very different origins, forms, and processes in the Andes and the Amazon - with erosion risk being greatest on the steep slopes of the Andes. Although soil erosion in the Andes and Amazon is widely documented, there is no systematic Amazon-wide assessment. We conducted a spatial assessment using available geospatial data and a literature-based database of known erosion events. The erosion data used for the model are related to natural processes and human activities. Natural processes include high runoff over large slopes, low infiltration capacity, and poor vegetative cover. Human causes include deforestation, inappropriate land use, livestock, and agriculture. These latter activities result in losses in terms of soil profiles, structure, and organic matter. Problems such as compaction, reduction in biological activity, and loss of infiltration capacity are also reported. For natural processes, long and intensive periods of precipitation produce losses of surface soils and sedimentation of valleys and flatter zones.

Existing evidence and Extrapolation Domain Analysis (EDA) were used to assess the status of soil erosion and productivity losses in the Amazon Basin (Otero et al. 2006). The method identifies areas that exhibit high or low probabilities for the occurrence of similar processes as those reported in the documented cases. Key environmental conditions within extrapolation domains are estimated by cross-referencing against population and/or ecosystems maps. Areas expected to suffer similar degradation are identified, highlighting where actions need to be taken both for protection or restoration. This approach helps in identifying the environmental service offered by the land in each individual pixel in terms of probability of environmental degradation.

EDA uses a combination of Bayesian and statistical modelling to determine the potential of a site to suffer erosion or losses in productivity. Bayesian modelling uses the weights of evidence (WofE) algorithm (Bonham Carter et al. 1989; Bonham Carter 2002) to determine the probability that target sites exhibit socioeconomic and other landscape attributes deemed to be critical to degradation. Similarities of climatic attributes with areas where the project originates are determined using Homologue (Jones et al. 2005). Homologue uses a time series of temperature, rainfall and evapotranspiration to produce some 32 different variables relevant to soil erosion that are analysed statistically against the spatial occurrence of known erosion problems. The two estimates are combined in a single estimate for each grid cell of 1 km^2 within the tropics.

2.6.1. Probability of erosion occurrence

Figure 2.5 shows the zones susceptible to erosion based on the EDA analysis. The 105 reported cases of erosion presented in the map (black points) were used for the Homologue model as well as for WofE modelling to obtain zones that present similar physical characteristics (Table 2.9).

Table 2.9 Variables included in the WofE and Homologue models

WofE modelling variables
1 km resolution SRTM elevation model
1 km resolution derived slope
1 km resolution accessibility model (Nelson 2007)
Vegetation cover (GLCF 2008)
Cation Exchange Capacity (for analysis of productivity losses)

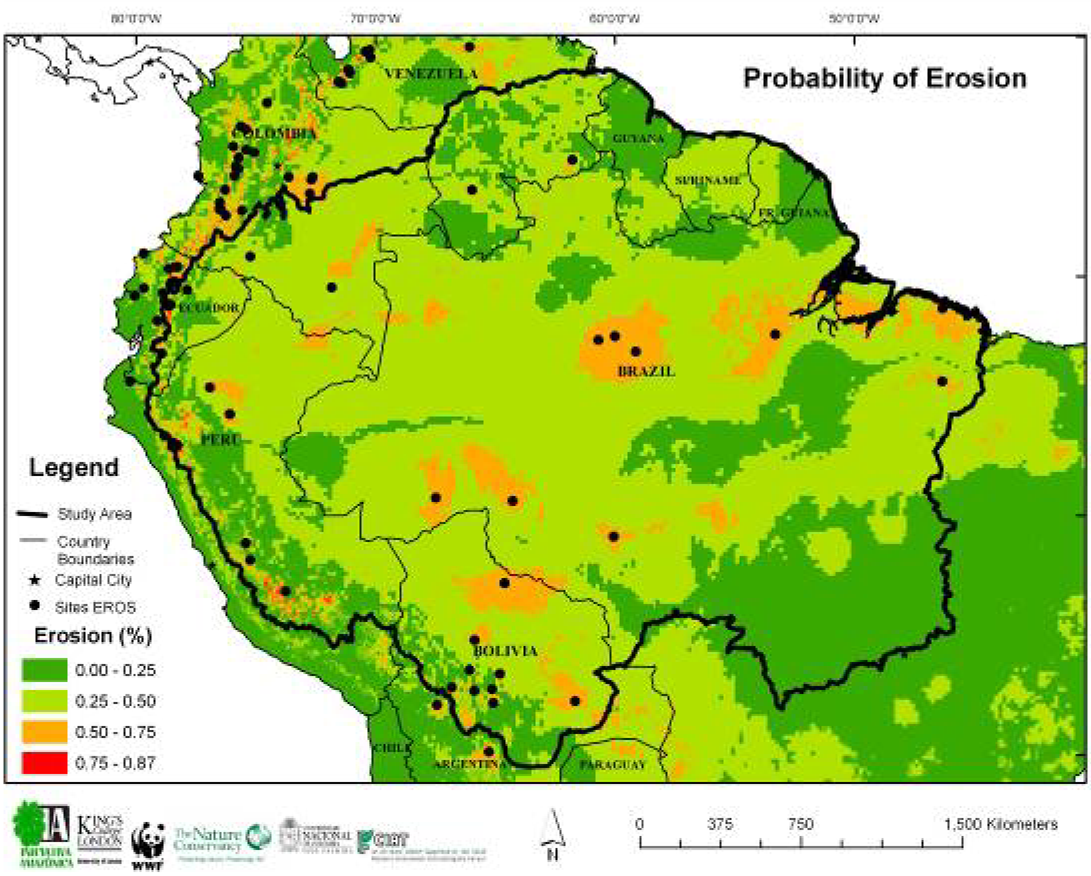


Figure 2.5 Probability of erosion in the Amazon basin

Distribution of erosion probabilities over the Amazon Basin was analyzed. Table 2.10 and Table 2.11 summarize these distributions related in ten different probability classes.

Table 2.10 Distribution of population and areas over ten erosion probability classes.

Class	Interval of probability (%)	Occurrence in area (%)	Cumulative area (%)	Population distribution (%)	Cumulative population (%)
1	0 – 10	11.07	100	11.51	99.89
2	10 – 20	9.27	88.93	8.22	88.38
3	20 – 30	15.12	79.66	13.22	80.16
4	30 – 40	18.55	64.54	16.16	66.94
5	40 – 50	37.91	45.99	30.53	50.78
6	50 – 60	7.66	8.08	14.70	20.25
7	60 – 70	0.25	0.42	2.89	5.55
8	70 – 80	0.10	0.17	1.49	2.66
9	80 – 90	0.07	0.07	1.17	1.17
10	90 – 100	0	0	0	0

Table 2.10 shows a probability of erosion higher than 50% over about 8% of area inhabited by 20% of the regional population. In terms of need and provision, 8% of the area is a potential producer of erosion; and 20% of the population is potential demander of actions to avoid it.

Table 2.11 Distribution of ecosystems (cumulative area in %) over ten erosion probability classes.

Class	**Ecosystem**								
%	*Dry forest*	*Guayanan ecosystems*	*Mangroves*	*Moist forest*	*Montane Forest*	*Montane Grasslands*	*Savanna*	*Swamp Forest*	*Várzea*
0-10	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
10-20	92.2	86.2	80.8	96.1	74.1	76.9	58.7	100.0	99.1
20-30	73.9	74.2	76.6	88.0	55.7	50.0	48.3	83.4	96.7
30-40	51.9	60.0	75.3	72.5	40.1	37.8	37.6	45.8	91.8
40-50	34.2	25.2	70.1	52.7	25.2	22.2	24.9	27.3	78.1
50-60	3.6	1.3	30.9	6.0	11.5	14.6	4.3	0.0	13.5
60-70	0.4	0.0	0.0	0.0	5.4	8.1	0.0	0.0	0.0
70-80	0.1	0.0	0.0	0.0	2.2	3.0	0.0	0.0	0.0
80-90	0.0	0.0	0.0	0.0	1.0	1.4	0.0	0.0	0.0
90-100	0	0	0	0	0	0	0	0	0

Table 2.11 shows that 31% of mangroves, 15% of montane grasslands, 14% of the *várzea,* 12% of montane forest, 6% of moist forest, 4% of savanna, 4% of dry forest and 1% of Guayanan ecosystems are subject to more than 50% chance of soil erosion.

2.6.2. Probability of productivity losses

The EDA allows inference of zones susceptible to losses in productivity based on the combination of WofE and Homologue models. Sixty-three cases of productivity loss were found (the black points in Figure 2.6). The variables used for the models are reported in Table 2.9.

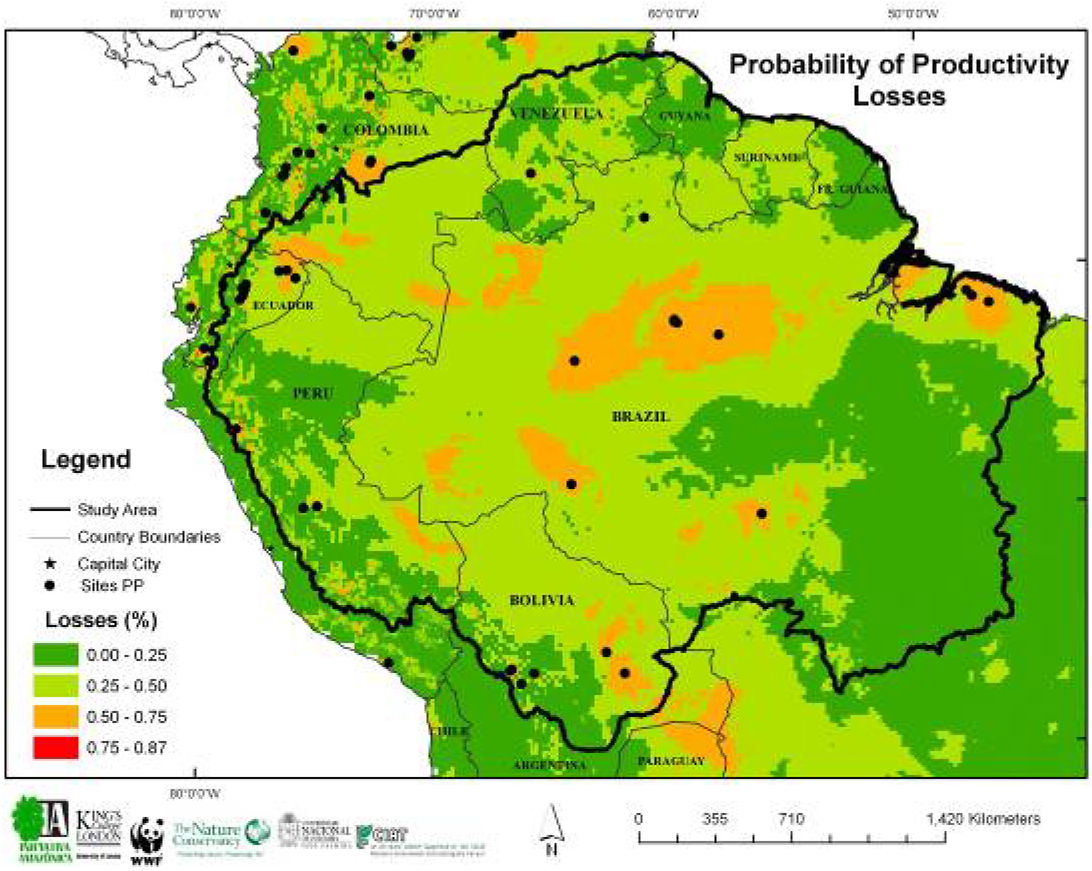


Figure 2.6 Probability of productivity losses in the Amazon basin

Following the same processes used for the erosion analyses, population and areas were quantified for each probability of productivity loss classes.

Table 2.12 and Table 2.13 summarize these distributions in ten different classes.

Table 2.12 Distribution of probability of productivity losses into ecosystems, population and total area.

Class	Interval of probability (%)	Occurrence in area (%)	Cumulative area (%)	Population distribution (%)	Cumulative population (%)
1	0 – 10	12.20	100	16.23	99.89
2	10 – 20	14.47	87.88	22.60	83.66
3	20 – 30	12.01	73.41	10.85	61.06
4	30 – 40	16.36	61.40	15.60	50.21
5	40 – 50	35.54	45.04	20.72	34.61
6	50 – 60	9.40	9.50	13.63	13.89
7	60 – 70	0.07	0.10	0.25	0.246
8	70 – 80	0.02	0.03	0.10	0.014
9	80 – 90	0.01	0.01	0.04	0.04
10	90 – 100	0	0	0	0

Table 2.12 shows that there is an erosion probability greater than 50% over about 10% of the region. This probability could eventually affect about 14% of the area's population.

Table 2.13 Distribution of ecosystems (cumulative area in %) over ten productivity loss probability classes.

Class	**Ecosystem**								
%	*Dry forest*	*Guayanan ecosystems*	*Mangroves*	*Moist forest*	*Montane Forest*	*Montane Grasslands*	*Savanna*	*Swamp Forest*	*Várzea*
0-10	100	100	100	100	100	100	100	100	100
10-20	89.2	85.1	82.3	93.1	73.4	73.0	68.9	100.0	93.6
20-30	61.2	76.3	81.1	82.6	42.7	33.3	50.4	94.0	86.4
30-40	45.5	62.9	80.5	70.9	29.9	24.6	36.2	78.1	81.7
40-50	35.8	30.9	76.4	53.3	13.5	6.0	23.0	42.3	70.7
50-60	8.7	1.2	42.8	9.9	4.0	2.3	1.1	1.0	19.9
60-70	0.2	0.0	0.0	0.0	1.2	0.8	0.0	0.0	0.0
70-80	0.1	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.0
80-90	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
90-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Potential productivity loss with probabilities higher than 50% were in 43% of mangroves, 20% of the *várzea*, 10% of moist forest, 9% of dry forest, 4% of montane forest, 2% of montane grasslands, 1% of Guayanan ecosystems, 1% of savanna, and 1% of swamp forest ecosystems.

2.6.3. Implications for poor local stakeholders

ES affecting soil productivity are clearly important for all rural dwellers (and some urban or peri-urban), but particularly for agriculture based livelihood strategies. Figure 2.6 suggests that productivity losses are most likely in areas dominated by small and large scale farmers in the Andes/Amazon. Small-scale farmers, often depending on slash-and-burn techniques, have typically few means to substitute natural soil fertility by improved technology and external nutrient sources. Hence, they are more vulnerable to soil productivity losses. Also traditional/indigenous people rely on agriculture. However, at least those living in specially designated areas, such as indigenous territories and extractive reserves (see also Chapters 3 and 4) often have more land at their disposal, which contributes to maintaining natural soil fertility.

Table 2.14 Stakeholders and soil related ES

Local stakeholder groups	Dependence on natural soil productivity	Well-being implications of key results
Urban	Generally low, but locally important	Reduced soil quality can affect urban and peri-urban agriculture based livelihood strategies, but access to substitutes is more likely than in rural areas.
Colonists/farmers	High dependence on natural soil productivity in widespread slash –and-burn production systems.	Reduced soil productivity means less staple food availability and income from sales. Staple food substitutes can be bought, but at relatively high prices.
Traditional/Indigenous	Moderate to high dependence on natural soil productivity. Especially for staple food crop production.	Results generally indicate low probability of soil productivity losses on land occupied by traditional/indigenous people. Exceptions to the rule can be landless traditional populations on illegally occupied lands and people living in indigenous territories or extractive reserves under both internal and external pressure (e.g. Southern and Northwestern Brazilian Amazon)

Key research questions to be addressed by ESPA: Soil erosion and productivity losses

1. Where and under what conditions is soil erosion poverty relevant on and off-site?
2. Identify best practices and economically, culturally, and agronomically feasible technologies to reduce soil erosion.
3. What factors constrain farmers in adopting practices and technologies that minimize soil erosion?
4. What is the economic loss associated with soil erosion on-site? Where is it high, where negligible?
5. Measure the downstream costs of soil erosion and evaluate whether they could cover opportunity costs of preventing it upstream. Evaluate tradeoffs and identify cost-effective management options (Chapter 3)

2.7. Ecosystem functioning

2.7.1. Services related to terrestrial biodiversity

Biodiversity provides people with services from food to timber to less tangible services such as pollination and nutrient cycling. Most rural Amazon communities depend in some way on biodiversity related ecosystem services. People in the Basin consume an estimated 148,171 tones per year of wild mammal meat (Fa et al. 2002). Timber and non-timber forest products provide food, fiber, construction materials, and market products that contribute to subsistence and income of local people. Research suggests that biodiversity may be important in reducing the risk of certain animal diseases such as Cutaneous *leishmaniasis* or Chagas disease (Ostfeld and Keesing 2000), though this is a matter of debate.

Terrestrial biodiversity in the Andes/Amazon also provides global benefits. Both the Andean and Amazonian regions harbour an array of biological resources, parts of which have been identified as global priorities for biodiversity conservation (Myers et al. 2000).

Although one of the most significant ecosystem services, the provision of biodiversity is notoriously difficult to quantify due to the great diversity in provisions (from genes to ecological processes) and the multiple beneficiaries at multiple scales. Given this diversity of provisions and of uses, we use the quality of the habitat as a proxy for the provision of the range of ecosystem services (including pollination, nutrient cycling, ecosystem stability, reducing disease risk and other ecological processes). This approach fits with the Millennium Ecosystem Assessment (2005) recommendations to ensure acceptable and resilient levels of biodiversity related ecosystem services in the long term, variation of genes, populations, and species and the variety of structure, function, and composition of ecosystems must be conserved.

We divided the provisioning of terrestrial biodiversity services into three elements; biodiversity provision as a source of biological resources and ecosystem services; timber and non-timber forest products; and ecotourism in protected areas.

2.7.1.1. Biodiversity provision

In order to assess the spatial distribution of biodiversity provision, two factors were mapped: 1. habitat quality, and 2. habitat and species diversity.

Habitat quality was used as a proxy of all the goods and services provided by biodiversity at a given place. The index was based on the analysis of biodiversity threats in South America (Jarvis et al. 2008). The immediate threat to a specific site in an ecosystem was considered to be a function of the magnitude of the threat and the sensitivity of the ecosystem to that threat. Seven threats were considered: grazing pressure, recent conversion, accessible population, infrastructure, conversion to agriculture, fire, and oil and gas exploration. The threat analysis represents the degree of degradation, but here the reverse was used as a proxy for habitat quality (Figure 2.7).

Future scenarios for the provision of biodiversity ES were generated based on two main sources of data: 1) a deforestation scenario developed by Instituto de Pesquisa Ambiental da Amazônia (IPAM) for the year 2020, and 2) data regarding road development in the Amazon region (based on the Initiative for Integration of Regional Infrastructure in South--IIRSA). These two data sources lead to the generation of habitat quality in the year 2020 through recalculation of the projected threat layers of accessibility and areas of recent conversion (left image in Figure 2.7).

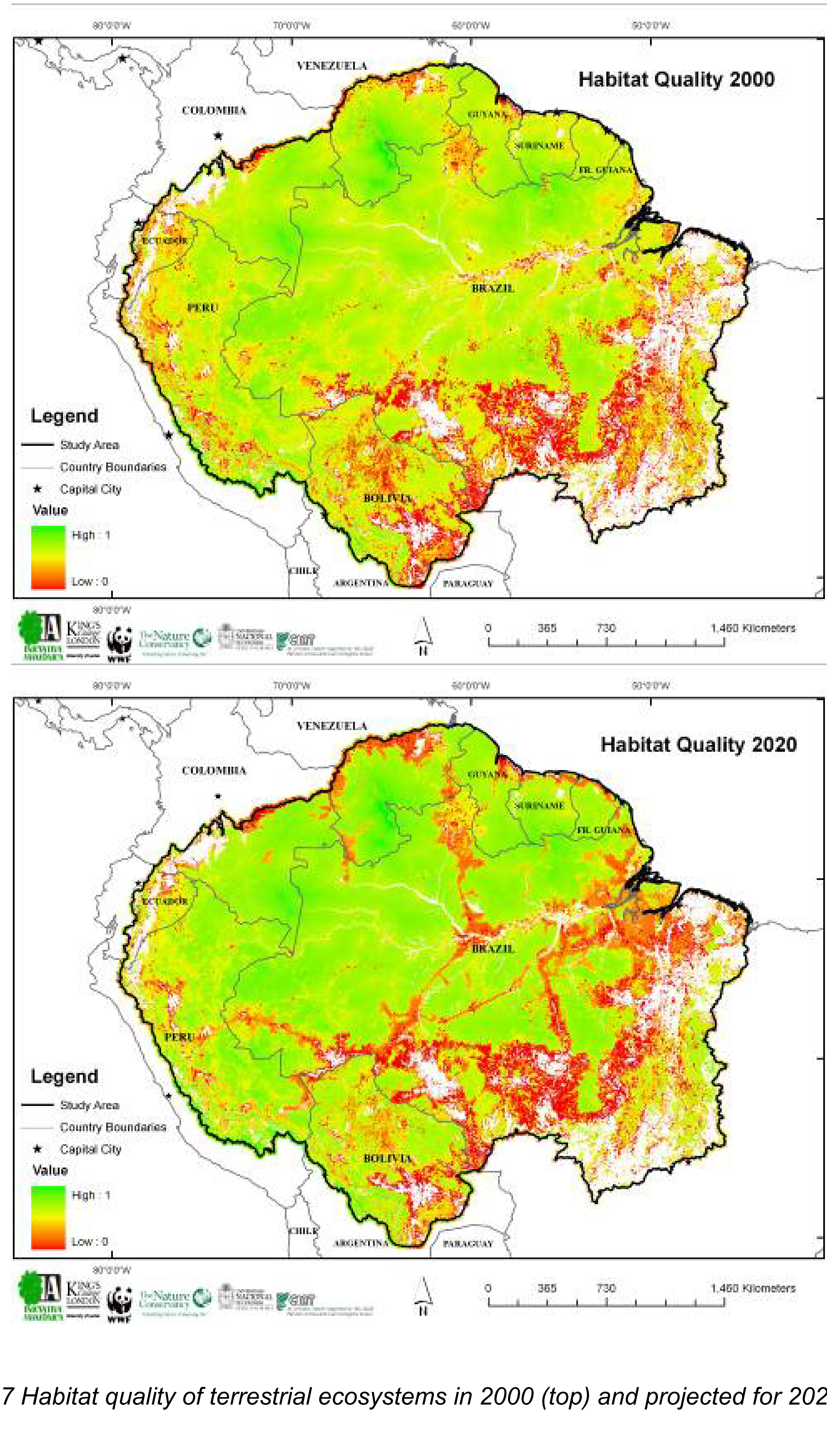


Figure 2.7 Habitat quality of terrestrial ecosystems in 2000 (top) and projected for 2020 (bottom)

Large areas of the study region are still natural ecosystems without evidence of degradation. Areas in the Andes as well as S and SE Amazon, however, have been highly degraded. Indigenous lands and protected areas show higher values of habitat quality. Moist forests and Guayanan ecosystems have the greatest habitat quality (0.81 and 0.84 respectively), whilst dry forests have the least habitat quality (0.66).

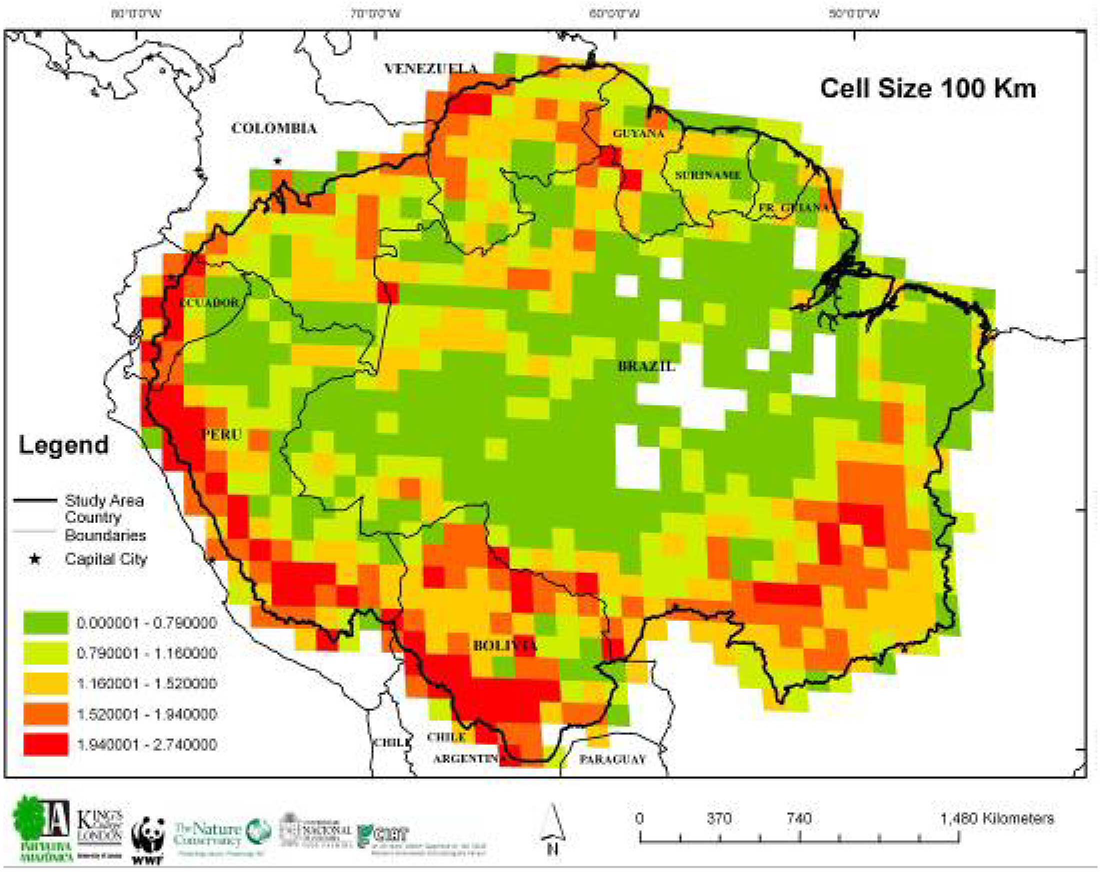
Table 2.15 Index of habitat quality for different major ecosystem types and general land-use areas (higher values, indicate higher habitat quality), with bracketed values representing the % change to 2020.

Ecosystem	Non-protected, non indigenous	Protected area	Indigenous territory
Dry forest	0.66 (-6.23)	0.80 (-3.95)	0.81 (-2.46)
Guayanan ecosystems	0.84 (-5.57)	0.87 (-1.47)	0.88 (-1.84)
Mangroves	0.77 (0.77)	0.76 (0.76)	0.88 (0.88)
Moist forest	0.81 (0.81)	0.84 (0.84)	0.85 (0.85)
Montane forest	0.77 (0.77)	0.80 (0.80)	0.79 (0.79)
Montane grasslands	0.85 (0.85)	0.78 (0.78)	0.75 (0.75)
Savanna	0.70 (-2.67)	0.78 (-1.90)	0.77 (-2.58)
Swamp forest	0.82 (-6.59)	0.80 (-2.06)	0.86 (-0.15)
Várzea	0.81 (-3.04)	0.81 (-4.51)	0.85 (-0.63)

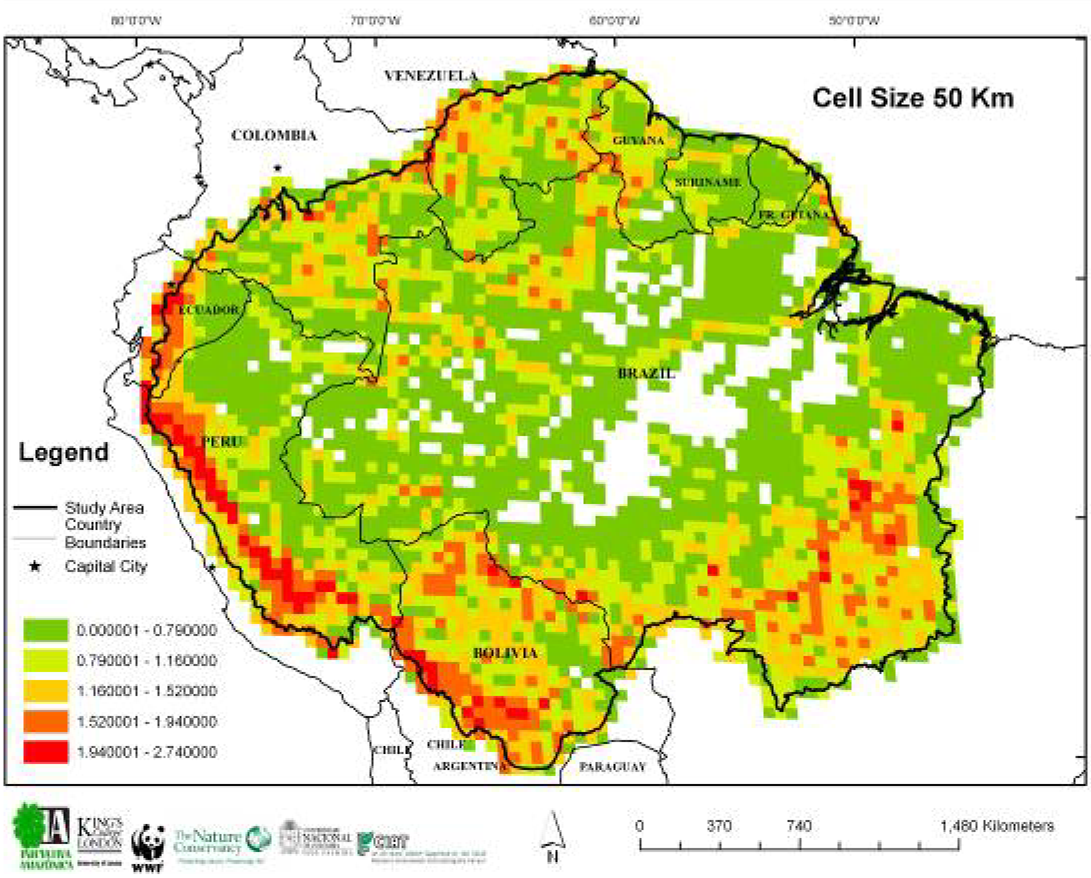
The habitat quality map for 2020 shows the greatest changes in the most accessible areas. The non-protected/non-indigenous areas show the highest loss in habitat quality--a likely outcome as these are the areas where accessibility will increase the most. The major ecosystems that show the greatest loss are dry forests, Guayanan ecosystems, swamp forests and *várzea*. Moist forests are least affected.

Species and habitat diversity was used as a proxy for ecosystem functioning. Although relationship between species diversity and ecosystem functioning is still under debate (Loreau et al. 2001), evidence does exist that indicates that species diversity is important to ecosystem functioning at large spatial scales (Bond and Chase 2002). There is now a growing consensus that species diversity maintains ecosystem stability in changing environments (Loreau et al. 2001).

For our analysis, the database of species distributions hosted by NatureServe was first processed to create maps of species richness for birds, amphibians and vascular plants. Second, multi-scale maps of ecological systems diversity (using a detailed map of 608 ecosystems) were created (at 20 km, 50 km and 100 km resolutions). The diversity of ecological systems in each grid cell was evaluated using a Shannon's diversity index. When the grid cell contains only one patch the diversity is zero, but increases as the landscape contains more types of ecological systems or as the distribution among types of ecological systems becomes more equitable (McGarigal and Marks 1994). Similar to the analysis of species distributions, these maps were used to compare patterns of habitat quality with regional patterns of ecosystem diversity (see Figure 2.8, three maps over the next two pages).



Cell Size 100 Km
VENEZUELA
COLOMBIA
GUYANA
SURINAME
FR. GUIANA
ECUADOR
BRAZIL
PERU
BOLIVIA
CHILE
ARGENTINA
PARAGUAY
Legend
Study Area
Country Boundaries
Capital City
0.000001 - 0.790000
0.790001 - 1.160000
1.160001 - 1.520000
1.520001 - 1.940000
1.940001 - 2.740000
0 370 740 1,480 Kilometers



Cell Size 50 Km
VENEZUELA
COLOMBIA
GUYANA
SURINAME
FR. GUIANA
ECUADOR
BRAZIL
PERU
BOLIVIA
CHILE
ARGENTINA
PARAGUAY
Legend
Study Area
Country Boundaries
Capital City
0.000001 - 0.790000
0.790001 - 1.160000
1.160001 - 1.520000
1.520001 - 1.940000
1.940001 - 2.740000
0 370 740 1,480 Kilometers