The Role Of Biodiversity In Climate Change Mitigation in Latin America (ROBIN)

PART 1 . Executive Summary

Tropical forest landscapes are hot spots for biodiversity and hold substantial stores of carbon. They are used by forestry, agriculture, nature conservation and other sectors, and they must provide for peoples' health, well-being and economic security. The aim of the EC's ROBIN project was to reconcile these many and potentially conflicting demands by understanding, measuring and quantifying the role of biodiversity in mitigating climate change and in providing other benefits to people. It addressed two main questions: do forests and forest landscapes rich in biodiversity store more carbon and deliver more ecosystem services than less biodiverse systems? And if so, what can we do to take advantage of this?

These questions are relevant to the Convention on Biological Diversity (CBD) and its 2020 targets. Answers will also inform the UN programme on Reducing Emissions from Deforestation & Forest Degradation (REDD+) which aims to enhance forest carbon pools by supporting the conservation, sustainable management and restoration of forests. ROBIN is particularly relevant to REDD+ co-benefits. ROBIN considers the impacts of land-use change in multi-functional landscapes in relation to IPCC Scenarios and is relevant to the achievement of the UN's Sustainable Development Goals.

ROBIN used data from field studies, remote sensing, land use and ecosystem modelling and participatory approaches. We worked at multiple scales (local, national - Mexico, Brazil, Bolivia and Guyana - and regional) using a common indicator framework. We used scenarios combining possible climate and land use futures with options representing how people and governments may respond. We improved two dynamic vegetation models (LPJmL-FIT and JULES) by including biodiversity more realistically. We tested the scenarios in the models to see how forest productivity, crop yield, carbon storage and other ecosystem services may be affected by future climate and land use change. We worked with a broad range of local people (farmers, foresters, government authorities, etc.) in three case study areas and used Fuzzy Cognitive Mapping to explore stakeholder options relating to land management, forest biodiversity, climate change and local needs.

ROBIN provided research evidence and products to support the following key messages:

- in relation to the role of biodiversity: biodiversity matters - biodiverse forests store more carbon and are more resilient to climate change than less biodiverse forests.
- in relation to monitoring: an indicator of ecosystem integrity can be calculated for data rich and data poor areas and has been used as a basis for a Mexican biodiversity monitoring programme.
- in relation to policies and management options: managing logged and secondary forests for biodiversity will help increase carbon storage and resilience.
- in relation to ecosystem functions: functional diversity and ecosystem integrity are linked to carbon storage, biodiversity and other forest benefits and can be easily monitored as part of a systematic approach to environmental management.
- in relation to climate change mitigation and other ecosystem services: spatial trade-offs among services change across spatial scales and contexts and ROBIN developed two decision-support tools to help assess options that are relevant to local or national situations.
- in relation to decoupling economic growth from environmental degradation: there may be creative opportunities for win-wins across bundles of services but the extent to which these are constrained by biophysical rather than socio-economic factors must be taken into account.
- in relation to benefits and human well-being associated: payments for ecosystem services and REDD+ schemes should be linked to agricultural policies targeted at smallholders.

Our spatial data warehouse for project data and ROBIN products is at www.conabio.gob.mx/robin
More information can be found on our web-site at www.robinproject.info

Part 2. Project Context and Main Objectives

2.1. The challenge and objectives

Tropical forest ecosystems are hotspots for biodiversity and play a key role in carbon storage and climate change mitigation programmes such as "Reducing Emissions from Deforestation and Forest Degradation" (REDD+) and similar "Payment for Ecosystem Service" (PES) schemes.

Currently we do not know what biodiversity is needed to sustain the ecosystem processes and ecosystem services needed for climate change mitigation or the delivery of social and environmental co-benefits. ROBIN's research will help fill this knowledge gap and provide policy makers and natural resource managers with simple decision support tools for assessing the likely outcomes of land management and policy options on biodiversity, carbon storage and other ecosystem services.

2.2 Working within the tropical rainforest landscapes of the Latin American region, the main objectives of ROBIN were to:

(i) quantify the role of biodiversity in terrestrial ecosystems in South and Mesoamerica in mitigating climate change;
(ii) quantify local and regional interactions between biodiversity, land use and climate change mitigation potential and the delivery of other key ecosystem services;
(iii) evaluate the socio-ecological consequences of changes in biodiversity and ecosystem services under climate change;
(iv) evaluate the effects of current climate change mitigation policies and actions on ecological and socio-economic conditions;
(v) analyse the impacts of alternative land-use scenarios aimed at maximising climate mitigation potential while minimising loss of biodiversity and ecosystem services; and
(vi) provide guidance on land-use planning and other climate change mitigation options with the aim of increasing carbon stores and avoiding undesirable ecological and socio-economic effects.

2.2. The General Policy context

The results from the project are relevant to the Convention on Biological Diversity (CBD) and actions to protect biodiversity and enhance its benefits to people. ROBIN is particularly relevant to the UN programme on Reducing Emissions from Deforestation & Forest Degradation (REDD+) which aims to enhance forest carbon pools by supporting the conservation, sustainable management and restoration of forests. ROBIN also considers land-use change in multi-functional landscapes and is relevant to food and energy security and delivery of the UN Sustainable Development Goals.

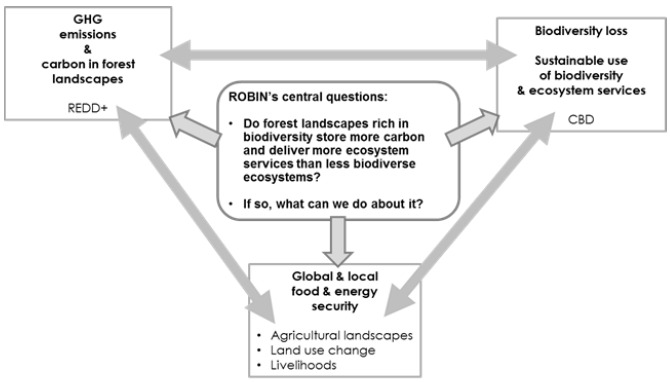


Figure 2.1. ROBIN's central questions and their relevance to programmes addressing inter-linked and cross-sectoral global environmental issues.

2.3. The UNFCC and REDD+ Context

The international climate change debate gained momentum in the early 1990s with the establishment of the UNFCCC in the aftermath of the 1992 Rio Conference. The probably best-known legally binding document linked to the UNFCCC was the 1997 Kyoto Protocol that contains specific GHG reduction programs, ignoring however emission reductions from deforestation and land-use change. The alarming increase of CO_2 levels in the atmosphere in recent years, as highlighted by the IPCC Fourth Assessment Report, gave way to the evolving concept of REDD. First put forward in 2003, it links reducing emissions from avoided deforestation and degradation to international carbon markets. REDD soon expanded to REDD+ to also cover activities of sustainable forest management and a consensus was reached on the need for implementing national REDD+ schemes based on participatory multi-stakeholder processes. The UN-REDD program has been set up to support (financially and technically) the efforts of developing countries to become 'REDD ready'.

The primary goal of REDD+ is reduction of greenhouse gas emissions consistent with the goal of the UNFCCC to achieve "stabilization of greenhouse gas concentrations in the atmosphere ….. ". REDD+ aims to enhance the role of forests as carbon pools by supporting the conservation and sustainable management of forests and the restoration of degraded forest areas. But REDD+ is also expected to contribute to multiple social and environmental co-benefits including: poverty alleviation, indigenous rights, improved community livelihoods, sustainable use of forest resources and biodiversity conservation. The implementation of REDD+ will be based on "payment by results" so policy makers and resource managers will need simple tools to assess the likely outcomes of management and policy options. Effective methods for monitoring, reporting and verifying (MRV) carbon stocks and co-benefits at community and national levels will also be needed.

ROBIN is particularly tasked to help stakeholders identify and implement actions that could increase or maximize these positive impacts**. A key research and policy challenge is to provide evidence of the links between biodiversity on forest ecosystems, ecosystem functions and ecosystem services and their influence on long-term human well-being and address the knowledge constraints that constrain more informed decision making related to climate change mitigation and adaptation.**

2.4. The whole-system conceptual and indicator framework

To meet these research objectives and the broad policy challenge, ROBIN adopted a whole system, inter-disciplinary approach based on the Integrative Science for Society and Science ISSE framework for socio-ecological systems (Figure 2.2).

One of the biggest challenges to define efficient and effective climate change mitigation options is to integrate our existing knowledge across sectors and scales. Achieving understanding on the interactions and feedbacks between sectors at different spatial levels as well as across ecological and social structures, could have a profound influence on the global mitigation capacity. The assessment of this complex social-ecological process requires analytical frameworks that are able to deal with the multi-scale, multi-sectoral interactions. Within this context, our framework was designed to facilitate integrated analyses of the impacts of land use and climate change on the social-ecological processes. Its key feature is that it provides a circular feedback loop, in which the links between the sectors within the social-ecological system are made explicit and measurable through a set of key indicators. This framework can be applied at different spatial levels in a consistent and flexible manner, allowing a multi-scale integrated assessment. The framework can also provide an understanding of the potential effects of changes in other 'land-use-related' policies not usually directly related to climate change mitigation, such as environmental and agricultural policies. Our framework thus provides the basic building blocks for a better understanding of the feed-back loops in the system, the interaction between scales and the testing of mitigation options.

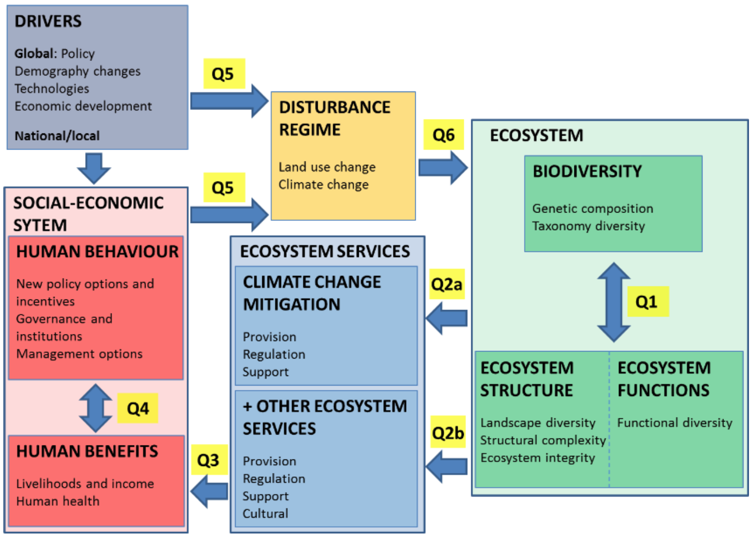


Figure 2.2. The socio-ecological research framework used in ROBIN to understand and manage the processes affecting links between biodiversity and climate change mitigation options. We will use this framework to address some of the key questions about the dynamics of the system:

Q1: How do changes in biodiversity affect key ecosystem processes that then affect the capacity of ecosystems and multi-functional landscapes to mitigate climate change?
Q2a and Q2b: How do changes in biodiversity and linked ecosystem functions affect climate change mitigation capacity and other key ecosystem services?
Q3: How do changes in climate mitigation capacity affect human outcomes (i.e. benefits to society) and what is the effect of taking into account other ecosystem services in this evaluation process?
Q4: How do changes in human outcomes affect human behaviours?
Q5: How do changes in policies and management options affect climate change and land use change?
Q6: How do changes in climate and land use affect the biodiversity and ecosystem functions?

2.5. The Indicator Framework

Based on the conceptual framework the ROBIN Project identified and used a set of 22 high level indicators to undertake integrated analyses of the impacts that land use change may have on social-ecological systems, at regional (Mesoamerica and South America) and national scales, under climate change scenarios. These indicators were structured according to the main conceptual boxes in the ROBIN analytical framework that covers: disturbance regimes (land use change and climate change), ecosystem components (including biodiversity and ecosystem integrity), ecosystem services (including climate change mitigation) and socio-economic system components. The indicators selected provide the basic building blocks for analysing the feed-back loops of social-ecological interactions for different land use types at different scales in the system, and therefore inform the key research questions in the project.

One of the criteria for selecting indicators was the potential to derive indicator thresholds, as part of a coherent approach to defining regional sustainability limits. For each potential indicator we identified whether it is appropriate to define a sustainability limit, what form that sustainability limit might take, and whether the limit is applicable at multiple scales ranging from national to local in the ROBIN context. The term 'sustainability limit' is used here to encompass concepts of both thresholds and targets, to accommodate different views from environmental and social sciences. They can therefore include: policy targets (e.g. CBD's no net loss of biodiversity by 2020); system threshold in terms of (ecological structures or functions (e.g. % woodland cover needed to main animal populations); legislative commitments, a legally binding threshold. (e.g. Reducing greenhouse gas emissions by at least 80% (from the 1990 baseline) by 2050) and social thresholds (e.g. levels of rural depopulation).

2.6. Methodological approach

Resources for additional data collection were minimal, so to address these challenging questions ROBIN was required to make creative use of existing data, models and tools. To do this ROBIN brought together an inter-disciplinary team from Europe and Latin America organised into 3 inter-linked modules:

Module 1 (Quantification of the role of biodiversity in climate change mitigation) quantified the spatial and temporal relationships between biodiversity, ecosystem processes and ecosystem services (CC mitigation) within ecosystems and within large scale multi-functional landscapes (addressing Q1 and Q2). This module made extensive use of remote sensing data and data from existing field sites. To ensure broad coverage of sites, ROBIN researchers collaborated broadly with other programmes that had access to field site data from Latin America such as through the Tropical Managed Forests Observatory (www.tmfo.org). Remote sensing was used creatively to estimate (surrogate) measures of climate change mitigation and biodiversity and for upscaling and downscaling between sites, landscapes, countries and regions.

Module 2 (Socio-ecological interactions and consequences of land use change and climate change in relation to biodiversity and climate change mitigation options*)* used the data and empirical relationships from Module 1 within an integrated modelling framework to look at the effects of future scenarios of climate change and land use on biodiversity, ecosystem processes and ecosystem services. Module 2 made use of existing models but in most cases adapted these to be more relevant to biodiversity related questions. Our integrated modelling approach was structured around the conceptual framework and was aimed at understanding the interactions between key drivers and pressures (e.g. climate and land use change) on carbon storage and biodiversity. We used models (or model platforms) covering land use change (CLUE), dynamic vegetation and land surface/ atmosphere interactions (LPJmL and JULES), ecosystem service modelling (ARIES) and biodiversity (e.g. Ecosystem Integrity). They were used in conjunction with a set of IPCC scenarios and within an assessment tool (QUICKScan) to evaluate current and potential synergies and trade-offs between biodiversity, climate change mitigation and other key ecosystem services related to human health (disease mitigation), food security and water security.

Module 3 (Options and solutions for using biodiversity and ecosystems for climate change mitigation) implemented participatory approaches to explore stakeholder views and governance effects and to ensure that recommendations for new policies or management options are relevant and useable. It also developed a decision support tool for natural resource and land-use management. Some of our field sites from Module 1 were also used for a series of stakeholder workshops to provide stakeholder informed perspectives on the factors affecting environmental degradation and human-wellbeing and their linkages to climate change mitigation and biodiversity objectives. In the forest landscapes covered by these sites we explored options and opportunities for maintaining and increasing biodiversity and carbon stocks while simultaneously delivering a wider range of other ecosystem services valued by the local communities.

PART 3 – Results and Outputs (25 pages max)

3.1 The role of biodiversity in climate change mitigation

3.1.1. Introduction

The first objective of ROBIN was to quantify the role of biodiversity in terrestrial ecosystems in mitigating climate change. We know that tropical forest ecosystems are hotspots for biodiversity and provide one of the biggest stores of terrestrial carbon (IPCC 2007) making their role in climate change mitigation programmes increasingly important (e.g. REDD, REDD+). Additionally, biodiversity plays a role in human well-being with a direct effect on provisioning, regulating and cultural ecosystem services, and an indirect effect on supporting ecosystem services. But currently we do not know how much biodiversity or what components of biodiversity are needed to sustain the ecosystem processes and ecosystem services needed for climate change mitigation.

3.1.2. Indicators of biodiversity

Biodiversity can be measured in many different ways, depending on the research objectives, scale of the study, and the approach taken. Singles measures of biodiversity normally capture only some of the key attributes of biodiversity, such as variability, function, quantity, and distribution.
As the type of biodiversity indicator used will have a large effect on any conclusions concerning these relationships, a variety of biodiversity indicators was used to assess changes in the spatial distribution, condition, quality, or stability and sustainability of ecosystems. Moreover the indicators selected were aimed at meeting policy requirements relevant to the assessment of biodiversity and the implementation of biodiversity and climate change mitigation policies. In particular, they should provide clear link s to ecosystem benefits, be quantifiable and easily measured using either remote sensing or in the field.

We divided biodiversity indicators into four composite indicators: taxonomic, functional, structural and landscape and also combined them into a single measure of "ecosystem integrity". The advantage of composite indicators is that they summarize many parameters dealing with specific attributes of biodiversity, allow scaling up field data collected in specific sites to the national and continental scale, and allow assessing biodiversity through time and allow monitoring biodiversity and climate change mitigation policies. The composite indicators used in ROBIN included: *taxonomic diversity* based on the number of species in an area; *structural diversity* based on national forest inventories and other systematic plot data; *structural diversity* derived from field data or medium resolution remote sensing data sets to provide a country and regional level proxy for biodiversity at a larger scale; and *landscape diversity* based on species richness with minimum area requirements for viable populations. The *ecosystem integrity* indicator ideally combines the four types of biodiversity indicators (taxonomic, functional, structural, and landscape diversity) to represent the overall "health" of the ecosystem. It also provides a simple measure of degradation that can be related to human activities and provides an integrated assessment of cross-sectoral impact of public policies on biodiversity and the capacity of ecosystems to provide ecosystem services.

3.1.3. Does biodiversity matter?

To assess the contribution of forest biodiversity to enhancing biomass and carbon storage across tropical forests of South and Central America we developed a conceptual framework (Figure 3.1.1) that represents how we believe the environment (climate and soils) affects forest biodiversity, and how the environment and biodiversity together affect forest carbon stocks and carbon dynamics.

This conceptual framework has been tested using field data collected in tropical forest sample plots established in sites spanning the complete latitudinal and climatic gradient across the lowland Neotropics, with rainfall ranging from 750 to 4350 mm y^{-1}. The studies range from single-site to multiple site studies, from studies with small and large ranges of environmental variation, and from studies carried out in old-growth forests[1] compared to those carried out in human-modified ecosystems systems.

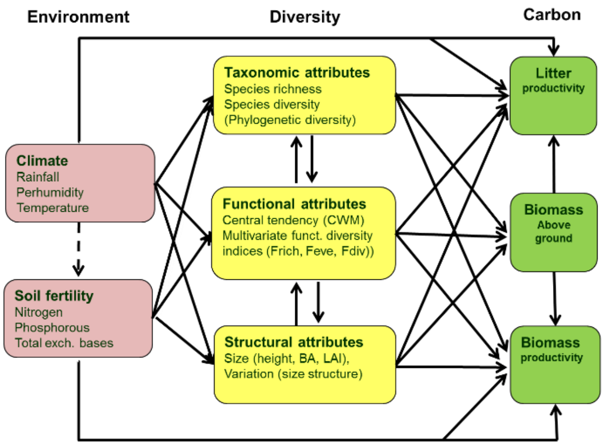


Figure 3.1.1. Conceptual diagram used within the ROBIN project to assess the relationship between diversity (i.e., vegetation attributes) and different components of carbon balance. The diagram shows how environment (purple boxes; climate, soil) affects vegetation attributes (yellow boxes; taxonomic attributes, functional attributes, structural attributes), and how environment and vegetation attributes together affect carbon stocks and processes (green boxes; aboveground biomass, biomass productivity, litter productivity). Continuous arrows indicate positive relationships, broken arrows indicate negative relationships.

In this work we focussed on three components of diversity: taxonomic attributes (e.g. tree species richness), functional attributes (e.g. stem wood density) and structural attributes (e.g. stem diameter). To determine the forest carbon balance we considered three components: (1) carbon stocks indicating how much carbon is stored in the standing forest biomass and soil (Mg ha^{-1}, about 50% of the vegetative biomass is generally made from carbon) (2) carbon sequestration indicating the rate at which carbon is removed from the atmosphere and taken up in vegetative biomass through primary production (Mg C ha^{-1} y^{-1}), and (3) carbon retention or longevity, indicating how long this carbon is retained in the vegetation (years).

Below we briefly describe our main results and conclusions that these observations have for potential climate change mitigation in 1) old growth forest, 2) secondary forest developing after slash and burn agriculture and cattle ranching, and 3) forest recovering after logging.

Biodiversity in old-growth forests

In old-growth forests the amount of carbon stocks, measured as above-ground biomass (AGB), increases with structural attributes (e.g., stand basal area, density of large trees, mean stem diameter). This indicates that structural attributes play an important role in determining AGB and could potentially be used as a metric to help monitor changes in carbon storage over time as these can relatively easily be measured at low cost and with simple tools by local communities in the field. The use of remote sensing together with field based measurements may also provide a straightforward way to scale up field data and produce spatially continuous AGB information over

[1] Old-growth forests are defined as forests that have not being subjected to recent human impact

large areas, thus providing a better understanding of global carbon storage and the impact of forest clearance.

In old growth forests the effect of species richness is scale dependent. At very small scale (0.1 ha) species richness had a positive effect on AGB where richness is lower and an additional species can still make a difference, while at intermediate spatial scale (1 ha) there was no effect as the species effect is saturated and the addition of new species has little effect. However, across large-scale environmental gradients species richness again had a positive effect on AGB, showing higher levels of AGB in sites with higher species richness.

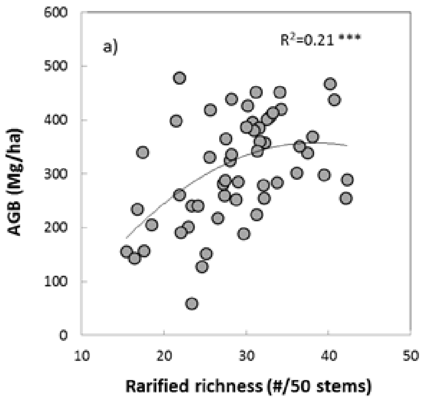


Figure 3.1.2. Biodiversity has a positive effect on above ground biomass and carbon storage.

When considering large environmental gradients, then AGB is most strongly driven by rainfall, whereas soil fertility had a negligible effect. The relation between rainfall and AGB shows an optimum at 2500-3000 mm y^{-1}. Because AGB shows an optimum in response to rainfall, predicted reductions in rainfall will likely have different implications for dry and wet forests. As rainfall decreases in wet forests, AGB is expected to initially increase until water becomes limiting, while in dry forests AGB will fall as drought stress increases.

We also confirmed that any increase in total biomass of the forest stand is negatively influenced by initial AGB of the stand, probably because of light limitations and competition between tree neighbours in full-grown old-growth stands. This implies that old-growth forests with higher carbon stocks have lower rates of carbon sequestration. Mitigation initiatives in a given forested area may need to focus more on the balance and trade-offs between carbon sequestration and maintaining carbon stocks.

3.1.4. What is the potential of human impacted forests?

We analysed aboveground biomass (AGB) recovery during secondary succession in 45 forest sites across the Neotropics. Secondary forests are highly productive and resilient, as biomass stocks increase rapidly during initial stages of secondary succession. Above-ground biomass recovery after 20 years was on average 122 Mg/ha, corresponding to an annual net carbon uptake of 3.05 Mg C/ha/yr, 11 times the uptake rate of old-growth forests. After 20 years biomass recovery varied 11-fold (from 20-225 Mg ha^{-1}) across the Neotropics. The recovery rate increased with water availability (higher local rainfall and lower climatic water deficit).

We analysed the rate at which forests managed for timber recovered their biomass stocks using data from permanent sample plots established in 10 sites across the Amazon Basin. These sites are part of the Tropical Managed Forests Observatory. Under the current timber harvesting intensities of 10 to 30 m^3/ha, logged Amazon forests recover their initial carbon stock in 7 to 21 years. This corresponds to an average annual net carbon uptake of 1.33 Mg C ha-1 yr-1, 4.5 times the uptake rate of old-growth forests. The rate of recovery of carbon stocks after selective logging depended almost exclusively on logging intensity, that is, on the amount of tree biomass removed or killed during timber harvesting.

3.1.5. Conclusions and recommendations on the role of biodiversity

In summary our field results indicate that diversity (measured as taxonomic, functional and structural attributes) had a direct positive effect on carbon stocks and carbon sequestration. Hence biodiversity conservation is important, particularly in old-growth forests. This leads to the following recommendations:

- Biodiversity matters for carbon stocks in these structurally complex hyper-diverse tropical forests. Therefore, biodiversity should be considered an integral component of policies and practices that will reduce the impact of climate change (e.g. REDD+), and not just a requirement related to co-benefits and safeguards.
- Mitigation initiatives in mature tropical forest should take into account possible trade-offs between carbon stocks and carbon sequestration in the decision process.
- Human-impacted forests (including secondary forests re-growing in abandoned agricultural areas and forest managed for timber) have higher net carbon sequestration rates than old-growth forests. These human-impacted forests sequester large amounts of carbon, and therefore, they should be considered in REDD+. Additional information is needed on total area covered by these forests, land use change dynamics and logging intensity.
- We need to produce biomass recovery maps that identify areas with high carbon sequestration potential for REDD+ programmes, or areas with high potential success for natural regeneration or restoration activities.

3.1.6. Ecosystem integrity as a composite indicator for measuring change in forest condition

Ecosystems provide us with a variety of goods and services simultaneously. There is mounting evidence suggesting that the provision of these ecosystem services, among them carbon sequestration, is related directly to ecosystem condition or ecosystem integrity. The evaluation of ecosystem integrity allows an assessment of the “health” of ecosystems relative to their “pristine” condition in the same location and, depending on the data used in its calculation, can take into account structural, functional and taxonomic components of biodiversity.

Ecosystem integrity, as calculated in Mexico from a combination of ground and remote sensing data, is correlated with changes in forest ability to absorb and store carbon as well as to the capacity to provide other ecosystem services (Figure 3.1.3). Ecosystem integrity in Mexican forests positively correlates with carbon storage (in terms of biomass). For example, forests in the peninsula of Yucatan show both high values of ecosystem integrity and high values of biomass. On the other hand, forests close to the coast in the Gulf of Mexico show low values of ecosystem integrity and also low values of biomass. These results indicate that a practical approach to increasing and maintaining carbon storage in a given ecosystem would involve the measurement, management and conservation of ecosystem integrity.

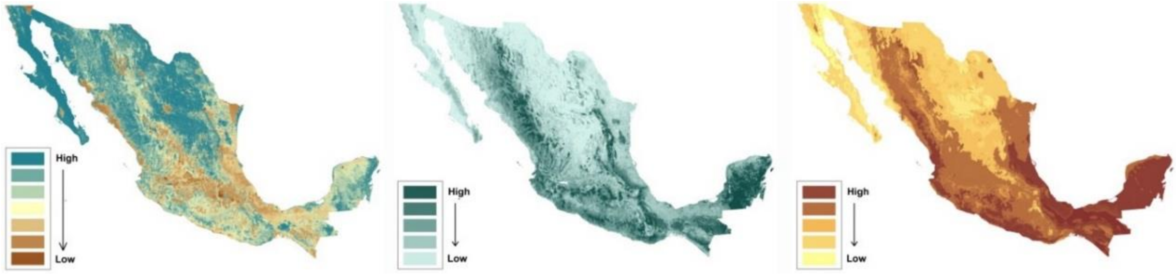


Figure 3.1.3. Evidence that ecosystems with lower integrity store less carbon and provide fewer ecosystem services. Maps of ecosystem Integrity and plant biomass in Mexico: left: Ecosystem Integrity; centre: Biomass; and right: correlation between ecosystem Integrity and biomass

In Mexico, this method is now being adopted as a way of consolidating existing systems in a nationally coordinated approach to monitoring and assessment of ecosystem degradation and its consequences. Ecosystem integrity is a suitable approach since it facilitates an integrated assessment of the impact of public policies on biodiversity as well as on the capacity of ecosystems to provide services needed for society. Finally, this approach can also be used to face the challenges of climate change and the construction of a sustainable future. Within Mexico the approach has been adopted by Governmental agencies responsible for studying, safeguarding, and monitoring terrestrial, marine, and freshwater ecosystems and has shaped the National Biodiversity and Ecosystem Degradation Monitoring System currently being implemented at a national level.

The approach is currently being discussed and explored outside the ROBIN project by Chile, Colombia and Peru within the Pacific Alliance. Opportunities also exist to apply the approach with in international initiatives (CBD, UNFCCC, IPBES) that recommend to integrate ecosystem-based approaches into their programmes for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development.

3.2. Effects of past land use change on ecosystem processes, carbon storage and climate change mitigation

Land use change is the biggest driver of changes affecting tropical forests in Latin America and the ecosystem services that these provide. We examined recent changes in land use and land cover and their effects on some indicators of biodiversity by: (1) quantifying the direct effect of land use change on biodiversity, carbon storage, sequestration; (2) determining the direct effect of changes in biodiversity on climate change mitigation capacity as expressed in lowered sequestration rates of carbon, and ecosystem integrity; and (3) assessing the potential of biodiversity over a range of REDD+ relevant ecosystems to boost carbon sequestration and maintain carbon pools. Here we present some results of the project concerning effects of land use changes on ecosystem processes, carbon storage and climate change mitigation was undertaken at national and continental scales.

3.2.1. National scale analyses

The concept of "ecosystem integrity" was developed as a practical approach to mapping biodiversity and developing quantitative relationships with land use and cover change (LUCC). At national scale case studies from Mexico and Brazil successfully tested the use of ecosystem integrity as a composite measure of biodiversity, ecosystem functions and ecosystem health that could be easily measured and related to land use change.

LUCC was analyzed for Mexico using the official LUC maps at a 1:250 000 scale and the main findings for the most important change processes (deforestation, forest degradation and natural regeneration) were presented in relation to direct and indirect drivers. Agricultural activities fostered by public policies are the principal drivers for LUCC, among which pastures have the highest impact on deforestation. EI was mapped with a suite of modelling techniques using all available systematic field data available and a set of GIS and RS products. Preliminary results for changes in EI between 2004 and 2007 based on a sensitivity analysis showed that impacts like roads and land cover change were very important drivers of EI dynamics. We also examined recent changes to establish empirical relationships between land use and land cover change and biodiversity loss.

A modified version of the method of mapping ecosystem integrity developed for Mexico was applied in Brazil. Whereas the approach in Mexico was based on a combination of field data and remotely sensed data, in Brazil the approach was developed solely on the basis of data from remote sensing. This approach is likely to be relevant to the majority of countries in Latin America and elsewhere that lack comprehensive field data.

3.2.2. Continental scale analyses

At continental scale we integrated ground data, remote sensing and spatial modelling to provide an assessment of deforestation patterns and the impacts on carbon (emissions) and changes in biodiversity. We used the Food and Agricultural Organization's (FAO) dataset developed for the Global Remote Sensing Survey. The information contained in the original dataset for each 10km x 10 km area provided data on forest gain, forest loss and net forest change between 1990 and 2000 and between 2000 and 2005. This was then compared with modelled data on carbon emissions, tree biodiversity, animal biodiversity and ecosystems services (carbon sequestration) to map the effects of land use change and identify areas where degradation risks are highest. Tree biodiversity was based on a dataset of 58 forest sites across Latin America where tree species were recorded between 2000 and 2010. Animal biodiversity was calculated using online maps (Jenkins, Pimm et al. 2013[2]).

Forests as a key part of climate-smart development in the tropics

The drivers for deforestation may vary among different regions. In order to find out the drivers leading to deforestation in South America, a global forest remote sensing survey (FAO) was analysed. From this analysis it was concluded that agriculture is responsible of almost 90% of the total deforestation. It is because of this that for reducing emissions from deforestation and forest degradation, forests have to be taken into account in the development of smart agriculture and development strategies. This includes efforts to foster sustainable supply chains, coherent multi-sector policies on the national (i.e. between forest and agriculture sector), and the development and implementation of landscape-scale solutions to land use that consider multiple objectives related to climate change mitigation, adaptation and food security.

Reducing carbon emissions also preserves biodiversity but magnitude varies regionally

When reducing emissions from deforestation, forest-related biodiversity is preserved (Figure 3.2.1). The figure emphasizes a series of important comparisons:

- the deforestation patterns (1990-2000) highlight the arc of deforestation in South America;

[2] *Jenkins, C. N., S. L. Pimm and L. N. Joppa (2013). "Global patterns of terrestrial vertebrate diversity and conservation." Proceedings of the National Academy of Sciences 110(28): E2602-E2610.*

- this pattern is correlated with those carbon emissions with Amazon forests having higher emission factors due to higher carbon stocks;
- deforestation area, carbon emissions and impacts on forest species diversity are correlated (especially carbon density and rarefied species richness) but there are regional differences; and that
- the impacts on animal diversity seems to have a somewhat different pattern (i.e. higher impact in Meso-America and in Western part of the Amazon).

These results show that REDD+ could provide biodiversity as co-benefits but that regional pattern should be taken into account.

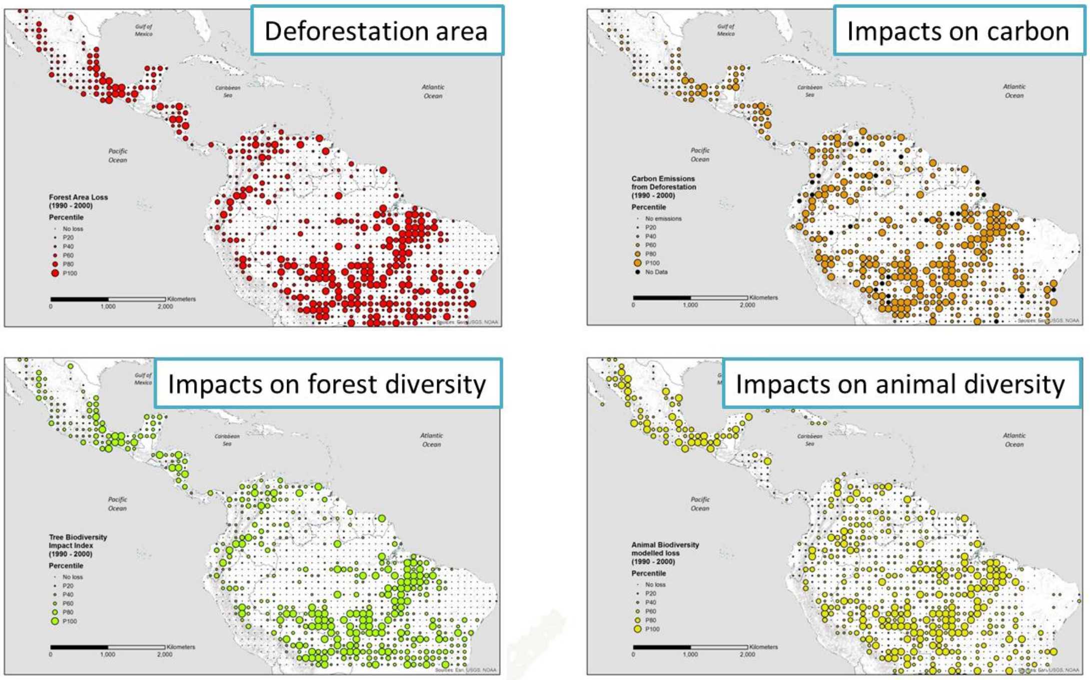


Figure 3.2.1. Comparing spatial patterns of deforestation (1990-2000 using FAO FRA RSS data), carbon emission from deforestation (impacts on carbon stocks), with those to deforestation-related changes in tree diversity (rarefied species richness) and on animal diversity. The values are expressed in 20% percentiles (20% of the total number of observations).

Biodiversity as key for forest resilience to climate change and reducing risk of reversals

Next to that, biodiversity fosters forest resilience to climate change by giving functionality to the forest. As a result, the risk of reversals or "failure" or REDD+ activities are reduced. So even if REDD+ activities are successful the need to have resilient forests is important to preserve them in the long-term under changing climate conditions. In this sense biodiversity is a safeguard for REDD+.

Enhancing forest (carbon stocks) requires functioning forest ecosystems

The ROBIN project has made important contributions in better clarifying the mitigation potential of the forest sink in the tropics – a previously under-researched topic. It has shown:

- the importance of various forest types (i.e. managed/degraded forests, secondary forests, and new forests/reforestation) in providing a large and previously unquantified sink; and that
- the effective sequestration of carbon in re-growing forests is very much related to biodiversity and the functioning of the forest ecosystem.

New data and impact for national and sub-national strategies and implementation

REDD+ as discussed under the UNFCCC will always have limitations in terms of how to consider biodiversity in implementation, since international programmes fail to be completely sufficient, clear and specific to regional situations. Thus, the key for integration between climate change objectives and those related to other conventions (i.e. UN CBD) will have to happen on the national and sub-national level. The ROBIN project has provided important new data and concepts to better include biodiversity concerns in the climate change mitigation activities and it is important that these findings have an impact on country specific strategies and how and where REDD+ activities can include issues on carbon, biodiversity, resilience and functioning of forest ecosystems in an integrated way.

REDD+ in terms of carbon performance may target areas with high carbon stocks in order to reduce emissions and preserve forests. It may further consider the distribution of tree diversity to look at areas of both high-carbon and high-biodiversity value or the other way around. Particularly when considering the forest carbon sink, the aspects of carbon sequestration potential and the ability of forests to recover after disturbances become of high-relevance. With a smart integration of ground-observations and remote sensing data, these maps can now be created with higher confidence and can provide a basis for targeting implementation. The presented results clearly highlight that there is a strong gradient between the Eastern Amazon and the Arc of deforestation, and the western and north-western Amazon. This gradient does not show in the carbon stock data alone and emphasizes the importance of such data and analysis to be taken into account for the planning and implementation of REDD+ mitigation options.

3.2.3. Conclusions from continental analyses

The results are summarized in the context on the ongoing discussions on REDD+ implementation.

Key messages related to tropical forests and climate change:

- Forest-related mitigation includes both sinks and sources and potential is ~25% of total greenhouse gas emissions
- No successful climate smart development/agriculture in tropical countries will be possible without considering forests

Key messages related to biodiversity and REDD+:

- Reducing carbon emissions also preserves biodiversity (a REDD+ co-benefit) but varies regionally
- Biodiversity fosters forest resilience to climate change and reducing risk of reversals (a REDD+ safeguard)
- Enhancing forest (carbon stocks) requires functioning forest ecosystems (a REDD+ requirement)

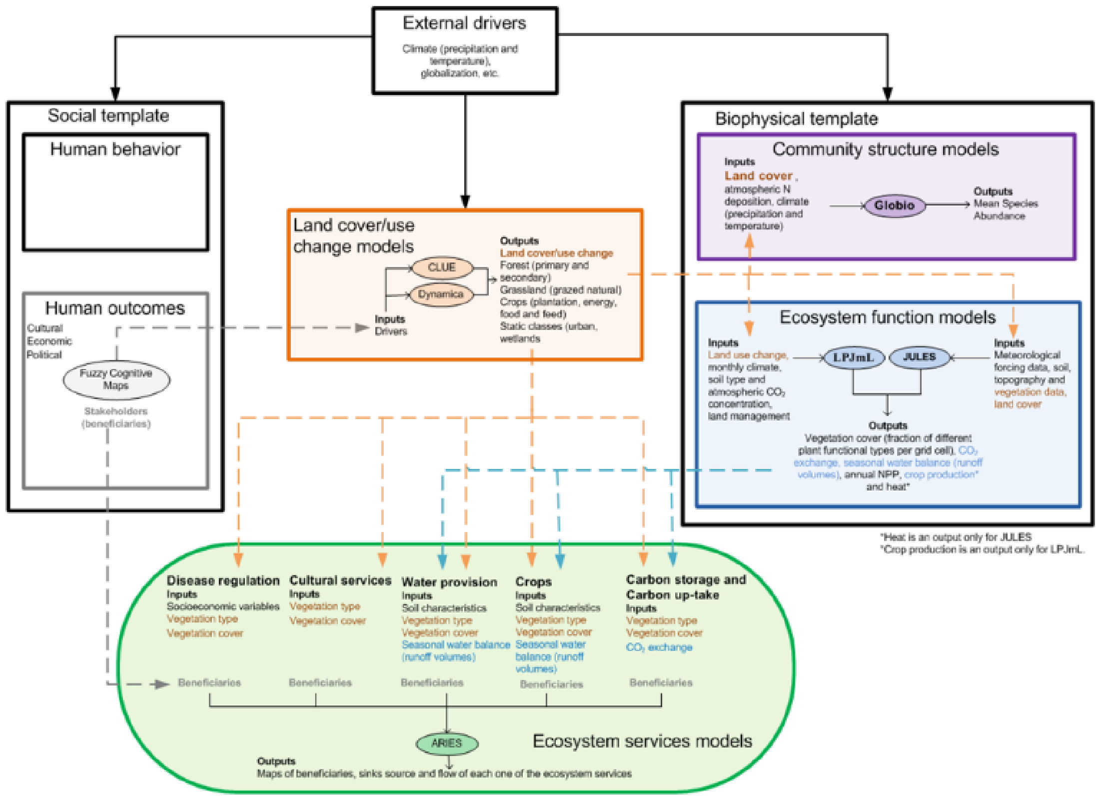
Key messages related to delivering knowledge for action:

- New data, for example on carbon sequestration, forest carbon tocks and tree species diversity, are available to underpin national and sub-national mitigation strategies and the implementation of REDD+.

3.3. Future impacts of alternative land-use and climate change scenarios on biodiversity and ecosystem functions

3.3.1. Integrated Modelling Framework

ROBIN analysed the impacts of alternative land-use scenarios in relation to biodiversity, carbon stores and ecosystem services using a set of loosely coupled models (Figure 3.3.1). These models examined the main components and linkages represented in the ROBIN analytical framework (Figure 2.2) using our agreed set of indicators (Section 2.5) and some of the new IPCC scenarios based on climate forcing and socio-economic pathways (Section 3.3.2).



Relationship between the conceptual framework proposed by Collins et al.(2011) and models in Robin. Solid lines show the relationship of external drivers as inputs for models and dashes lines indicate relationships between models.

Figure 3.3.1 Overview of the models used in ROBIN to model the whole socio-ecological system in relation to future scenarios of change.

3.3.2. Scenarios used in ROBIN

ROBIN scenarios were based on the developing IPCC 5th Assessment Report (AR5) scenario process, including the socio-economic context (Shared Socioeconomic Pathways -SSPs) and climate forcing (Representative Concentration Pathways – RCPs) that together form future scenarios. It was not possible to use all SSPs or RCPs so ROBIN selected a practical combination of scenarios and policies for use in the ROBIN project. These are summarised in Box 3.1.

The ROBIN project focuses on climate mitigation options and the role of biodiversity in tropical systems. The main policy mechanisms likely to be of interest are REDD+ type policies and their subsequent development to provide safeguards for biodiversity and ecosystem services provision (taking into account unintended consequences to issues such as water security, human health, food security and tourism). In order to provide a consistent framework within which to explore these ideas in the project, we defined a sequential set of policies which progressively focus on the key mechanisms in terms of land management. The policy options are progressive in that each is additive to the option previous to it. This makes the assumptions about how they would be implemented more straightforward, and allows direct comparison of the additional benefits of implementing a policy.

These policy options, which will be explored within each SPA cell, are: deforestation, degradation, re-forestation and afforestation, biodiversity and ecosystem services, as defined below. In all cases, the policy descriptions are strongly dependent on the SSP context, and will therefore be applied differently in each SSP and also within each country.

Box 3.1. IPCC scenarios used in ROBIN

Selected SSPs:

SSP1 – Sustainability (Heaven): Challenges are low for both adaptation and mitigation to climate change. This is a world making good progress towards sustainability, with sustained efforts to achieve development goals, reducing resource use intensity and fossil fuel dependency. Globally and locally there is a reduction of inequality, rapid technology development, and a high level of awareness regarding environmental degradation. Governance is efficient. In Latin America, efforts to reduce deforestation are successful, and there is increasing demand for sustainable products including green energy, which boost economic growth. Governments reinvest in measures which improve health and education.

SSP5 – Conventional development (Development first): Challenges are low for adaptation but are high for mitigation. This world stresses conventional development oriented toward economic growth as the solution to social and economic problems. The energy system is dominated by fossil fuels; human development goals are attained; there is a highly engineered infrastructure and highly managed ecosystems. In Latin America, the technofix attitudes mean significant progress can be made e.g. for ecosystem services, but may not benefit biodiversity, depending on interpretation. Growth of biofuel crops is low.

Policy options of relevance to the selected CLUE-ROBIN-Runs

[C0] - Reference in absence of Carbon-focused or other policies)

This policy option represents a lack of any policies to manage carbon stocks or additional safeguards. In the more extreme SSPs, deforestation and degradation continue or return to previous high rates, due to the abandonment of, or failure to enforce, existing policies. A severe example e.g. under SSP4 could be a return to forest clearance rates in Brazil between 1990 and 2005.

[C1]. Carbon focus 1 (preventing deforestation only)

[C2]. Carbon focus 2 (preventing both deforestation and degradation)

[C3]. Carbon focus 3 (preventing deforestation and degradation, promoting replanting)

[C3 + BD]. Carbon + Biodiversity (focus on Carbon and safeguarding biodiversity)

[C3 + BD + ES]. Carbon + Biodiversity + Ecosystem Services (focus on Carbon, biodiversity and considering other Ecosystem Services)

This builds on the Carbon + Biodiversity theme with the addition of a policy focus on managing for multiple ecosystem services, particularly greenhouse gas emissions, water supply and quality, disease control and tourism. This policy requires cross-sectoral considerations. A number of policies already being implemented in the region include: Payments for Hydrological Services (PSAH) in Mexico – for areas of hydrological importance; the Forest Law 7575 in Costa Rica, which recognizes four basic environmental services: GHG mitigation, hydrological services and water provision, biodiversity conservation and scenic beauty for ecotourism; the Iwokrama Research Site (PES scheme), implemented since 1996 in Guyana, which combines climate change protection with sustainable forestry and eco-tourism.

3.3.2. Modelling Land Use Change in Latin America

Forecasts of future land use patterns based on the scenarios and policy options described in Box 3.1 were modelled using the CLUE-S model. Eight land use classes were dynamically modelled into the future till 2050: forest, shrub-land, grazed shrub-land, grassland, grazed grassland, cropland for food, feed and fodder, cropland for food with perennial crops and cropland with energy crops. These outputs were used in other parts of the project as summarised in Figure 3.3.1.

CLUE output is given in the form of a time series of land use maps. Changes in land use can be seen from the maps (visually: amount of change, location of change). Overall the most prominent changes are the decrease in forested area and the increase in grazed land. This holds true under all scenarios. Relatively, cropped land could increase drastically in several countries (e.g. energy crops in Ecuador). CLUE output is given in the form of a time series of land use maps that will be uploaded into ROBIN's data portals.

From the continental runs, we see that the general implementation of policies that focus on carbon and biodiversity and that consider other ecosystem services has a noticeable effect on e.g. the rate of the decrease in forested area. However, most policies will be implemented at sub-national and national levels. Hence, the effect that the implementation of policies has in Bolivia, Mexico and the Amazon will better be projected by the runs at local scale.

Below, we show the CLUE original land use (2005) and future land use (2050) maps under three scenarios. Overall, in absolute sense (number of grid cells), most prominent changes are the decrease in forested area and the increase in grazed land. This holds true under all scenarios. Relatively, there can be large differences between land use types and countries. For instance, the percentage of cropped land could increase drastically in several countries (e.g. energy crops in Ecuador) at the expense of the percentage of forest. In these countries, the current deforestation rates are relatively large, which is translated into as high deforestation rates in the future (especially under scenario SSP5S).

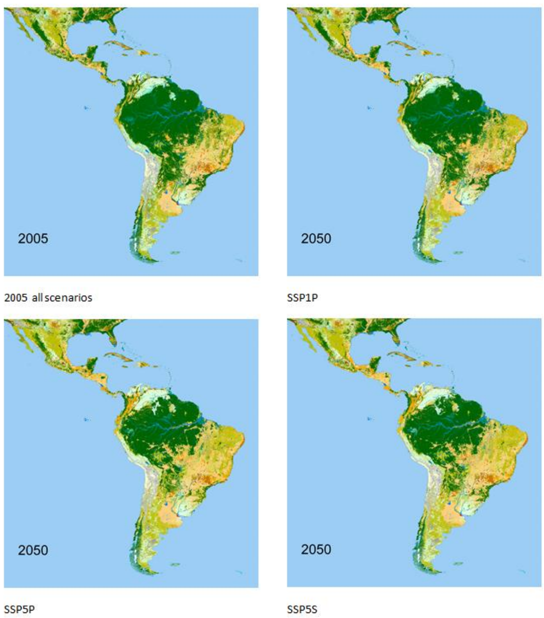


Figure 3.3.2. Example outputs from CLUE land use modelling. Original land use (2005) and future land use (2050) under three scenarios (see Box 3.1 for a description of the Scenarios)

The area allocated to energy crops is relatively small compared to the area of other dynamic land uses, both on the initial land use map as on the projections. Only for Brazil, a reasonably large area is covered by energy crops. Hence, for most other countries, the few grid cells that are allocated to energy crops appear where other land uses are less suitable. Therefore, for these countries the accuracy of the location of the energy crops is less.

3.3.3. Land Use Change Impacts on Habitat Connectivity and Population Viability

For many wildlife species, it is important to have large patches of habitat, for preventing local population extinction, and a certain connectivity across the landscape, enabling movement between patches and promoting gene flow. Habitat connectivity is thus an important factor for biodiversity conservation, and connectivity can be used as a proxy for biodiversity. Connectivity can be measured and modelled on the basis of maps and scenarios more easily than biodiversity. We presented two different habitat connectivity approaches produced by two different models: GLOBIO and GRIDWALK/LARCH.

We used two species for the analysis: the Jaguar (*Panthera onca*) and the Sloth (*Bradypus variegatus*). The Jaguar is representative for species that need large undisturbed areas for a viable population but can disperse through unsuitable habitat relatively well (large MAR but good disperser). The home range size of the jaguar is estimated to be ca. 30 km^2 (Soisalo and Cavalcanti, 2006), and it can disperse to a distance of 50 km. The sloth on the other hand is representative for species that don't need much area for survival, but have very restricted dispersal (small MAR but bad disperser).

We can conclude from this connectivity analysis that future land-use change under any scenario is going to further compromise biodiversity conservation, and this will be especially the case in a business as usual scenario, and with no environmental protection policies. The only real change for the better would be is to lower the demands for crops, and to focus on other sources of energy than biofuels. An environmentally friendly future (such as SSP1P), although good for the climate, is not necessarily always better for biodiversity conservation. Locally, the focus on energy crops instead of fossil fuel can lead to extra habitat loss. Also policies meant to protect natural habitat may lead to unwanted consequences as demand-driven land use change will happen elsewhere as long as the demands remain the same.

This analysis uses models (GLOBIO and GRIDWALK/LARCH) that make many simplifying assumptions. They do not take into account climate change impacts, only land-use change. They disregard many other factors such as hunting. So the results are best used to support discussions, and are not to be regarded as a prediction of the future.

3.3.4. Impacts of joint land use and climate change and biodiversity on tropical vegetation

The land use change outputs from the CLUE model provide the basis for assessing how climate change will affect carbon storage over the next 50 years and how this might be affected by biodiversity. Outputs from the CLUE model were used in two vegetation dynamics models to assess how key ecosystem functions and services that depend upon them will respond to environmental changes.

Modelling ecosystem functions and processes

Two dynamic vegetation models (DGVMs) JULES and LPJmL were used to project future land cover and vegetation change across Latin America for the 21st century. They were also used to quantify, model and map ecosystem services related to the carbon cycle, which can be linked to biodiversity and climate change.

The standard version of the Lund-Potsdam-Jena managed Land model (LPJmL) is a process-based dynamic global vegetation model (DGVM) which simulates the land-atmosphere carbon and water exchange influenced by the growth, production and phenology of 9 generic plant functional types (PFTs). For natural vegetation, each grid cell can contain several PFTs competing for light and water. For ROBIN, LPJmL was re-implemented to account for the competitive effects among trees with unique key trait combination forming a highly diverse community of possible tree growth strategies. This new model version, LPJmL-FIT was used to quantify the role of functional biodiversity on the carbon cycle, i.e. carbon storage and sequestration which has major importance for climate change mitigation.

The JULES model (Best *et al.*, 2011, Clark *et al.*, 2011) is a process-based land surface model designed to work within a climate and numerical weather prediction model of the UK Met Office. It includes a simple DGVM and also simulates the land-atmosphere exchanges of heat, water and carbon at the hourly time-scale. The plant carbon fluxes are used to calculate the growth of 5 generic plant functional types which is then used to calculate the dominant PFT within a grid based on their competition for light. For ROBIN, JULES was improved to represent the vegetation in Latin America by introducing broadleaf evergreen and dry-deciduous trees. The model was adapted to include a dry-deciduous tree PFT that responds to soil water limitation rather than temperature.

Within the ROBIN project, these models were employed to predict future vegetation changes across Latin America under land use and climate change scenarios. The land use change input came from the land cover model CLUE. The models quantify the impact of anthropogenic changes in vegetation cover on the regional to continental-scale carbon and water cycle. These outputs were then used as inputs for the ecosystem services models (Figure 3.3.1).

The novelty of the vegetation modelling approach in ROBIN is that patterns of functional and structural diversity are quantified applying two different dynamic global vegetation models (DGVMs) driven by the same abiotic forcing and land use change data. Through this approach, ROBIN accounts for the spatio-temporal heterogeneity in current and future environmental conditions. The DGVMs JULES and LPJmL have been extended in ROBIN to add ecological realism by improving their representation of functional biodiversity.

All data generated by JULES and LPJmL under the ROBIN project are secured in the ROBIN data repository for use within the project and externally.

Here we present just a few of the major results in the form of continent-scale maps based on the future coupled simulations of 3 land use scenarios from a land use change model (CLUE) linked to the LPJmL model and then driven by 2 emission scenarios from the latest IPCC AR5 report.

Carbon stock and carbon sequestration

We modelled the supply and value of ecosystem services using the LPJmL model. For carbon stock, supply is defined as the average amount of carbon stored in the terrestrial ecosystem. Three C pools were assessed: aboveground biomass (AGB), soil and litter. Carbon sequestration is defined as the ecosystem level balance between the amount of C that is taken up and the amount that is released. To calculate the economic value of C stock and sequestration, we considered the state of forest carbon markets in the studied countries.

Modelled total C stock under current land use was highest for the Amazon, followed by Mexico and Bolivia. The fraction of total C stock from each pool differed between countries. We found a positive ecosystem level balance of C sequestration in all studied regions. Nevertheless, the final balance was quite small because we found large values for C release compared to uptake.

The modelled total carbon stock value showed that the national carbon price market underestimates the value of this ecosystem service in the three countries. For C sequestration values, which are based on actual ecosystem level C balance, we found large areas with negative C balance, which are ineligible area for credits in global market.

We looked at how much carbon (C) is stored and sequestered in Mexico, Bolivia and the Brazilian Amazon under current land use conditions, at the change in C stock and sequestration as a result of past changes in land use, and at the relevance of our results to the design of policies. We found that:

- Total country level carbon stocks were highest in the Amazon, followed by Mexico and Bolivia. There was a small, positive ecosystem level balance of C sequestration in all studied countries.
- Carbon stocks and carbon sequestration have decreased in all countries as a result of past land use changes.
- Total carbon stock value is two times greater than the value recognized by national price markets in the countries studied, while the eligible area for C sequestration credits is overestimated in the global market.
- We recommend that estimations of the economic value of the carbon tropical forests can store and sequester need to take into account different C pools and ecosystem level C balance

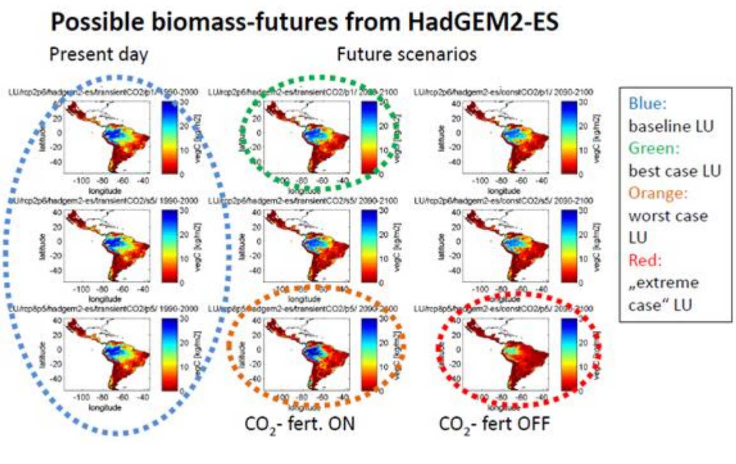


Figure 3.3.3. Present-day and future vegetation carbon maps from standard LPJmL for all tested RCP and land use scenario combinations under the climate forcing of the GCM HadGEM2-ES. Left column: avg. vegetation carbon from 1990-2000. Middle column: avg. vegetation carbon from 2090-2100 including the CO_2-fertilization effect. Right column: avg. vegetation carbon from 2090-2100 at constant CO_2 (atmospheric concentration frozen at year 2000). Large-scale projected shifts of the tropical rainforests biome where vegetation carbon is high (>25kg/m²) are visible as the blue areas on the maps. The "best case" / "worst case" scenario under land use change including CO_2-fertilization is marked in by a green / orange circle. The extreme case without CO_2-fertilization is circled in red.

Resilience: biodiversity has a direct effect on carbon stocks and forest biomass resilience

Both DGVMs were extended and improved to represent different aspects of functional and structural diversity of vegetation. In doing so, a special focus was placed on modelling tree diversity in the Amazon region because it is the largest remaining natural forest with high tree functional diversity in Latin America and is of critical importance for the global carbon cycle and its feedbacks on the climate system.

Major trends are that the forests in the Amazon region will be dramatically reduced in the worst case scenario under strong climate forcing (RCP 8.5). Under low climate forcing (RCP 2.6) and assuming a strong fertilization effect, however, vegetation carbon is projected to remain stable across Latin America and even to increase in the Amazon region. The model results further show that land use change has a considerable impact on landscape fragmentation, whereas the changing climate may cause large-scale biome shifts in the second half of the century from closed to open forests in the best case scenario and from moist rainforests to deciduous forests and savannah-type biomes in the worst case one.

Using the LPJmL-FIT model we also found compelling evidence that the biodiversity of the Amazon can ensure its resilience under climate change. Model simulations showed that a naturally diverse forest is able to recover its biomass and height structure after several hundred years under predicted future climate conditions. Our results provide the first evidence that plant trait diversity acts as an insurance against climate change impacts across large spatio-temporal scales by maintaining biomass resilience.

From this we conclude that:

- Biodiversity is an effective means to mitigate climate change in the Amazon basin and beyond, and should no longer be reduced to a co-benefit of ecosystem conservation – this supports the conclusion of the analysis of empirical data on biodiversity and carbon storage reported in Section 3.2.
- The adaptive capacity of trees should be an integral part of ecosystem model forecasts that evaluate the future status of tropical forests as a carbon source or sink.

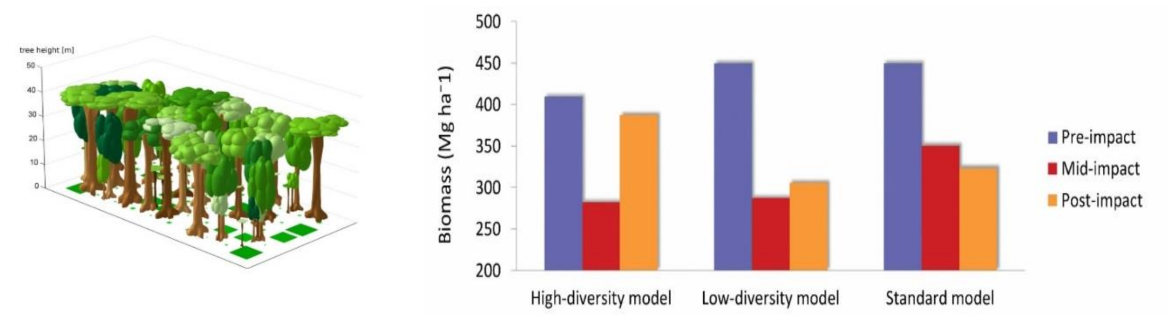


Figure 3.3.4. Simulated biomass of a forest site in the Amazon with different levels of biodiversity. Forest recovery after severe biomass reduction through climate change occurs only when biodiversity effects are incorporated in the model.

Conclusively, the new methodology of representing functional diversity in DGVMs and the simulation results enable to test biodiversity-related hypotheses, such as that carbon storage changes with biodiversity, by associating changes in functional and structural diversity on ecosystem-level indicators of plant performance, e.g. biomass. Due to the novelty of the approach with the improved DGVMs, the large-scale spatial and temporal patterns of these relationships are still vastly underexplored, but will be investigated in the final year of the ROBIN project.

3.4 How will the interactions between land use change, climate change and biodiversity affect key ecosystem services including carbon storage?

3.4.1 Climate change and ecosystem service trade-off analyses

Climate change will alter the way we utilise land across the globe and will change the rate and balance of natural processes such as carbon sequestration. As a result, the ecosystem services provided by natural systems will most likely be diminished, with consequences for human wellbeing and economic productivity. The ROBIN project used novel mixture of modelling techniques to assess these future climate impacts on a range of ecosystem services.

Climate change will alter the world we know in many different ways. The way we use land will change as some crops are no longer viable to cultivate in their traditional geographical regions, and we would need to change to alternative crop types, or to novel ways of growing existing varieties. The rate and balance of natural processes like flooding regulation or carbon sequestration will adapt to changing rainfall and temperature patterns. This will have far-reaching consequences for the ecosystem services generated by our landscapes. The consequences for human well-being range from reduced crop yields and income to farmers, human health impacts as insect-borne diseases spread, and greater social and economic damage from extreme natural events. There may also be opportunities such as the potential to grow crops in new areas, previously limiting to growth.

The design of development policies towards sustainability needs to take into account the trade-offs that emerge from them. The central questions addressed here are: i) is fostering climate change mitigation in line with or opposed to fostering biodiversity conservation, agricultural production, and water availability?; and ii) how much do these alternative policies align with the needs of different stakeholders? The resulting difficult choices are particularly important for the case of tropical forests but more information is needed on the nature of these trade-offs into the future under alternative climate change and alternative development scenarios at different spatial scales.

Future scenarios of climate and socio-economic change were used to assess these trade-offs for Latin America to 2050 using the three scenarios summarised in Box 3.1. To evaluate the effects of these scenarios on ecosystem functions we combined model outputs from the land us change model (CLUE) and the dynamic vegetation models (LPJmL and JULES) with the ARIES (Artificial Intelligence for Ecosystem Services) modelling platform. We used these model output with the QUICKScan tool (Section 4.2.4) to assess the main trade-offs between biodiversity, climate change mitigation measures and other ecosystem services and human well-being at national scale and in local case study areas**.** Country level study areas included: Mexico, Bolivia, the Brazilian Amazon and Guyana. For each of the countries a local study area was assessed: the Southern Coast of Jalisco, for Mexico, the Tapajós National Forest in Brazil and the Guarayos province in Bolivia.

3.4.2 What are the socio-ecological consequences of future climate change on ecosystem services?

We modelled a total of thirteen ecosystem services. Some of the main results are summarised below.

Carbon sequestration. A positive, but small, ecosystem level balance of carbon sequestration was found for all studied regions, due to elevated heterotrophic respiration. Our results suggest that areas with high aboveground carbon uptake do not necessarily show a positive ecosystem level carbon balance. Total country level carbon storage changed little into the future except for the high climate forcing and conventional development scenarios. Instead, important increases in both uptake and release of carbon were observed under high climate forcing. All scenarios showed carbon release higher than levels agreed as targets for the studied countries.

Water flow has increased in all countries as a result of past changes in land use for the three countries. Absolute water scarcity, jeopardizing food security, agricultural yield and industrial activities, was found for large fractions of Mexico and Bolivia for current conditions and especially under high climate forcing. Increased water stress was observed for all future scenarios, but was particularly dramatic under high climate forcing and conventional development.

Crop yield increased for both climatic scenarios and for the three countries, being highest for the scenario for high climate forcing. Some areas showed clear yield decreases mostly in response to changes in temperature regimes. Large uncertainties in our results were associated, among other sources, to data scarcity and to our current inability to project the impacts of severe pest outbreaks or weather extremes. A net increase in areas available for grazing was predicted for all future scenarios, but large uncertainties due among other sources to the difficulties of integrating extensive free range cattle farming were associated to these results. Calibration and validation of greenhouse gas emissions are currently ongoing.

The regulation of *Cutaneous (CL) and Visceral Leishaniasis (VL),* caused by protozoan parasites transmitted by sandflies with high global impacts, was linked to land use change and to temperature seasonality. Habitat fragmentation increased human exposure to CL, and VL. Urban land cover and that of irrigated lands was important for the regulation of VL and edge of perennial crops and forest cover for CL. CL was predicted to increase up to 4 fold in spatial extent under low climate forcing and conventional development, while VL increased up to 3 fold under high climate forcing and sustainable development. The tight link between increased *Leishmaniasis* and fragmentation needs to be taken into account for the design of REDD+ schemes.

Patterns and trade-offs. Preliminary explorations of the links between biodiversity and ecosystem services confirm some previously expected patterns. Ecosystem integrity was negatively correlated with cattle production, positively correlated with carbon storage, and percent natural vegetation was negatively correlated with carbon uptake. Further work will be needed to confirm apparent changes in the nature of these correlations among countries and when using ecosystem integrity or percent natural vegetation. Under future scenarios carbon storage consistently increased with percent natural vegetation, while evaporation, interception, crops and cattle decreased, as the result of the functional relationships assumed in the construction of the corresponding models.

Preliminary explorations of trade-offs among ecosystem services suggest that increased carbon sequestration correlates negatively with carbon stocks, water flow, crop and cattle production and positively with the regulation of cutaneaous *Leishmaniasis* under current conditions. The nature of the correlations among trade-offs differed among countries, and further explorations are needed to explore how much these differences emerge from the expression of different drivers operating in different countries or from the differential data availability among them. Yet, these results highlight the importance of the strong trade-offs that emerge from policies aimed at increasing climate change mitigation only.

At multiple spatial scales, a Bayesian approach and the use of ecosystem integrity can provide a system wide perspective of the complex interactions between biodiversity, ecosystem services and human well-being. These approaches are being currently developed for Mexico and Brazil to support the design of national level REDD+ policies.

Human well-being. We also explored how ecosystem services link to well-being indicators at national and local scales. Results have been summarised at municipality level to analyses relationships with social and economic data. Initial results from the Mexican state of Jalisco indicate increased well-being at the cost of ecosystem degradation. They also suggest that the greatest challenge is to make the contributions from ecosystem services to well-being more visible. A framework for doing this is suggested.

We have also begun to assess the spatial patterns of bundles of ecosystem services and their relationships with biodiversity through the use of a land use intensity index. These analyses reveal which services are co-located in space, and whether optimal groups of services differ among socio-economic context. Assessing these patterns under the alternative scenarios into the future will show to what extent REDD+ type policies can influence ecosystem service provision and well-being.

Summary
The information described in this report will be integrated with a recently developed analytical framework. We will build efficiency frontiers that to depict the highest possible values of bundles of ecosystem services and biodiversity indicators. This approach has already shown where there may be creative opportunities for win-wins across bundles of services although the extent to which these are constrained by biophysical rather than socio-economic factors needs to be taken into account.

A wealth of information has been generated by the ROBIN project to assess how understanding of the trade-offs between biodiversity, ecosystem services and human well-being under current and future scenarios can be used to inform the design of REDD+ policies. Most of the corresponding analyses that will allow this integration are currently been undertaken.

ROBIN project outputs will feed into the 'QuickSCAN' decision support tool (Section 4.2.4) to help communicate project findings to policy makers, NGOs and other stakeholders in the EU and Latin America. The tool will allow data exploration, including comparison and trade-offs between ecosystem services and other indicators. In particular, it will enable the exploration of complex trade-offs between biodiversity, ecosystem services and human well-being at different spatial scales.

3.5. Analysis of stakeholder-driven scenarios and options for biodiversity-based climate change mitigation

3.5.1. Introduction

As part of our work *to provide guidance on land-use planning and other climate change mitigation options* we have completed workshops in Bolivia, Brazil and Mexico using methods described in a ROBIN "handbook for the participatory process" (Section 4.2.2). The objective was to identify options for the integration of biodiversity and ecosystems in climate change mitigation through participatory scenario development and optimal land use appraisal.

A series of three series of stakeholder workshops were performed in the case study areas of Guarayos (Bolivia), Flona Tapajós (Brazil) and Chamela (Mexico) to map local present and future environments and drivers of change and select options for integrating biodiversity in climate change mitigation.

3.5.2. Results

Results from the first round of workshops indicate that biodiversity loss and deforestation are likely to continue in the near future but that the implementation of adequate agricultural policies, jointly with good coordination of policies and institutions, could lead to less negative environmental consequences.

From the 2nd SH workshops and a state-of-the-art review on current approaches to CCM in Latin America we are identifying options for delivering favourable outcomes. These options have been incorporated into a multi-criteria assessment tool to support decision-making on land use and natural resource policy development.

In the 1st workshop, the present situation in each case study site was mapped using Fuzzy Cognitive Mapping (FCM) (Figure 3.5.1). Stakeholders identified deforestation as the central factor in the mapping, with agricultural expansion considered as being one of the strongest causes of deforestation in each site.

In the 2nd workshop, stakeholders were asked to develop a FCMs of the future (2050) based upon contextualised IPCC-guided socio-economic scenarios. Stakeholders developed two diametrically opposed local scenarios of each case study site: positive (good life/ desired) and negative (bad life/ undesired). The future positive maps were driven by factors such as access to health and education and articulation of public bodies (Brazil); access to credit, institutional coordination and new infrastructure (Bolivia) and responsible, functional government and training and education (Mexico).

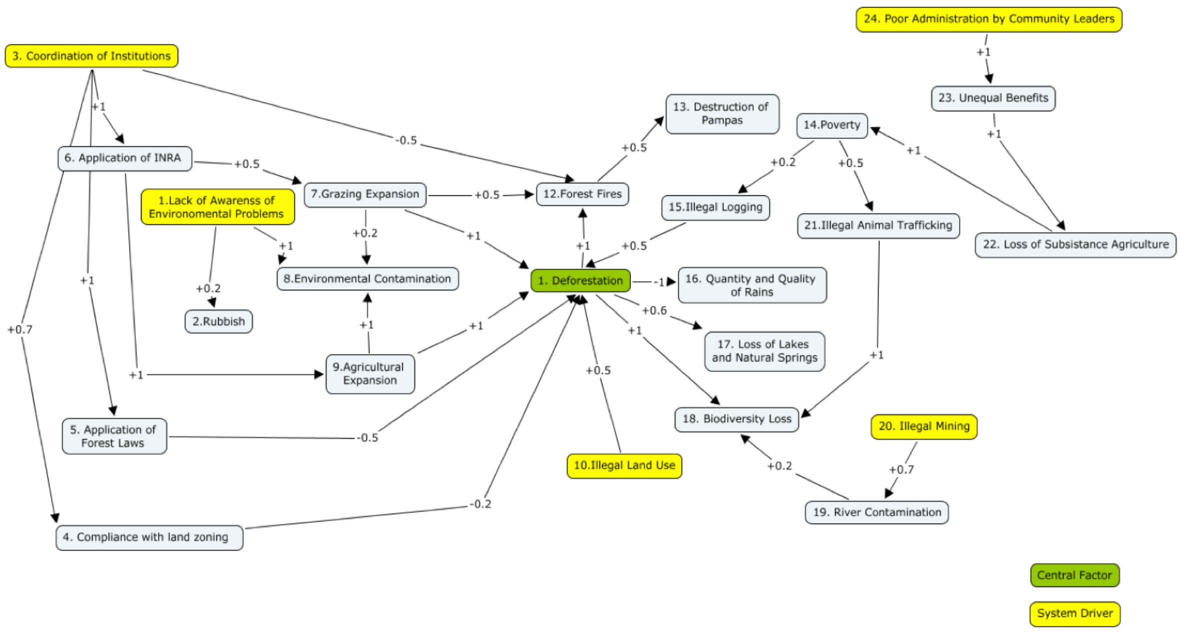


Figure 3.5.1. An example of a Fuzzy Cognitive Map produced in a facilitated workshop showing concepts, factors and their relationships to deforestation as agreed by the local stakeholders.

In the 3rd workshop, in Bolivia and in Brazil, potential options to mitigate climate change and conserve biodiversity were selected. Options were initially selected from the future positive FCMs developed from the 2nd round of workshops and were prioritised using the Analytic Network Process (ANP). Stakeholders selected and characterised additional options and prioritised them all using participatory voting. Stakeholders in Bolivia selected technical training, programmes to assist subsistence farmers and improving land use implementation as the most preferable options.

Whereas in Brazil: governmental coordination, investment in health and education and programmes to aid integration of agricultural and forestry activities were prioritised as the three most important options.

Conclusions

Stakeholders in Bolivia prioritised the following three options; technical training, programmes to assist subsistence farmers and improving land use implementation and building a database of land uses as being the most important. These three factors were characterised by stakeholders to have high social acceptance, but with moderate-very high costs of implementation, but all were considered to be compatible with present legislation. Whereas in Brazil: governmental coordination, investment in health and education and programmes to aid integration of agricultural and forestry activities were voted as being the most important. These options were found in general to have considerably high social acceptance, with high levels of associated implementation costs and widespread compatibility with present legislation.

The results indicate that those policy options selected would receive widespread social acceptance, but would not be without costs both economically and legislatively.

3.5.3. Multi-scale perspectives

In addition to the local level participatory development of policy options selected by stakeholders in participatory workshops described in Section 3.5.2, we performed a multi-scale approach to identify options for the integration of biodiversity and ecosystems in climate change mitigation at national and provincial scales. . At the national scale we analysed the drivers of deforestation across Latin America and the Caribbean. At the provincial level, bio-economic modelling was used to assess potential policy options for forest conservation and climate change mitigation in agro-ecosystems. Using this multi-scalar approach we developed a suite of options that could be developed and used by decision makers to integrate biodiversity and ecosystems in climate change mitigation.

National scale assessment of drivers of deforestation

As part of this multi-scalar approach, this research identified socio-economic, institutional, biophysical and technical factors that determine deforestation at the national scale across Latin America and the Caribbean, which has contributed to the characterisation of different regional deforestation patterns. To achieve this, statistical analysis and econometric modelling were performed using a database developed for 27 Latin American and Caribbean countries, containing over 70 variables (biophysical, socio-economic, agricultural, technological and governance) for the years 2000, 2005 and 2010.

This national scale analysis developed both statistical analysis and econometric modelling to characterise said deforestation patterns, whilst identifying explanatory variables of deforestation across Latin America and the Caribbean. The analysis firstly demonstrated that countries could be grouped together using two endogenous and independent variables, forest cover and deforestation rate. Further, it has identified five clear clusters in which the 27 countries could be positioned, depending upon their forest cover and rate of deforestation. The econometric analysis highlighted that total population growth, male and female mortality rates, a corruption metric and an instrumented forest cover variable (which is estimated from arable land area, permanent crop area, rural population growth, and a rule of law metric) could explain a considerable level of the variation (68%) in deforestation across Latin America and the Caribbean between 2000 and 2010.

This analysis has demonstrated that patterns and drivers of deforestation are subtly different across countries; therefore policies developed for conservation or climate change mitigation should consider localised differences. It also highlights that governance, economic and social factors are determinants of these national differences. Using this analysis, policy development consideration should not only address the immediate threats of deforestation, but also should address the diffuse threats and focus upon the development of social and institutional mechanisms to support development and conservation.

Provincial scale bio-economic modelling

The provincial scale analysis was formulated using data collected from extensive fieldwork in the Province of Guarayos, Bolivia[3]. As part of this fieldwork, 31 semi-structured, informal, one-one interviews were performed with farmers, agricultural experts and technicians in two of the three municipalities of the Province. The information collected from the fieldwork and enriched from a review of the literature and national statistics was processed, and farms were grouped together using cluster analysis based upon their inherent characteristics into representative farm types. These farm types were subsequently specified using a multi-period optimisation bio-economic model, permitting the simulation of various policy measures. Four policy measures (economic incentives, disincentives and enabling measures) were analysed to identify their efficacy for conserving ecosystems within the agro-forestry systems of the Province of Guarayos. A similar fieldwork has been performed in Brazil[4] where over 70 interviews were performed with farmers, agricultural experts and technicians across three municipalities of the State of Pará, where a similar bio-economic model is being developed to simulate the impacts of potential policy options.

The development of the model and simulation of the individual impacts of policy options on both conservation and income highlighted a number of conclusions. Firstly, whilst considering environmental protection and the trade-offs with socio-economic development, the socio-economic optimal solution for the individual may not be the societal optimal. Further, the outcomes of the modelling suggest that the application of policy measures can be duplicitous depending upon the farm type and should be context and site specific. On one farm a policy could be largely beneficial, whereas the same measure, in the same region, could result in a distinct outcome on another; therefore consideration of this should be made before enforcement. To conserve forests in regions where deforestation has not already been banned, will require high compensation costs and in turn large public expenditure. The development of economic, agricultural and nature conservancy policies will need to be integrated and coordinated in the future to find synergies and develop a balance of actions for the future.

3.5.5. Conclusions and recommendations from the multi-scale assessment of deforestation

From this multi-scale analysis a number of patterns have emerged that appear to repeat themselves. It appears imperative that for effective conservation of ecosystems that there is the provision of cross-ministry and local-national scale governmental coordination. This provision appears fundamental, not only to direct coordinated and coherent policies, but also to initiate the

[3] Biodiversidad y bienestar humano ante el cambio global en áreas tropicales protegidas de América Latina. Project No.: AL13-PID-18. UPM Grants for activities with Latin American countries. Universidad Politécnica de Madrid, International Relations Office.

[4] Biodiversidad y cambio climático en la Amazonía: perspectivas socio-económicas y ambientales. Project No.: AL14-PID-12. UPM Grants for activities with Latin American countries. Universidad Politécnica de Madrid, International Relations Office.

integration of environmental, agricultural and development policies. Over a longer period the benefits of such policies would benefit regions and countries as a whole, both socio-economically and environmentally. This therefore would support the idea that the most effective policies can improve well-being at a local-scale.

Finally, this analysis has demonstrated that one-size fits all policy options are very unlikely to be successful. Therefore, policies should be tailored specifically for each farm, province and region, rather than implementing one policy per country. It has been repeatedly shown throughout this document and its predecessors the heterogeneous patterns of change that affect each local, province and country. To achieve such complex, tailored and site-specific policy development will require considerable governmental effort and may be highly dependent upon improved multi-scale governmental coordination and policy integration.

The over-arching conclusion is that environmental policies should be integrated with agricultural and development policies to be successful. In addition:

- Scale matters: Zooming down to the local scale demonstrates the link between socio-economic and environmental issues.
- Stakeholder's perceptions of the present environment were similar across the case study sites: biodiversity losses, deforestation and poverty considered to continue in the immediate future. However, visions of a sustainable future diverge: Brazil focusing more on societal and institutional development, in Bolivia on technical and agronomic factors.
- Stakeholders generally selected institutional and political coordination as their preferred option for biodiversity conservation and climate change mitigation.

3.6. Guidance on land-use planning and other climate change mitigation options

ROBIN's programme of research was primarily designed to contribute scientific evidence concerning the role of biodiversity in climate change mitigation that would inform decision making at multiple levels.

In addition to this it produced a number of specific reviews, tools and products that or of direct use to decision makers. These are described in the next Section on "Impact, Products and Dissemination".

3.6.1. Review of Current approaches to Climate Change Mitigation in Latin America

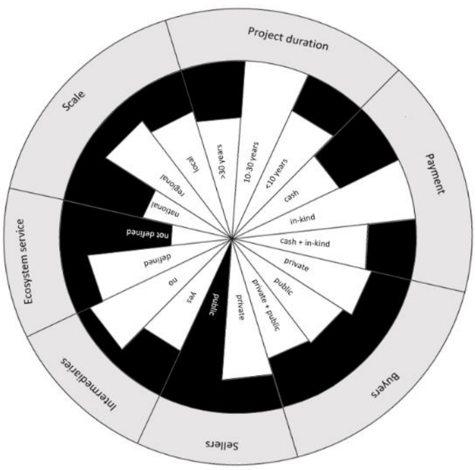
The ROBIN project undertook a state-of-the-art review on current approaches to climate change mitigation (CCM) in the forest sector in Latin America, particularly in relation to the REDD+ concept of reducing emissions from avoided deforestation and degradation to international carbon markets. The review include a comparison of 40 Payment for Ecosystem Services (PES) cases which produced a set of recommendations on factors related to successful schemes.

With growing climate change concerns, the concept of REDD+ as an approach to reconciling forest conservation with productive activities has taken centre stage in international forest conservation debates. The operational principles underpinning REDD+ however are far from new. Especially Latin American countries have a long track record in integrated conservation and development projects, and some (e.g. Costa Rica and Mexico) also have a history of ecosystem payment schemes. At the same time, Latin America and Caribbean forests are home to some 40 million indigenous people, many of whom have traditionally performed an important role as forest custodians. In light of these aspects, Latin America undoubtedly plays a vital role in current REDD+ debates.

Most Latin American countries are currently developing national REDD+ strategies, which either incorporate pre-existing forest conservation programs and/or pilot carbon and biodiversity schemes. Progress in REDD+ strategy design, however, varies considerably between the countries. Costa Rica, Mexico and Brazil are considered the “REDD+ leaders”. All three of them face similarly high deforestation rates in the past, which have triggered their governments to take substantial action. Also, Costa Rica took the lead in the region in setting up payment schemes for ecosystem services as part of their mainstream forest policy. Mexico took similar measures and could fall back on substantial experience in community-based forestry programs. Brazil’s experience in forest conservation, on the other hand, is far more recent, decentralized and, to a certain degree, fragmented. Brazil though has set up a growing range of diverse REDD+ pilot projects on the ground, incorporating a variety of stakeholders.

Bolivia, Ecuador, Panama, and Guyana are classified as the “REDD+ latecomers”. Bolivia and Panama have both been founding members of the UN-REDD program and both have quite a well set-up institutional setting for forest policy. Bolivia looks back on almost two decades of decentralized forest management, giving more weight to municipal governments and civil society. Ever since the presidency of Evo Morales, indigenous organizations have been strengthened, thereby providing an effective platform for REDD+ negotiations. Bolivia’s government though firmly opposes market mechanisms for financing REDD and takes a firm stand against industrialized countries. Guyana’s position is different. With its small land area and low population density, it has enjoyed historically low deforestation rates. Forests play a pivotal role in the Guyanese economy. Guyana has been an active player in REDD+ debates and has set up a functioning REDD infrastructure. However, the country lacks the necessary experience in a wide stakeholder consultation for REDD+ to be successful. Cooperating with the large Amerindian community will be vital for the country’s REDD+ strategy to become a successful political project.

As part of our review we compared 40 Payment for Ecosystem Services (PES) cases (including biodiversity, landscape, water, carbon) in Latin America and examined their rate of success according to criteria that are especially relevant for a developing country context. To assess the success of PES schemes we defined ‘success’ as a combination of (a) the extent to which the original goals of the PES scheme are met, and (b) the added value in terms of overall improvement in the ecological, economic and social conditions of the region, beyond intended objectives. The criteria used to analyse the PES cases were: (1) ecosystem being traded (i.e. biodiversity, landscape, water, carbon); (2) scale (i.e. spatial, temporal); (3) transaction types (i.e. cash, in-kind); and (4) actors involved (i.e. buyer, seller, intermediaries). The following figure displays the factors enhancing the success rate of PES schemes in terms of benefits to ecosystem conservation and human wellbeing. This leads to the following recommendations:



- PES and Reducing Emissions from Deforestation and Forest Degradation (REDD+) schemes should be managed by actors known and trusted by the community
- Always combine PES provisioning services with livelihood components that have a clear (communal) benefit
- Ensure medium- to long-term funding before starting a PES scheme
- Start local and/or regional pilots and conduct a rigorous impact evaluation before expanding the scheme
- PES and REDD+ schemes should be linked to agricultural policies addressed at smallholders.

PART 4. Impacts, Products and Dissemination

4.1 ROBIN Products

The final objective of ROBIN was “to provide guidance on land-use planning and other climate change mitigation options with the aim of increasing carbon stores and avoiding undesirable ecological and socio-economic effects”. Although ROBIN’s programme of research was primarily designed to contribute scientific evidence concerning the role of biodiversity in climate change mitigation that would inform decision making at multiple levels. In addition to this it produced a number of specific reviews, tools and products that have a direct value to decision makers. Table 4.1.1 summarises these key products and how they met the general user requirements identified at the start of the project. In Section 4.2 we provide examples of specific products and in Section 4.3 we explain the steps we have taken to disseminate new knowledge and products to stakeholders

Table 4.1.1. Examples of general requirements related to the implementation of climate change mitigation policies and non-carbon benefits and some of the specific ROBIN products that are now available to help address them.

General requirements	Examples of specific ROBIN products
Evidence (for or against) concerning the role of biodiversity in climate change mitigation within “whole systems”	• A set of information notes summarising key message from ROBIN particularly relation to the role biodiversity in climate change mitigation and the delivery of co-benefits (e.g to ecosystem services and human well-being).
Improved information on baselines for biodiversity and ecosystem service accounting, and improved methods for monitoring carbon and biodiversity indicators for REDD+ reporting	• A monitoring system for biodiversity and ecosystem integrity adopted in Mexico and some other Latin American countries. • National and continental scale datasets on biodiversity and ecosystem services derived from combinations of field data, remote sensing and models.
Strategies and tools for climate change mitigation at local and national scales	• ROBIN project outputs and decision support tool (QUICKScan) for data exploration allowing investigation of trade-offs between ecosystem services. • Public access to web-based project data products through a portal
Maps showing the potential contribution of biodiversity to CCM under future climate change, land use change and policy (REDD+) scenarios;	• Continental and national scale maps of ecosystem ecosystem services based on land use change and vegetation models and IPCC scenarios
Decision support tools for implementation of REDD+ or similar “Payment for Ecosystem Services” schemes to help decision makers compare options for using biodiversity and ecosystems for climate change mitigation.	• Large scale maps of risks & resilience of ecosystems to drivers of change. • A decision support tool (OPTimas) to help local stakeholders assess land management options.
Examples of good practice, including engagement” mechanisms, with key stakeholders and recommendations for the implementation of REDD+ taking into account biodiversity and ecosystem related benefit.	• A review of “Current Approaches to Climate Change Mitigation in Latin America” –relevant to REDD+ • A handbook describing the participatory approach with local stakeholders • Mitigation and adaptation “options” from 8 stakeholder workshops • Factsheets and recommendations

4.2. Product Summaries

In this section we describe some of the key products produced by ROBIN.

4.2.1 Review of Current approaches to Climate Change Mitigation in Latin America

The ROBIN project undertook a state-of-the-art review on current approaches to climate change mitigation (CCM) in the forest sector in Latin America, particularly in relation to the REDD+ concept of reducing emissions from avoided deforestation and degradation to international carbon markets. The review include a comparison of 40 Payment for Ecosystem Services (PES) cases which produced a set of recommendations on factors related to successful schemes. Results from this review are summarised in Section 3.6.1.

4.2.2. A Handbook of the Participatory Process

One of the general aims of the ROBIN project is to work with local stakeholders to provide science based information and tools to help them manage sustainable agro-ecosystems delivering benefits for biodiversity, climate change mitigation, livelihoods and human welfare. As part of our work *to provide guidance on land-use planning and other climate change mitigation options* we completed workshops in Bolivia, Brazil and Mexico using methods described in a ROBIN "handbook for the participatory process". It provides a review of the methodology used in the development of stakeholder-driven scenarios for ROBIN. This includes co-design of the participatory process with country partners, through regular negotiations, an inclusive training activity and analysis of the ecological, socio-economic and institutional structure and dynamics in the project's study sites. This document should also form a useful "handbook" for the application of the participatory approach in similar projects.

4.2.3. A decision support tool for natural resource and land use management: OPTamos

Sustainable resource and land-use management is a complex goal with many competing interests and stakeholders involved. For example, decision making by land owners takes place often as a response to higher scale interventions or policies (subsidies, market opportunities, infrastructure and technology available, etc.). To ensure the success of PES interventions, it is crucial to consider all local stakeholder needs, knowledge, fears and perspectives concerning the different land management options. To do so, novel methods and tools for effective stakeholder participation are needed.

Under ROBIN, we have developed an easy-to-use tool designed to help decision makers at all levels explore options and solutions for using biodiversity and ecosystems for climate change mitigation.The OPTamos decision support tool is based on the Social Multi-Criteria Evaluation (SMCE) approach designed to deal with pressing social and environmental problems in a complex world. The SMCE approach weighs the different values and options (e.g. for land management) against a number of criteria in order to enable discussion and highlight the most acceptable result for all stakeholders involved. Multi-criteria evaluation methods can help decision makers to: integrate expertise of different stakeholders and scientific knowledge; structure discussion among different stakeholders; and learn about optional pathways and the actions needed to reach them.

We developed the OPTamos tool by deriving land use options, decision guiding criteria, and their relative importance from stakeholder workshops in Latin American case studies and comparing those options to national policies and supporting measures like Payment for Ecosystem Services and REDD+ schemes. To summarise, SMCE is built on a participatory process, giving structure to complex decision making and room for reflection on personal preferences as well as room for deliberating on common goals and the way to embark towards them. Using this methodology, ROBIN developed OPTamos – an online computer tool to aid decision-makers. OPTamos needs information on: possible land management options in a specific region; criteria stakeholders consider relevant for decision making; relative importance of options and criteria. OPTamos provides a framework in which stakeholders can supply and check this information as part of a heuristic process of decision making. An example of the output from OPTamos is shown in Figure 4.2.1.

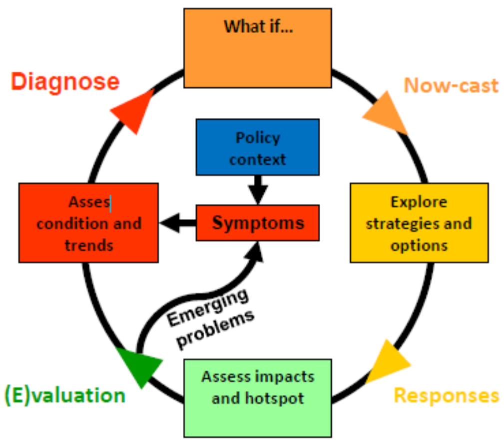
Figure 4.2.1. OPTamos results are presented graphically and in a table

The SMCE approach and the OPTamos tool was successfully tested in one of ROBIN's case study areas in the Cuitzmala watershed in Mexico. The test confirmed that land managers, decision makers, consultants, and researchers working at local and regional level may benefit from its use, since results from OPTamos can be used by those stakeholders in order to enable discussion, promote participation, and enhance the acceptance of measures.

The OPTamos tool is available for use at http://robin-decisionsupport.aau.at . An information and training video is also available on the same site.

4.2.4. A decision support tool for addressing climate change and biodiversity policy options in Latin America – QUICKScan

The sustainable management of forests and wider forest landscapes management depends on effective policies addressing forest carbon stocks, protection of biodiversity and ecosystem services, and human livelihoods in the wider landscape. QUICKScan is widely used for facilitating participatory decision-making and has been used in many countries to explore policy questions at national and regional levels. In ROBIN we produced data to assess the impact of climate-related policy options and land use change in different socioeconomic contexts in Brazil, Bolivia, Mexico and Guayana. We have used the QUICKScan tool to integrate this information, with a focus on REDD+ policies aimed at preventing loss of carbon, while at the same time safeguarding biodiversity, and protecting valuable ecosystem services.



The QUICKScan tool was selected for use in ROBIN due to its high existing functionality in terms of data visualisation, and flexible routines to combine and represent data (see Figure 4.2.2) . Further functionality required for ROBIN was required, and QUICKScan was adapted to incorporate the following features:

- Incorporation of key indicators for biodiversity, ecosystem services and human well-being
    - Visualisation of trade-offs among indicators
  - Visualisation of results for the scenario and policy combinations
  - Creation of composite indicators (=bundles) from single indicators.
  - Incorporation of sustainability limits for indicators, which may differ by geographic region.
  - Creation of aggregate sustainability limits for bundles of indicators.

Figure 4.2.2. Overview of the QUICKScan approach

Within the ROBIN project, data were produced for key indicators which summarise the impact of land use and climate change on ecosystem state, ecosystem services, and human well-being. Sustainability limits have also been defined for many indicators, to aid an integrated sustainability assessment. With these data, the tool can be used (see Figure 4.2.3) to address key questions such as:

- How will future policies affect land use in Latin America?
- What impacts will climate change have on ecosystem services?
- What are the trade-offs between biodiversity and ecosystem services in Latin American countries?

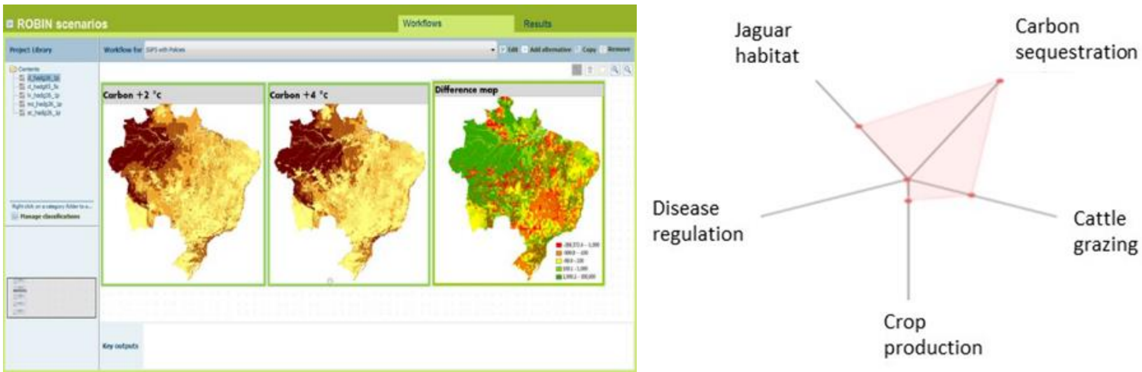


Figure 4.2.3 Uses of QUICKScan : Left - comparing scenarios for carbon stock. Right - scenario outcomes for five ecosystem services

Who can use QUICKScan? Policy questions change and need to be answered in a short period to fit the time horizon of policy and decision making. Policy advisers require an easy-to-handle toolbox that is fast, flexible and transparent, and requires relatively little data to explore alternatives in multi-stakeholder settings. Scientists can also use the tool to make sense of complex information on a spatial basis for scientific questions, and to visualise and explore results spatially in a stakeholder participatory context.

4.2.5. Public access to web-based project data products

ROBIN undertook work to develop and apply remote sensing (RS) data to upscale plot level to landscape level to regional results investigating the interactions between biodiversity and potential climate mitigation. As part of this work several remote sensing products have been developed at different scale levels ranging from the local landscape to national and continental. These include products such as:

- Functional diversity: species richness for Bolivia
- Structural diversity: several structural forest parameters for Bolivia
- Landscape diversity: phenology indicators at continental scale, cycle number and duration for swidden agricultural systems (areas of land cleared for cultivation by slashing and burning vegetation) in Brazil
- Carbon stocks and dynamics: 3D vertical tree profiles for forest plots in Guyana
- A new forest typology for the Amazon based on HANTS phenology indicators.
- Maps of “evergreen”, “deciduous” and “mixed” forest areas for Meso- and South America (based on synchronicity of leaf phenology)

These and other spatial data products (e.g. from models) will be made available through two ROBIN geoportals. Data will be documented and uploaded to the geoportals in servers hosted by CONABIO (Mexico) and Wageningen University (WUR, Netherlands). Data will be publically available after an embargo period of a maximum of one year to ensure that project participants can publish their research. Some data can already be accessed through our portals at:

- CONABIO server: http://www.conabio.gob.mx/robin/
- WUR server: http://scomp5062.wur.nl/projects/robin/

Table 4.2. 1. Example of data products to be made available on the ROBIN Data Portal

Product Name	**Size estimate (GB)**	**Contact organisation**
Hants Phenology	50	WU
CLUE model output	5	WU
JULES, LPJml output	0.5	PIK, CEH
Amazon resilience	5	EMBRAPA
Ecosystem integrity + CLUE Amazon	5	EMBRAPA
Tipping point simulation output	5	WU
Ecosystem services	5	CEH, UNAM
Continental Phenology	10	CEH
Ecological integrity Mexico	56	CONABIO
Remote sensing Mexico	150	CONABIO

4.3. Dissemination Activities

4.3.1. Contribution to the Evidence Base on the role of Role of Biodiversity

ROBIN was primarily a research project and as such its primary aim was to deliver objective scientific evidence concerning the role of biodiversity. The main criterion for success in reaching this aim is publication of results in peer reviewed scientific literature. A full list of current publications can be found at: http://robinproject.info/home/products/publications/ and some example titles showing the range of subjects covered are given below:

- Land-use intensification effects on functional properties in tropical plant communities.
- Monitoring forest cover loss using multiple data streams, a case study of a tropical dry forest in Bolivia.
- Diversity enhances carbon storage in tropical forests.

- Biomass is the main driver of changes in ecosystem process rates during tropical forest succession.
- Hyperdominance in Amazonian forest carbon cycling.
- Leaf and stem economics spectra drive diversity of functional plant traits in a dynamic global vegetation model.
- Explaining biomass growth of tropical canopy trees: the importance of sapwood.
- Does functional trait diversity predict above-ground biomass and productivity of tropical forests? Testing three alternative hypotheses.
- MAD-MEX: Automatic Wall-to-Wall Land Cover Monitoring for the Mexican REDD-MRV Program Using All Landsat Data.
- Linking Bayesian Belief Networks and GIS to assess the Ecosystem Integrity in the Brazilian Amazon
- Effects of disturbance intensity on species and functional diversity in a tropical forest
- Ecosystem services research in Latin America: The state of the art.
- Biodiverse carbon capture
- Framework for multi-scale integrated impact analyses of climate change mitigation options
- Biomass resilience of Neotropical secondary forests

4.3.2. General Communication of Project Key Messages and Recommendations

We have published a set of factsheets for public use. These summarise the key messages and recommendations from the research. These have been distributed in hard-copy form in a ROBIN folder at key events (see below) and most are now available at: http://robinproject.info/home/products/factsheets/ . The factsheets currently available address the following subjects:

1. The Role of Biodiversity in Climate Change Mitigation (ROBIN): a whole system approach
2. Biodiversity has a positive effect on carbon stocks and carbon sequestration
3. Measures of ecosystem integrity provide a health check on human land use
4. Modelling ecosystem services for policy: carbon stocks and carbon sequestration
5. PES and REDD+ schemes should be linked to agricultural policies addressed at smallholders
6. Model indicates Biodiversity has a direct effect on carbon stocks and forest biomass resilience – coming soon
7. Ecosystem integrity assessment serves as a common approach for multi-sectoral public policy in Latin America
8. OPTamos – a decision support tool for natural resource and land use management
9. A decision support tool for addressing climate change and biodiversity policy options in Latin America
10. Ecosystems with lower integrity store less carbon and provide fewer ecosystem services
11. The potential of human-impacted forests – coming soon
12. Towards a better socio-environmental response to climate change by understanding multiple stakeholders’ perspectives
13. Environmental policies should be integrated with agricultural and development policy to be successful

4.4. Direct Interactions with Policy Stakeholders

Representatives of the ROBIN Project have been involved in key science/policy events in Europe and Latin America since the outset of the project.

4.4.1. Global Events and links to UN Conventions

ROBIN has presented its work and recommendations arising from it at side-events at meetings of the UNFCCC and the CBD.

In 2011, at the UNFFCC/COP17 meeting in Durban, ROBIN participated at a side-event organised by the EC on the "non-carbon benefits of REDD+". The discussion confirmed the urgent need for developing methods for monitoring, reporting and verification tools for use at national and local levels and which included assessments of biodiversity and other ecosystem services.

In 2012, ROBIN co-organised a side-event with the EC at the CBD/COP 11 in Hyderabad, India on "Mechanisms for delivering biodiversity benefits from REDD+". We discussed the monitoring and governance systems required for the implementation of REDD+ at local and national levels and explored options for providing the operational indicators relevant to the delivery of CBD 2020 targets to restore and safeguard ecosystems that provide essential services that contribute to health, livelihoods and well-being (Aichi Target 14) and to enhance the resilience of ecosystems and the contribution of biodiversity to carbon stocks (Aichi Target 15).

September 2015. ROBIN's Mexican Partners presented the "Mexican National Biodiversity and Degradation Monitoring System" as an oral and written paper to the XIV World Forestry Congress in Durban, South Africa.

In December 2015 at the UN Framework Convention on Climate Change, COP21-in Paris, ROBIN Co-ordinated an EU side event on "Realising the Potential of Nature and People in the Implementation of REDD+ and its Safeguards". This included set of 5 talks from different organisations designed to promote discussion on the more effective implementation of safeguards in RDD+.

4.4.2 Dissemination to European Policy Makers

In November 2013: ROBIN participated in an EC meeting in Brussels on "Biodiversity and Ecosystem Services: A Strategic Dialogue Between Science and Policy. As part of the dialogue ROBIN prepared factsheets addressing questions that had been drafted by EC participants from policy and science Directorates including DG Environment, DG Agriculture and DG Climate. ROBIN factsheets covered the following two questions:

- How have we advanced our understanding of the links between ecosystems, ecosystem functions and ecosystem services and their influence on long-term human well-being and what are the knowledge constraints on more informed decision-making?
- How will ecosystem services (and in turn society and economy) be affected by climate change?

In June 2015: ROBIN co-ordinated a stand at the "Green Week" event in Brussels in June 2015 on the overarching concept of " Sustainable management of natural resources in Latin America" in collaboration with two other EC funded projects (COMET-LA and COBRA). ROBIN's contribution showed how we have advanced our understanding of the links between biodiversity, ecosystem functions and ecosystem services in tropical forest landscapes and their influences on human well-being. It demonstrated some practical monitoring and decision support tools for informing decision-making at local and national levels.

In October 2015: European Parliament, Brussels. EU decision-makers and stakeholders gathered in the European Parliament to discuss the ROBIN project and to highlight the pivotal role of tropical forests and the carbon and non-carbon benefits they provide. ROBIN demonstrated that biodiversity is part of the solution towards mitigating climate change, and is an exemplary project highlighting the links between mitigation, adaptation, biodiversity and the maintenance of sustainable tropical forest landscapes.

In December 2015: ROBIN was invited to participate in a workshop organised by DG Environment on the MAES programme ("Mapping and assessment of ecosystems and their services"). This provided an opportunity for project results to be communicated to some policy Directorates. Break-out groups worked on the natural capital & ecosystem service questions that are of interest to the EC policy directorates. The recommendations coming out of the workshop will go to next presidencies.

4.4.3. Latin American Events

From January 2013 to August 2015: ROBIN held a series of 8 participatory stakeholder workshops in Brazil, Bolivia and Mexico as part of the process of a trans-disciplinary scientific process of understanding stakeholder perspectives and co-developing possible options for land management, climate change mitigation and adaptation. These workshops are explained in more detail in Section 3.5.

In October 2015: ROBIN partner CONABIO held coordination meetings with Mexican governmental institutions (including the National Forestry Commission (CONAFOR) on the implementation of a conceptual framework on Ecosystem Integrity (Section 3.1.6) and the implementation of the National Biodiversity Monitoring System.

In October, 2015. ROBIN partners (UNAM, INECOL) had a meeting at the Department of Foreign Affairs, Santiago, Chile to present ROBIN and the Mexican National Biodiversity Monitoring System.

In November 2015: ROBIN was invited to speak at a Brazilian-EU international seminar on "Nature Based Solutions and Sustainable Urbanization" to talk about its inter-disciplinary and socio-ecological approach and because ROBIN provided a very good example of Brazilian/EU research collaboration. Our Brazilian Partner (Embrapa) represented ROBIN.

4.5 Current and Expected Outcomes

The results from the project are relevant to the Convention on Biological Diversity (CBD) and actions to protect biodiversity and enhance its benefits to people. ROBIN is particularly relevant to the UN programme on Reducing Emissions from Deforestation and Forest Degradation (REDD+) which aims to enhance forest carbon pools by supporting the conservation, sustainable management and restoration of forests.

The main outcomes of our work should be increased storage of carbon in forest landscapes and the delivery of social and environmental co-benefits through REDD+ and similar PES schemes. The work will inform national and local stakeholders in forestry, agriculture and nature conservation sectors. Advice will be provided on how to increase carbon stocks and biodiversity while simultaneously delivering a range of other ecosystem services to communities, particularly those operating in multi-functional landscapes. The work will also inform the implementation of UN Convention on Biological Diversity (CBD) in relation to some of the CBD (Aichi) 2020 targets.

ROBIN also considered land-use change in multi-functional landscapes and is relevant to food and energy security and delivery of the UN Sustainable Development Goals. For example, Sustainable Development Goal 15.2 for 2020 is particularly becoming prominent: "promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally". While the focus remains on carbon and GHG for REDD+, the sustainable development goals and the findings of ROBIN once again highlight that REDD+ implementation has to consider biodiversity beyond being just a safeguard and co-benefit. We like to think that ROBIN's input to the UNFCC climate change discussions in Paris in December 2015, made a small but timely contribution to the successful outcome of COP21, particularly in relation to the increasing support for nature based solutions to climate change mitigation and adaptation.

The work will also strengthen existing observing capacity and deliver data products that will contribute to the Group on Earth Observations (GEO) Global Earth Observation System of Systems (GEOSS). Specifically, the ROBIN will contribute to the GEO Forest Carbon Tracking (GEO FCT) task and the GEO Global Biodiversity Observation system (GEO BON).

4.5.1 The Mexican National Degradation and Biodiversity Monitoring System

The most direct significant outcome from the ROBIN project so far has been the development and adoption of a "National Biodiversity and Ecosystem Degradation Monitoring" programme in Mexico as part of its approach to implementing the REDD+ mechanism. ROBIN partners have also helped adapt this approach to other countries.

The Mexican National Degradation and Biodiversity Monitoring System

Within the framework of the ROBIN project and its work on ecosystem integrity, the Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO) and the Institute of Ecology (INECOL) have helped develop a monitoring system in Mexico to support specific national commitments of reporting and policy formulation. The system will also be employed to report in the frame of international commitments, for instance to report to conventions like UNFCCC, REDD+ mechanism, and the UN-CBD. The National Forest Commission (CONAFOR) in its Forest Inventory collects the data. The National Commission of Natural Protected Areas (CONANP) is implementing the monitoring in selected protected areas. Data is stored centrally in the facilities of CONABIO with real-time access for scientists and the relevant federal and state institutions. The data will be key in supporting the assessment of national policies to halt or even reverse the loss of diversity in natural systems.

In the frame of Mexico's foreign policy regional initiatives with its partners in Central and South America, the system will be adapted to regional needs and implemented mutually by Chile, Peru, Colombia and Mexico. Thus, creating a region with standardized monitoring stretching from the Antarctic to the North American Prairies.

The monitoring will be used to provide data for the calculation of ecosystem integrity and used in reports on forest productivity and biodiversity conservation. It will inform goals in the national development plan linked to the aim of increasing forest revenue and productivity without reducing or jeopardising biodiversity. Ecosystem Integrity will also be used in the national emission reporting for safeguard reporting. CONANP will use ecosystem integrity internally for the reports on efficacy and efficiency of national park management and measures to reduce biodiversity loss and additionally for the national reports to the CBD. In the frame of the Pacific Alliance, agreement has been reached that ecosystem integrity will be used flexibly to account for the different levels of input data availability. It has also been proposed and accepted to showcase the usefulness of EI to the System for economic and environmental accounting (SEEA) of the United Nations.

4.6 What is planned after the end of the project?

In Latin America we will continue to advance the use of the monitoring techniques based on remote sensing and field data in the form of ecosystem integrity particularly in the countries directly involved in the project: Mexico, Brazil and Bolivia. Our Mexican partners will also continue to lead an initiative to apply the methods in the countries of the Pacific Alliance.

The next Conference of the Parties for the Convention on Biological Diversity will take place in Mexico in 2016. We are planning to use results of the ROBIN project at that meeting.

The ROBIN research partners will continue to produce research papers based on data, information and products developed in ROBIN and we will maintain at least one of the data portals so that data products are available for general use in science and policy.

We will also continue to develop and promote ROBIN's key messages including the over-arching message that:

"ROBIN was a successful international inter-disciplinary EU-funded research project that advanced our scientific understanding of the roles that tropical forests and their rich, biodiverse ecosystems play in mitigating climate change and providing benefits or 'services' to local communities. The project's guidelines, products, tools and recommendations will continue to feed into policymakers' debates and inform ways to strike an optimal balance between protecting forests and biodiversity, and ensuring communities continue to enjoy the economic and social benefits derived from them".

4. Website address

Our website is at www.robinproject.info and provides a link to our spatial data portals.

Our spatial data portals can also be accessed directly at:

- CONABIO server: http://www.conabio.gob.mx/robin/
- WUR server: http://scomp5062.wur.nl/projects/robin/