Collaborative Project

Role Of Biodiversity In climate change mitigatioN

ROBIN

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Assessment of main trade-offs between biodiversity, climate change mitigation measures and other ecosystem services and human well-being at regional scale and in local case study areas

ROBIN Deliverable D 2.3.3

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Publishable Executive Summary

1. 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.

2. Three future scenarios were used to assess these trade-offs for Latin America to 2050. They result from combinations of two socio-economic pathways, sustainability and conventional development, and two climate forcing scenarios, low and high. The resulting changes in land use and vegetation dynamics were modelled using CLUE and LPJmL. Ecosystem integrity was assessed for current conditions. These outputs were used to model ecosystem services, either directly or using the ARIES platform. Current conditions were modelled with the same tools and contrasted for some cases with those resulting from potential vegetation. The country level study areas include: Mexico, Bolivia, the Brazilian Amazon and Guyana (only available for some outputs). For each of the countries a local study area was assessed: the Southern Coast of Jalisco, for Mexico, the Tapajós National Forest in Brazil, The Guarayos province in Bolivia.

3. 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.

4. 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, 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.

5. 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.

6. 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, being urban land cover and that of irrigated lands was important for the regulation of VL, and edge of perennial crops and forests 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.

7. 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 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.

8. 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.

9. Complex trade-offs between biodiversity, ecosystem services and human well-being are in the process of being addressed at different spatial scales and using a range of methodologies.

10. At the local scale, the drivers underpinning trade-offs, current trends and alternatives towards sustainability were assessed. For the case of the southern coast of Jalisco, biodiversity declines, the replacement of crops for local food security by those of commercial importance, the increase in fodder cultivation, and labour expulsion by increased technification indicate threats to human welfare. For the case of Tapajós National Forest, governmental coordination could reduce biodiversity loss, deforestation, and negative impacts on ecosystem services; agricultural expansion, linked to low environmental awareness, would have the

opposite effect; increased environmental awareness, governmental coordination and the protection of traditional forest communities could mitigate negative impacts on biodiversity and ecosystem services. In Bolivia, the implementation of the INRA (National Institute of Agricultural Reform) law, that reduces the development of traditional agriculture, can contribute to biodiversity loss, deforestation, and ecosystem service decline; the coordination of forest protection laws and the increased coherence between agricultural and environmental policies can revert these impacts, and contribute to agricultural expansion with few environmental impacts.

11. 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.

12. Explorations of how ecosystem services link to well-being indicators at national and local scales are also underway. Pilot explorations for the case of Mexico for the state of Jalisco suggest 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 so is suggested.

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

14. The information gathered in the work described in this report will be integrated with a recently developed analytical framework. We will build efficiency frontiers to depict the highest possible values of trading of bundles of ecosystem services and biodiversity indicators. Conflicts among policies at the national level and among stakeholders for each study case will be summarized graphically and super imposed upon these efficiency frontiers. We will identify conflicts, obstacles and opportunities towards reducing the intensity of hard choices for each country and scale under current and alternative future scenarios.

15. In summary, 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.

Content

1. Introduction

Ecosystems such as forests and lakes contribute to human well-being through the delivery of vital ecosystem services (ES) such as provisioning services including timber and food, regulating services such as temperature and flood control and cultural services such as ecotourism and sense of place. However, ecosystems do not necessarily deliver the same benefits, and variations in management strategies affect the combination of ES that can be obtained from ecosystems. The combination of possible services of a given ecosystem is known as bundles -or packages- of ES (Raudsepp-Hearne et al. 2010, Reyers et al. 2013, Howe et al. 2014). Trade-offs among bundles of ecosystem services occur when ecosystems are managed to intentionally increase the delivery of some ES due to the detriment of some other services (Rodríguez et al. 2006). In general, trade-offs frequently occur between provisioning ES (such as agricultural production or wood extraction) and regulating ES (such as climate change or flood regulation), or cultural ES (such as ecotourism or sense of place) (Bennett et al. 2009). Trade-offs may occur spatially (across locations and regions) or temporally (over time) (Rodríguez et al. 2006).

Trade-offs among ES are tightly linked to disparities between stakeholders´ interests and preferences. Indeed, the very term “trade-off” can be considered as highly anthropocentric because a trade-off occurs when the delivery of services to one group of stakeholders comes at the expense of another. Consequently some ecosystems deliver benefits to certain stakeholders and not others (Hein et al. 2006). The stakeholders can vary and they transcend scales and organizational levels: some ecosystems deliver public benefits to local communities, whole countries or the whole planet, such as the regulation of water quality or climate change mitigation (Balvanera et al. 2011). Others ecosystems provide private benefits to the landowner or manager (Balvanera et al. 2011), such as agricultural production (González-Esquivel et al. 2015). Finally, stakeholders differ in their preferences for certain ES (Martin-Lopez et al. 2012), management alternatives (for ES delivery) (Howe et al. 2014) and their power to influence the delivery of different services (Yahdjian et al. 2015) and in their access to these ES (Daw et al. 2011).

Difficult choices have to be made, when making management decisions about ecosystems and the services that they will produce, for example between cutting down forest for agriculture to foster human well-being by enhancing provisioning services to support economic and social development, or maintaining biodiversity conservation for its own sake and providing cultural services, and management to ensure ecosystem sustainability of resources and regulating services into the future (McShane et al. 2011, Cavender-Bares et al. 2013). Economic, social and environmental agendas across multiple scales are colliding at the current time (McShane et al. 2011) and the situation will become more difficult in the future with pressure from increasing populations and rapid environmental degradation. Consequently, securing the world's future food supply, while maintaining biodiversity and mitigating climate change and its social and economic impacts, is not an easy task (Heller and Zavaleta 2009, Foley et al. 2011, Bennett et al. 2014).

These difficult choices of which ES are most important in any location and the management decisions that will sustain their delivery are particularly intense and relevant for tropical forests. Tropical forests host a large fraction of the world's biodiversity (Mittermeier et al. 1998), and many tropical forest species cannot survive elsewhere (Gibson et al. 2011). Tropical forests deliver a suite of ecosystem services critical to both local food provision and house building materials and global stakeholders through climate regulation (Balvanera 2012, Brandon 2014) as they play a key role by holding with a large fraction of the planet's carbon stocks (Dixon et al. 1994, Pan et al. 2011), by acting as carbon sinks through CO_2 uptake through by mature forest growth (Phillips et al. 2009, Pan et al. 2011, Phillips and Lewis 2014, Brienen et al. 2015), and by directly regulating global temperature through high albedo and sustained evapotranspiration (Anderson-Teixeira et al. 2012). On the other hand, the conversion of tropical forests to agriculture has expanded (Foley et al. 2011) with the increasing local demands for food and in the developing countries (Cavender-Bares et al. 2013), and to satisfy external demands for food in China (Naylor et al. 2005) and in the global north (Gibbs et al. 2010). To ensure sustainability food production must increase while, at the same time, agriculture's environmental impact is detrimental to the services provided by forests.

Little is known about the consequences of alternative economic, social and environmental policies for the tropics into the future will be needed to deal with the difficult choices between different ecosystem services for the different needs and groups of needs of stakeholders. The consequences of future scenarios for biodiversity, ecosystem services, climate change mitigation, and well-being of local to global stakeholders have seldom being explored. Here the ROBIN project (ROBIN 2011) considers some of the important issues through the use of models and scenarios.

In this report we summarize methodological approaches and key findings with respect to: a) modelling ecosystem services under current conditions and into alternative future scenarios, b) trade-offs between biodiversity and ecosystem services, c) trade-offs among ecosystem services, and d) trade-offs between biodiversity, ecosystem services and well-being. The latter issues are addressed at several spatial scales and using different approaches: i) assessments at local spatial scales through participatory workshops, ii) a Bayesian approach to assess system wise trade-offs at multiple scales, iii) links between ecosystem services and human well-being at state and local scales, iv) spatial patterns of trade-offs between bundles of ecosystem services and biodiversity and v) implications for future sustainability and integration across scales.

Three future scenarios were used to assess these trade-offs for Latin America to 2050. They result from combinations of two socio-economic pathways (sustainability and conventional development) and two climate forcing scenarios (low and high). The resulting changes in land use and vegetation dynamics were modelled using CLUE and LPJmL. Ecosystem integrity was calculated for current conditions. These outputs were used to model ecosystem services, either directly or using the ARIES platform. Current conditions were modelled with the same tools and contrasted for some cases with those resulting from potential vegetation. The country level study areas include: Mexico, Bolivia, the Brazilian Amazon and Guyana (only available for some outputs). For each of the countries a local study areas was assessed: the Southern Coast of Jalisco, for Mexico, the Tapajós National Forest in Brazil and the Guarayos province in Bolivia.

2. Models of future scenarios at regional scales

The ROBIN project used three future scenarios for Latin America (Table 1) (Jones and Kok 2013). These were developed to cover alternative climate forcing (Representative Concentration Pathways-RCPs) conditions and socio-economic development pathways (Shared Socioeconomic Pathways-SSPs). The two levels of climate change forcing conditions chosen were: low climate forcing RCP2.6 Wm^{-2} and high climate forcing RCP8.5 Wm^{-2}, which means the future levels of climate change, where the numbers represent climate forcing measured. Two future socio-economic contexts (SSPs) which summarize alternative challenges faced by society with respect to climate change mitigation and adaptation: Sustainability SSP1 (low challenges for adaptation and mitigation to climate change) and Conventional development SSP5 (low challenges for adaptation but are high for mitigation). Further details are found in Jones and Kok (2013).

Table 1. Future scenarios used to cover the connection between climate forcing (Representative Concentration Pathways-RCPs) conditions and socio-economic context (SSPs). Potential vegetation scenarios were obtained in LPJmL model simulation, and only incorporated climate forcing conditions.

Representative Concentration Pathway (RCP, W/m^2)	Shared Socio-economic Pathways (SSPs)		Potential vegetation (PV) (scenario within humans)
	SSP1 **Sustainability** Mitigation: low Adaptation :low	*SSP5* **Conventional development** Mitigation: high Adaptation: low	
RCP 2.6 **Low climate forcing** (Climate $3Wm^{-2}$, 1.5 °C T y 490 CO_2 ppm before 2100)	RCP2.6P1	RCP2.6P5	RCP2.6
RCP 8.5 **High climate forcing** (Climate $>8Wm^{-2}$, 8°C T, >1370 CO_2 ppm in 2100)		RCP8.5P5	RCP8.5

At a continental scale, the consequences of the two SSP on changes in land use were modelled into the future until 2050 using the CLUE model (Conversion of Land Use and its Effects) (van Eupen et al. 2014). CLUE models use information and data on FAO-maps with land use statistics like grazing and cropping densities, combined with land cover databases using expert rules at a resolution of 1x1 km for each grid cell. The outputs from CLUE provide estimates of changes in land use and maps (visually: amount of change, location of change). The results from these CLUE scenarios and climatic data corresponding to the two climate change forcing conditions were used to model their consequences on the vegetation dynamics using the LPJmL model (Lund-Potsdam-Jena managed Land) (Thonicke et al. 2014a). Control runs with/without CO_2-fertilization effect were also conducted for current and future modeling. The resolution of LPJmL is 50X50 Km grid cells.

These outputs were used to quantify, model and map ES at regional (Amazon Brazilian) and national (Mexico, Bolivia) scales using LPJmL outputs directly (that already include CLUE outputs), and using the ARIES modelling platform (see below).

3. Modelling services at regional scales and validating them for current conditions

3.1 Modelling services using LPJmL

Authors: Quijas S., Balvanera P., Boit A., Thonicke K., Jones L. & Zarco-Arista A.

3.1.1 Generalities of the approach

Ecosystem service models are increasingly being developed (Bagstad et al. 2013a, Martínez-Harms & Balvanera 2012). Despite these advances, ecological processes have rarely been explicitly integrated into ES models and into predictions of the spatial and temporal variation in ES as a result of changes in climatic conditions or land use scenarios.

Ecosystem service modelling can be significantly advanced by explicitly incorporating the ecological process involved in vegetation dynamics resulting from changes in climatic conditions and land use. Such an opportunity is available through the use of the Lund-Potsdam-Jena managed Land model (LPJmL). The LPJmL model quantifies the dynamics of terrestrial ecosystems, the carbon and water cycles and the dynamics of plant populations (Sitch *et al.* 2003; Bondeau *et al.* 2007). Output variables associated with these carbon balances and hydrological processes are increasingly used as proxies to ecosystem services (Krausmann *et al.* 2013).

3.1.2 Models for carbon stocks and carbon uptake

Authors: Quijas S., Boit A., Tonicke K., Murray-Tortarolo G., Mwampamba T., Simoes M., Ascarrunz N., Peña-Claros M., Jones L., Zarco-Arista A., Arets E., Jaramillo V., Lazos E., Poorter L., Skutsch M., Toledo M., Martorano M. & Balvanera P.

3.1.2.1 Conceptual and methodological underpinning

The supply and value of the ecosystem services carbon (C) storage and carbon sequestration were modelled using LPJmL to support policy design related to payments and voluntary markets. C storage supply is defined here as the average amount of carbon stored in the terrestrial ecosystems on during the study period. Three different carbon pools were assessed: vegetation (i.e. aboveground carbon), soil and litter. C sequestration is defined as the ecosystem level positive balance between the amount of carbon that is absorbed and the amount of carbon that is released by vegetation per year. CO_2 uptake is given by Net Primary Productivity (Malhi et al. 2015). CO_2 release is given by the sum of heterotrophic respiration, carbon emissions by fire and carbon emissions per crop cultivation. These values were obtained for each year from the outputs produced by LPJmL using data from 1980 to 2000 under current vegetation and potential vegetation scenarios (Table 1)

(Thonicke et al. 2014b). Ecosystem services models for C storage and C sequestration were developed for Mexico, Bolivia and the Amazon region in Brazil.

To highlight the importance of considering ecosystem level C balance rather than just the above ground C uptake, we calculated the value of C sequestration in two different ways. The first method values, innovatively, the ecosystem level balance of C sequestration ($Payment_{balance}$) for the CV scenario. The second method values, as most approaches to C sequestration valuation do, only the uptake component of C sequestration, concretely the Net Primary Productivity ($Payment_{npp}$) in the CV scenario. To assess the differences among the two approaches, we obtained the ratio of $Payment_{balance}$ / $Payment_{npp}$.

3.1.2.2 Results for current conditions

Total carbon stock under current land use were highest for the Amazon (85.5 PgC), followed by Mexico (9.3 PgC) and then Bolivia (12.6 PgC). Country-level values showed close correspondence to the total area of the countries and the region. The fraction of total carbon stock contributed by each carbon pool (i.e. aboveground biomass -AGB-, litter and soil) were very different between countries.

A positive ecosystem level balance of C sequestration was found for all studied regions. Nevertheless, the final balance was quite small because large values of C release, specifically those contributed by heterotrophic respiration, respective to those of C uptake (Fig. 1).

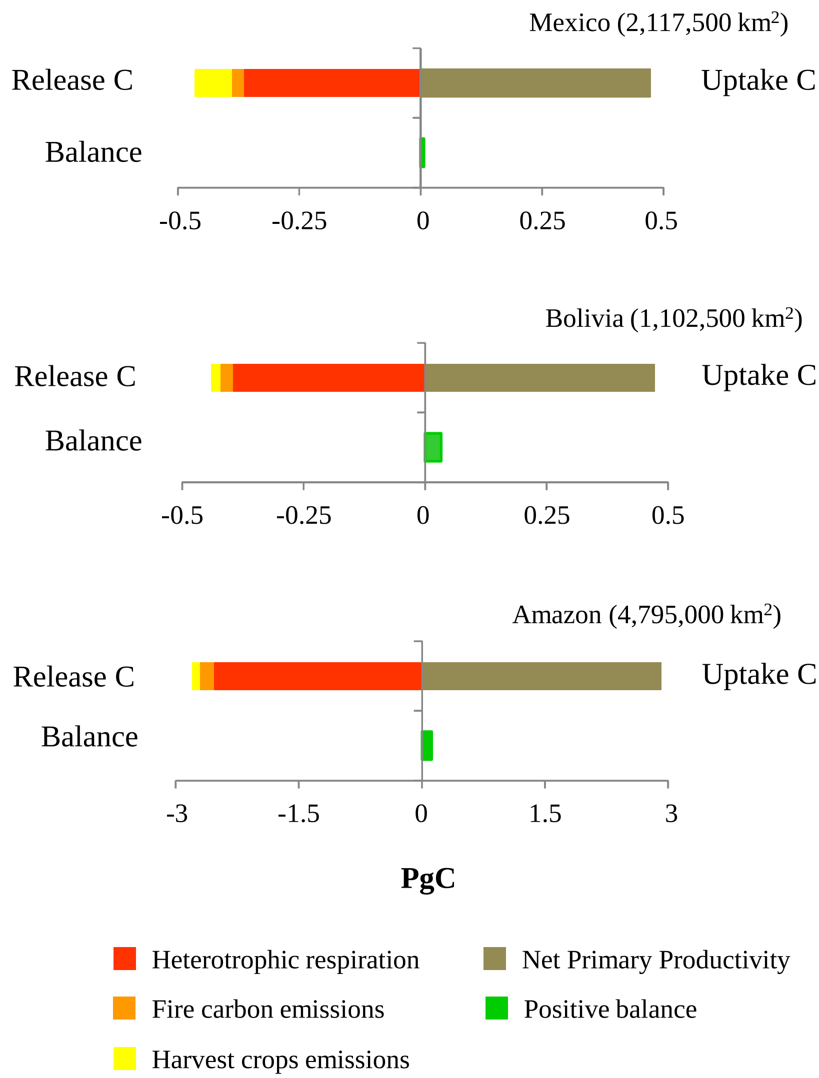


Figure 1. Carbon sequestration balance between uptake (brown columns) and release (red, orange, yellow columns) in Mexico, Bolivia and Brazilian Amazon region. Total area of each country and region are provided study. Note that the scale of the x-axis differ among countries and region.

3.1.2.3 Validation of results

The values obtained here with LPJmL for total C storage were higher than those previously reported for Mexico (SEMARNAT 1997) and Bolivia (Plurinational State of Bolivia 2000), and Amazon region was consistent (Ministry of Science and Technology 2004). For Mexico, previous data (between 4.3 to 5.7 PgC) was lower than the estimates from LPJmL for the AGB component. Same situation is for Bolivia but with data more different (between 2.3 to 9.1 PgC). For the Amazon, previous data are very consistent, and match well the results found here for the contribution of the AGB (between 54.9 to 82.6 PgC).

The values of total C uptake and C release obtained from LPJmL were much larger than those from official reports (Plurinational State of Bolivia 2000, Ministry of Science and Technology 2004) except for the case of C release in Mexico (SEMARNAT 1997). Values from LPJmL showed uptake levels that were 200 times (for Amazon), 60 times (for Bolivia) and five times (Mexico) larger than governmental estimate. In terms of C release the results (in the Amazon), but smaller (a third) for the case of C release in Bolivia.

3.1.2.4 Implications for policy design at national scale

Commonly used approaches to C sequestration valuation, which are based on ABG C uptake, overestimate the area of the three countries eligible for credits for voluntary carbon markets. Our estimates, which are based on actual ecosystem level C balance (Fig. 2) suggest that some areas that show high C sequestration based only on ABG C uptake in fact show negative C balance, given that C releases from soil, litter and biomass, are higher than C uptake within them There is otherwise concordance between values associated with only C uptake and C balance in the rest of the studied areas.

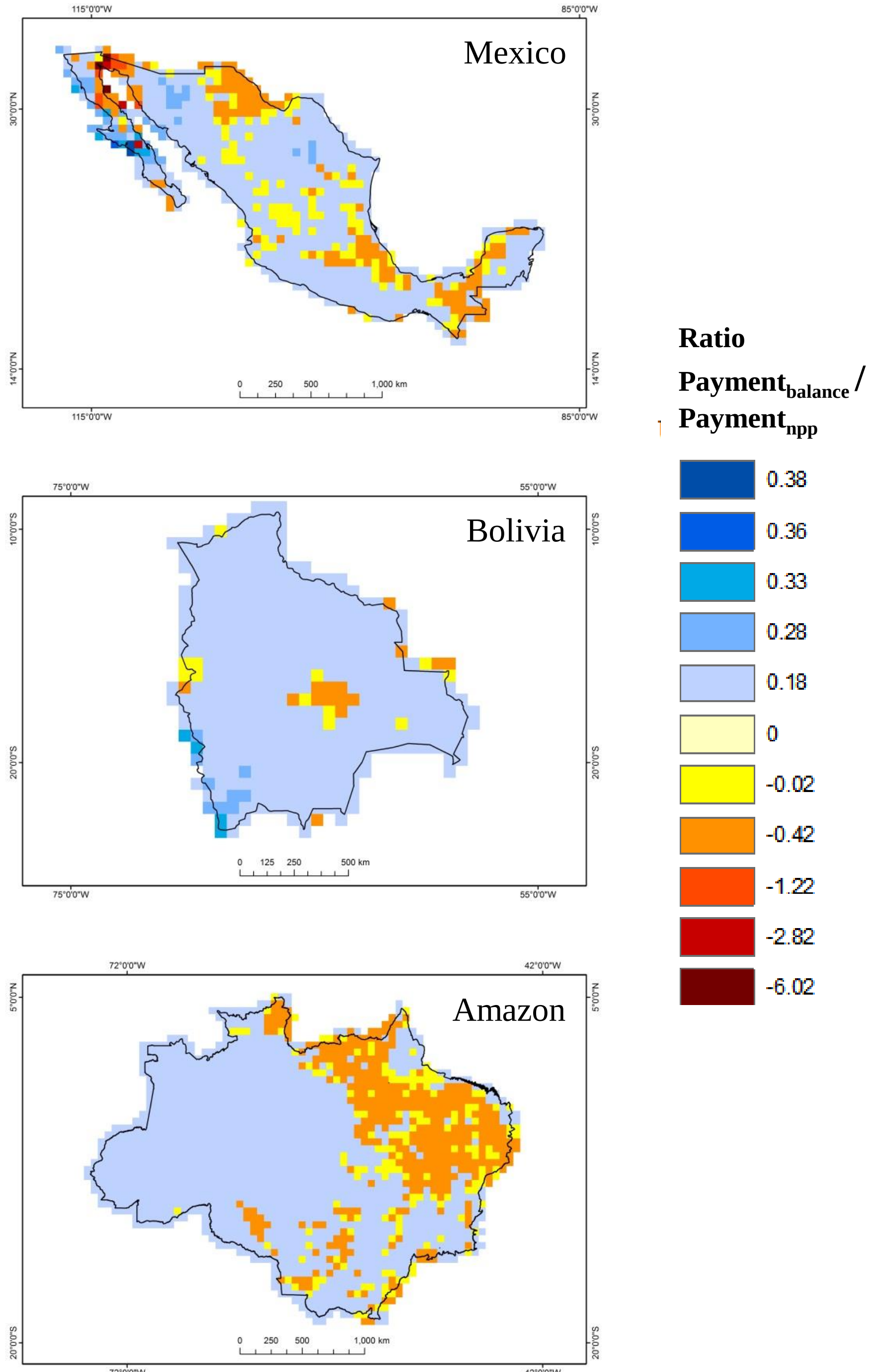


Figure 2. C sequestration valuation approach based on aboveground biomass C compared on actual ecosystem level C balance in countries (Mexico and Bolivia) and region (Brazilian Amazon). Maps showed that 30% of Mexico, 3.4% de Bolivia and 29% of the Brazilian Amazon should not be eligible for credits give that C releases is higher than C uptake in those areas (i.e. a negative C balance, yellow-red-brown grids).

3.1.2.5 Modelling carbon stocks using LPJmL into the future (2050)

Authors: Quijas S., Boit A., Tonicke K., Murray-Tortarolo G., Jones L., Zarco-Arista A., Jaramillo V. & Balvanera P.

Total country level carbon storage changed little into the future for the three countries/regions. The exception was the case of high climate forcing, conventional development, with and without CO_2 fertilization. The differences for these two scenarios (high climate forcing with CO_2 fertilization *vs*. high climate forcing without CO_2 fertilization) in the future were between 3.0 PgC (for Mexico), 2.4 PgC (for Bolivia) and 15.0 PgC (for Amazon).

Instead, the dynamics of carbon uptake and release were highly contrasting among the alternative climate and land use change scenarios (Fig. 3). The most dramatic impacts, resulting in the largest uptake and release of C were observed under the scenario high climate forcing scenario. In general under low climate forcing both emissions and uptake were lower for the Sustainability scenario than for the Conventional development land use scenarios. In all cases CO_2 release was higher than the levels agreed as target by the different countries for 2030 or 2050.

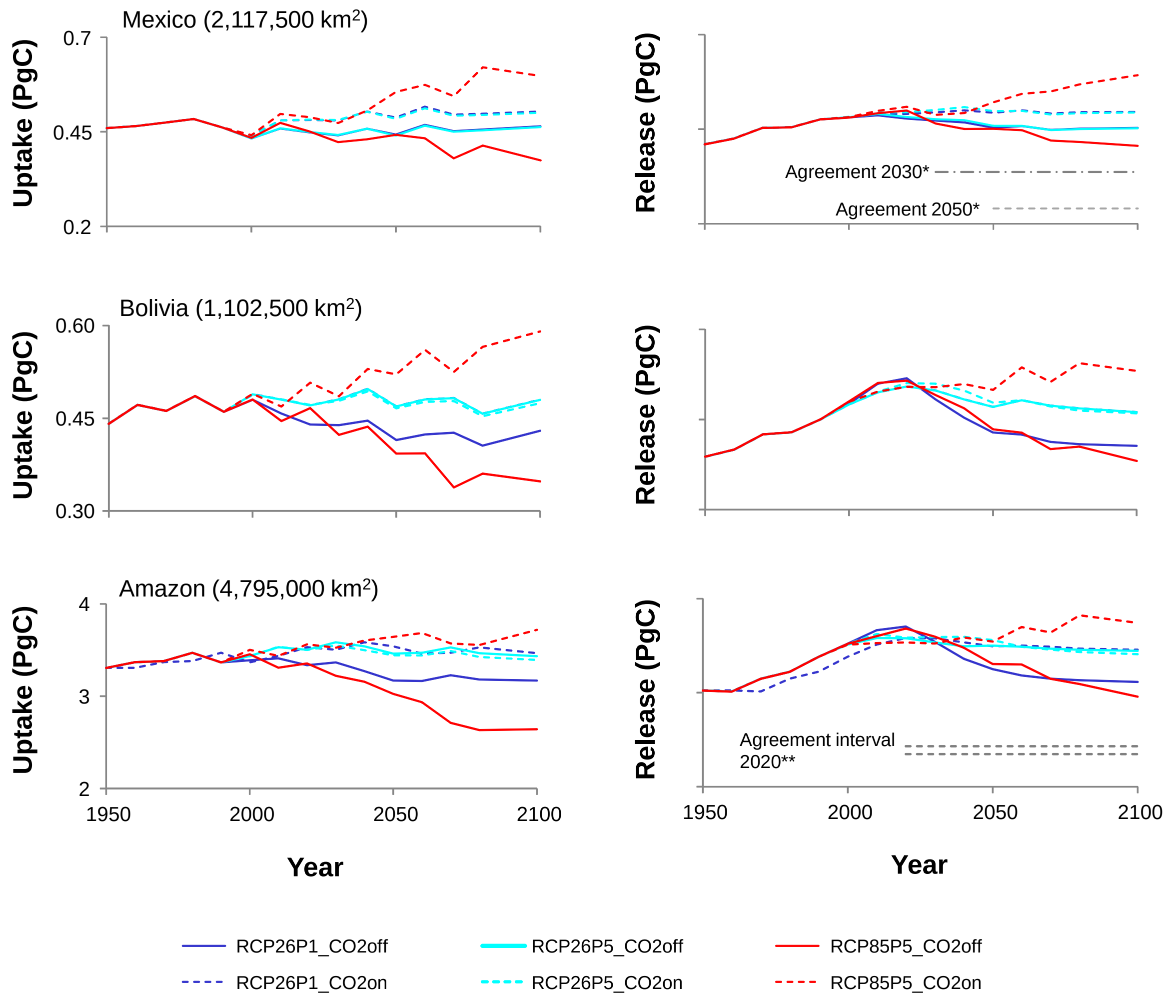


Figure 3. Carbon uptake and carbon release for all climate forcing conditions (RCP) and land use scenarios (SSPs) combinations under the climate forcing for countries (Mexico and Bolivia) and region (Amazon). The scenarios considered two levels of climate change forcing conditions: low climate forcing (RCP2.6) and high climate forcing (RCP8.5); two alternative socio-economic contexts: Sustainability (P1) and Conventional development (P5), and two CO_2-fertilization effects: with effect (CO_2on) and without effect (CO_2off). Y-axis scale varies among countries and region.

3.1.3 Models for hydrological provisioning, regulating and supporting services

Authors: Quijas S., Balvanera P., Boit A., Thonicke K., Zarco-Arista A., Jones L. & Ascarrunz N.

3.1.3.1 Conceptual and methodological underpinning

Hydrologic services encompass the benefits to people produced by terrestrial ecosystem effects on freshwater (Brauman et al. 2007). These include provisioning services, such as superficial or in-stream water supply, regulating services such as that of water quality or flood regulation, cultural services such as spiritual fulfillment, and supporting services including those that modulate plant growth and those that have impacts on climate regulation. Here we emphasize only the provisioning service of superficial water supply (hereafter called flow), for its direct relevance to society. We also consider the supporting services evaporation, transpiration and interception, given they are non-consumptive uses of water, and for their importance for climate regulation (Sitch et al. 2003, Lawrence et al. 2007, Rost et al. 2008). These services were modeled using LPJmL.

LPJmL simulation for each grid cell was obtained from the amount of water from the grid cell and the amount of water that flows from one pixel to the adjacent one as a result of topography and water flow within the watershed (Rost et al 2008). Flow considers total runoff (accounted for as surface, lateral and seepage). The incoming flow of water into a cell from all adjacent upstream cells is calculated with the discharge variable.

Superficial water consumption was also estimated for each grid cell from governmental statistics (INEGI 2009, INE 2014). With water flow and current human population were used to calculate the water balance. Current human population size from governmental statistics was used to calculate per capita water balance. The per capita water balance was then compared with standard indicators of water availability for human consumption (Falkenmark 1992) to define categories of scarcity and availability (Bojorquez-Tapia et al 2009).

Water flow was assessed for recent conditions (average of data for 1980-2000) by comparing potential vegetation and current land uses to account for the effects of past changes in land cover on this service. Current vegetation conditions and current superficial water consumption was calculated to estimate water balance. Water flow into the future was modeled using LPJmL. We used the same per capita consumption and estimations of population size into the future to estimate future changes in water balance.

3.1.3.2 Water hydrological services under current conditions

Water flow has increased as a result of past changes in land use for the three countries (Fig. 4). These changes are particularly dramatic for all the tributaries of the Amazon, the north-eastern part of Bolivia, and the southern part of Mexico. Minor changes were found in most arid areas, such as the north of Mexico and the south of Bolivia.

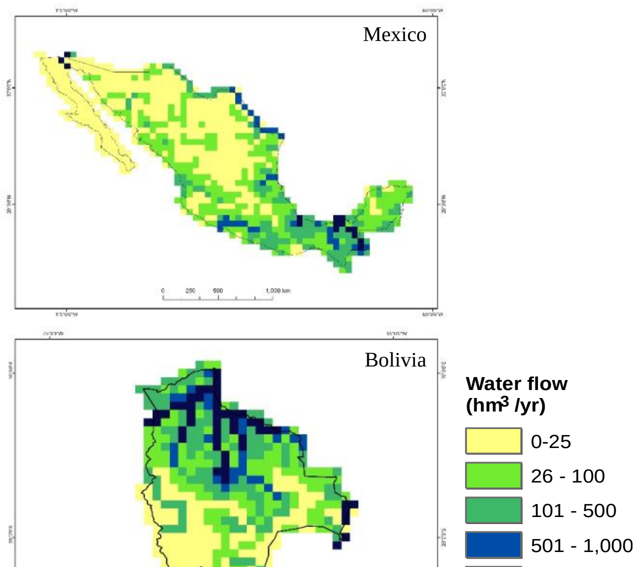


Figure 4. Differences in water flow resulting from changes in land use for countries (Mexico and Bolivia) and region (Amazon) calculated from water flow with current land use minus water flow under potential vegetation.

Current water balance is very variable across the studied countries (Fig. 5). Absolute water scarcity was found today for a large fraction of central and western Mexico, and for south-western Bolivia. Absolute water scarcity, that is water levels below 1,000 m^3/capita year (Falkenmark 1992), known to jeopardize food security, agricultural yield and industrial activities was found for a large fraction of Mexico and close to half of Bolivia. Instead, high water availability was found only in mountainous areas of the northwest and south-east of Mexico, and the north-eastern half of Bolivia.

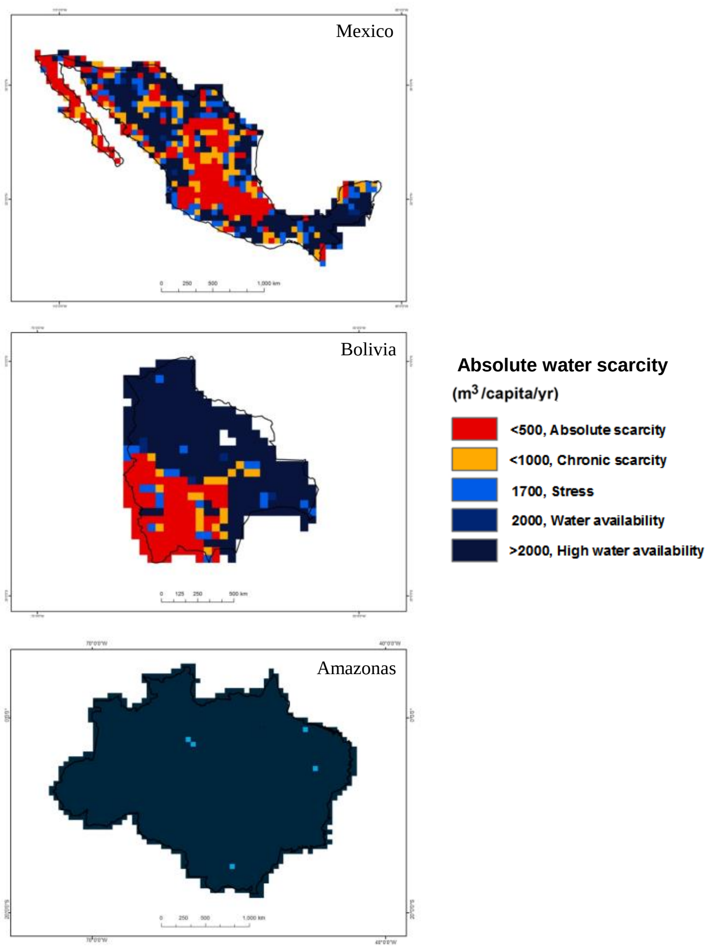


Figure 5. Absolute water scarcity based on current conditions of land use in Mexico and Bolivia calculated from water flow, water consumption and population size per grid cell.

3.1.3.3 Water hydrological services under future conditions

Severe climate forcing will lead to dramatic decreases in water flow in Mexico, substantial reductions in water flow in Bolivia, but no clear changes in the Amazon (Fig. 6). The most dramatic contrasts for future transpiration were found for severe climate forcing for the Amazon and Bolivia, with the highest evaporation values when there is no CO_2 fertilization on vegetation growth, and the lowest one with CO_2 fertilization (Fig. 7). In the case of Mexico transpiration dropped for both severe climate forcing conditions. Evaporation did not change among scenarios into the future for any two countries and Amazon region. Interception, instead was highest with severe climate forcing and fertilization, and lowest with no fertilization (Fig. 6). Effects of land use change on water supporting services were only clear for transpiration, for the case of Bolivia, where Conventional development leads to higher transpiration than Sustainability under low climate forcing conditions.

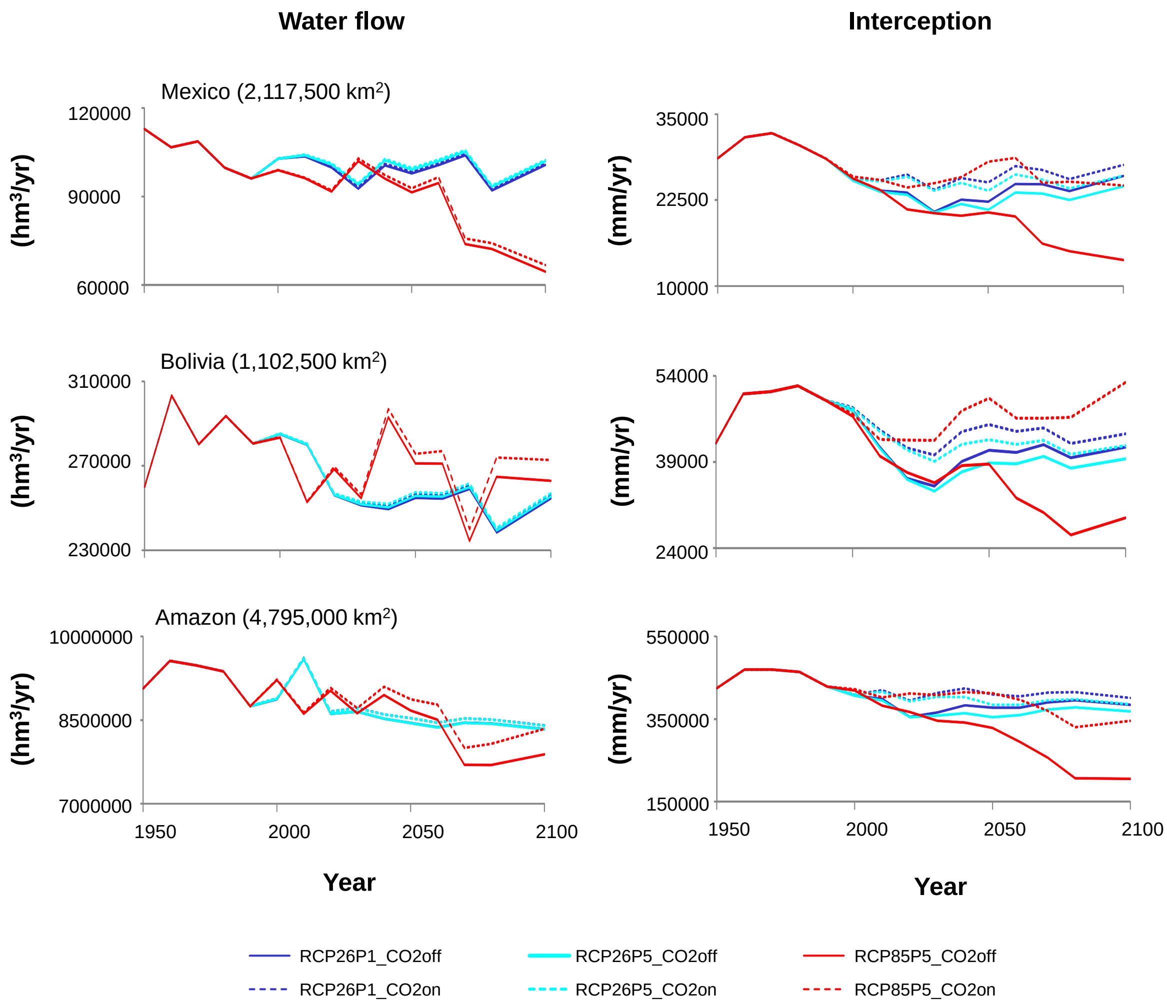


Figure 6. Future trends for water flow and interception, provisioning and supporting hydrological ecosystem services. The scenarios considered two levels of climate change forcing conditions: low climate forcing (RCP2.6) and high climate forcing (RCP8.5); two alternative socio-economic contexts: Sustainability (P1) and Conventional development (P5), and two CO_2-fertilization effects: with effect (CO_2 on) and without effect (CO_2 off).

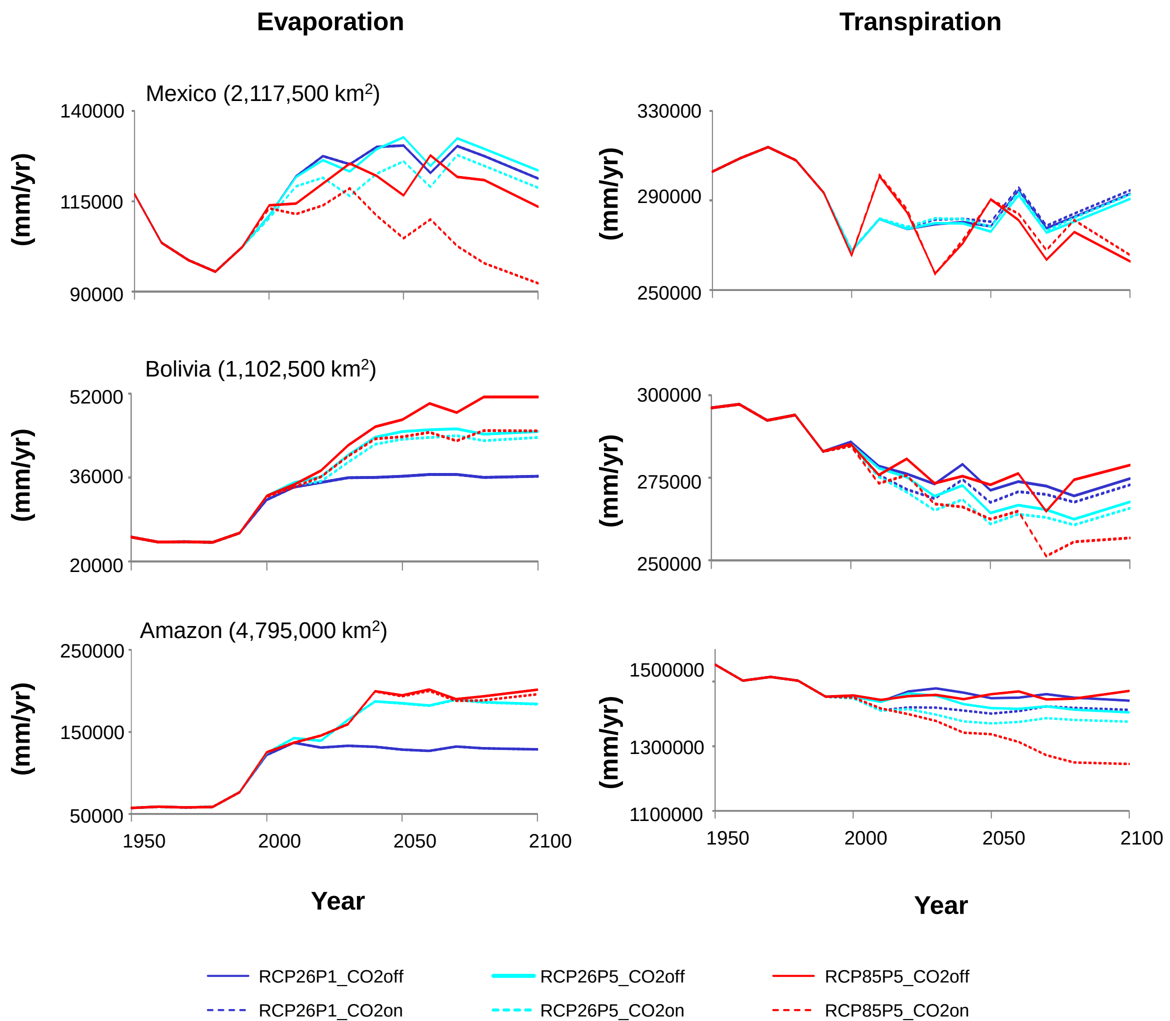


Figure 7. Future trends for evaporation and transpiration, both supporting hydrological ecosystem services. The scenarios considered two levels of climate change forcing conditions: low climate forcing (RCP2.6) and high climate forcing (RCP8.5); two alternative socio-economic contexts: Sustainability (P1) and Conventional development (P5), and two CO_2-fertilization effects: with effect (CO_2 on) and without effect (CO_2 off).

Water stress will increase under all future climate forcing and development and land use scenarios. The increase was particularly dramatic for the case of high climate forcing under the scenario of “Conventional development” and without CO_2 fertilization.

3.1.4 Issues faced with modelling timber and fuelwood

The ROBIN project aimed to model timber and fuelwood using LPJmL but that was not feasible because of double counting. LPJmL outputs, such as aboveground biomass (vegetation carbon; gC/m^2) and Net Primary Productivity (NPP, gC/m^2/yr), are generally used as a proxy for modelling and mapping services of timber and firewood. Yet, they had been used to account for carbon storage and carbon sequestration models, they could not be used to model timber and firewood to avoid double counting. Further explorations could be done with the individual-based LPJmL-FIT model version, using output variables such as tree density (ind./Ha), wood density (g/cm^3), stem diameter (m), wood mass (gC), tree biomass (gC/m^2), and tree height (m), and modules that would simulate levels of timber and firewood extraction (Thonicke et al. 2014b).

3.2 Modelling services using ARIES

Authors: Masante D. & Jones L.

3.2.1 Generalities of the approach

The ARtificial Intelligence for Ecosystem Services (ARIES; http://www.ariesonline.org) can be used to model supply, demand (delivery), flow (the link between the areas of supply and those of delivery), depletion (the balance between supply and delivery), and values (differential preferences among stakeholders) of ecosystem services (Bagstad et al. 2013). Models are built from Bayesian belief networks informed by user data. A suite of conceptual models exist which can be adapted to specific applications at different spatial scales and for particular social-ecological contexts or new conceptual models can be constructed, as applied in the ROBIN work.

Modelling provisioning services are the key to assess the consequences of alternative land uses and potential impact of climate change into the future. In particular, agro-ecosystems support food production and are the major drivers of tropical deforestation.

The modelling approach used here was intended to cover a very broad area, spanning over a surface of over 11 millions of square km at a resolution of about one km. To achieve the aims of the ROBIN project in modelling ES for current conditions and future scenarios, we created new conceptual models for crop growth and livestock numbers, flexible enough to be parameterised for different crop/livestock types in a range of bio-climatic zones. These were spatial correlative models were constructed to accommodate for scarcity of spatial data about future scenarios, while at the same time to allow for a greater generality, flexibility and applicability at wide scale. This approach was taken instead of running highly parameterised and data hungry crop growth models at field or local scale, which would not be possible for the scenarios analysis and spatial scales across multiple countries within the scope of the ROBIN project. These conceptual models were then adapted and parameterised to produce six crop models (for soya, maize, cassava, sugarcane, rice, coffee) (Section 3.2.2) and one livestock model for cattle density (Section 3.2.3).

Each of the models were then translated into a corresponding Bayesian network. Data for explanatory and response variables were selected among an ensemble of biophysical and socioeconomic global datasets, available at resolutions ranging from 0.00833 degrees (~1 km at Equator) to 0.08333 deg. (~10 km at Equator) (see Section 3.2.2.1). When multiple proxies were available, a correlation analysis was carried out to select only the single one most related to the response variable of crop yield or livestock density, as appropriate.

Land cover was used to mask the ARIES model outputs to the relevant land classes. Land cover was provided from CLUE model projections provided medium resolution (1 x 1 km) land use maps under specific land use change scenarios from 2000 to 2050. Current day land use maps were masked on the relevant classes for crop production or grazed land. These cells were then split into two parts: two-thirds of the data for model calibration and one-third for model validation.

Once the link was established between data and the Bayesian network, the models are trained using a machine learning algorithm (Expectation-Maximization), to finally produce the model of reference for each crop type. The EM algorithm provided a mechanism for building and training probabilistic models, enabling parameter estimation with incomplete data or latent variables (Do and Batzoglou 2008). Although the conceptual models for the different crop/livestock were similar, they diverged in the underlying probabilistic parameterization and, as a consequence, in their response to environmental drivers.

Calibrated models were then coded into the ARIES modelling language, Thinklab (Villa et al. 2014), and calibrated on current day data (spanning the years 1990-2010, depending on data availability) across Brazil, Bolivia, Mexico and Guyana. For any given region, ARIES produced a map of the variable of interest, calculating the expected value at each location of the region through probabilistic reasoning. In case of missing data or irregular scale of those available, the system is able to cope with the issue, selectively choosing and integrating the best available data at each location, based on a flexible and transparent definition of model components (usually referred to as ontology).

Model validation was carried out by comparing expected values with their actual values using the independent validation dataset. In other words, separate subsets of the spatial data across the study region are used for model training and for model validation. Models were compared using a suite of accuracy metrics to select among model variants for the best model. Maps of difference between predicted and actual data are also produced to identify critical regions for model performance.

Finally, validated models were applied to future ROBIN scenarios for 2050, using specific projections for dynamics variables (e.g. climate and land use) or leaving unchanged from current day for static variables (e.g. slope, soil). Model uncertainty is assessed for each scenario by means of the coefficient of variance and uncertainty maps are produced.

Concerning the methodology, for long term projections and scenario analysis, the availability of high quality data at a fairly good spatial resolution is key to reduce model uncertainty and to return reliable results, while high temporal resolution and detailed field scale data are less important when following the above methodology at coarse spatial scales. An advantage of the Bayesian approach over other methods is the ability to integrate non-quantitative variables directly into the model, such as socio-economic data, and the possibility of easily refining models when better data becomes available.

3.2.2 Models for crops (soya, maize, cassava, sugarcane, rice, coffee)

Authors: Masante D., Jones, L., Balvanera P., Balbi S., Villa F., Martorano L., Simoes M.

3.2.2.1 Conceptual and methodological underpinning

Six crops were selected for their importance in Latin America and to be representative of a wider range of crops: maize, soybean, rice, sugarcane, coffee and cassava. Criteria for selection were harvested area, economic impact, usage (including cultural elements) and diversity of life history traits. These crops were modelled across all the ROBIN study countries using the approach described in section 3.2.1.

The wide scale conceptual model of crop yield was based on the following explanatory variables: total annual rainfall, annual mean temperature, fertilisers inputs, presence of irrigation systems, soil natural fertility, slope and yield gap, where the latter is intended as a proxy of complex socio-economic drivers and, to a lesser extent, of extreme adverse natural events.

Land use maps from CLUE projections were masked on selected sub-classes (food/feed/fibre, energy and perennial croplands), reflecting the crops of interest. The data were then split in two parts: three quarters were used for model calibration, the remaining for testing model performance at a later stage.

Relevant explanatory variables and available spatial information about present crop yield were from national data (Monfreda et al., 2008) extracted to match the extent of CLUE sub-classes at year 2000 and linked to the conceptual models in the Bayesian Network.

After calibration, models were run for current day conditions for all crops, and model performance was tested. Modelled crop yield for current day generally showed good fit to the current crop yield data, confirming the approach for prediction of these provisioning services at the given scale and with the data inputs available. Validated models were then applied to the future scenarios.

3.2.2.2 Results for future conditions

Results generally showed an increase of crop yield under both climatic scenarios, with yield in the high climate forcing exceeding low climate forcing scenario (Fig. 8). However, spatial distribution of changes was different among scenarios (Fig. 9).

Sensitivity analysis among input explanatory variables showed that temperature regime and yield gap were the most influential determinants, followed by precipitation. Soil fertility had relatively less impact on yield outcome, while slope was highly influential for sugarcane only. Therefore, yield relied heavily on climate conditions, even in presence of human inputs such as fertilised.

For all crops the highest uncertainty was associated with the extreme values of the predicted range of yield, but particularly for areas of lower yield. This was likely due to additional factors resulting in sub-optimal yield such as socio-economic context or cultivation of older, lower-yielding varieties. However, extensive testing of available socio-economic data (farmer education, GDP, mechanisation, etc.) with suitable resolution and spatial coverage was not able to further improve the models.

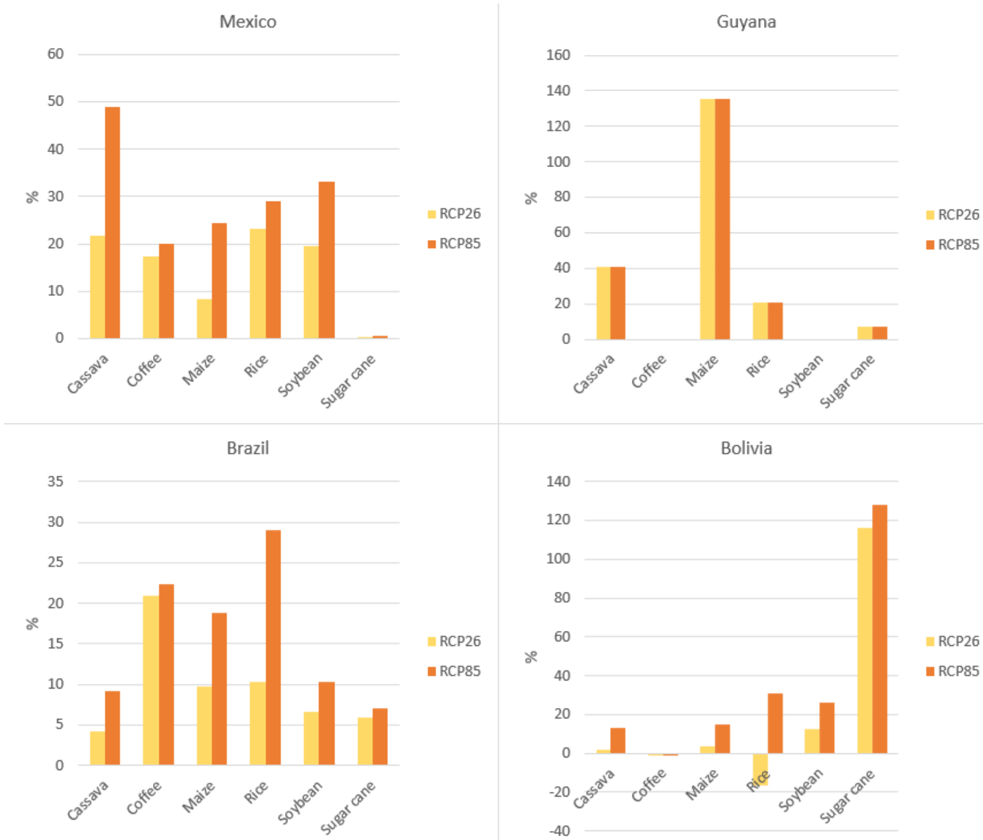


Figure 8. Relative change in yield (t/ha) to 2050 for countries study. The scenarios considered two levels of climate change forcing conditions: low climate forcing (RCP2.6) and high climate forcing (RCP8.5).

Even though crop yields may increase under climate change, some land areas showed clear decreases (Fig. 9). In fact, production depends on both yield and cropped area: a slightly lower yield in an important agricultural region may well exceed a doubling of yield in a marginal area. Production for each crop has not been calculated yet, but it is likely that absolute production will increase in all scenarios due to expansion of the land under crop classes in CLUE. This fact matches with demographic projections implying a global increase of demand for agricultural products.

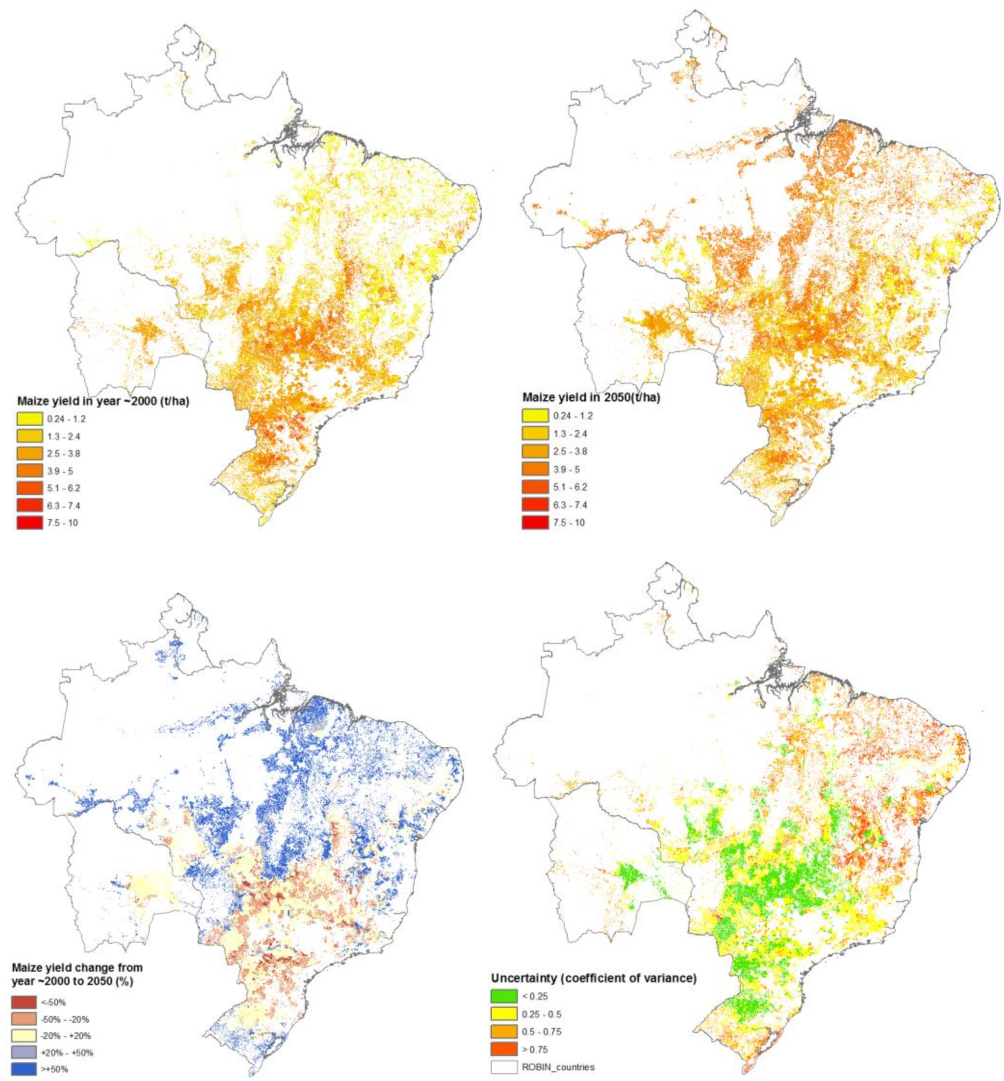


Figure 9. Maize yield from Bolivia and Brazil. Upper panel, from left to right: maize yield for current day; maize yield under RCP8.5. Bottom panel: percentage change from 2000 to 2050 under SSP5P land use change and RCP8.5 scenarios. Uncertainty of model projection expressed as coefficient of variance.

Given that exceptional events such as pest outbreaks or weather extremes are not predictable in the long term, it is not possible to implement them properly in any projection to 2050. However, these extreme events have been shown to badly affect primary productivity and crop production (Ciais et al. 2005) and are forecasted to increase in tropical regions (IPCC 2012). So it should be kept in mind that their higher frequency and magnitude may balance or reduce some of the benefits resulting from an increased productivity.

3.2.3. Models for cattle production

Authors: Masante D., Jones, L., Ferraz R. & Balvanera P.

3.2.3.1. Conceptual and methodological underpinning

Two livestock types were selected initially, cattle and sheep. Others (e.g. poultry, pigs) were excluded as less dependent on land cover as they tend to be raised in intensive animal husbandry units and are therefore very difficult to link to environmental conditions.

Similarly to the crop models above, a conceptual model was built, taking into account variables sensitive to the ROBIN scenarios. Livestock distribution was assumed to be mainly dependent on climate (as a proxy for primary productivity of pasturelands and animal well-being) and on access to market and facilities for farmers. Specifically, total annual rainfall, annual mean temperature and accessibility from urbanized areas were the variables used as model inputs, in addition to current livestock distribution as provided by Robinson *et al.* (2014).

Maps of projected land use to 2050 from CLUE were masked on selected sub-classes (grazed shrublands, grazed grasslands and grazed sparse vegetation), allowing for various degrees of grazing intensity. Available spatial data about current livestock distribution were extracted to match the extent of CLUE sub-classes in year 2000, along with explanatory input variables, and then split in two parts: two-thirds were used for model calibration, the remaining part for the validation of the model itself.

3.2.3.2. Livestock under future conditions

After model calibration, model performance was tested by checking if the predicted values matched the actual numbers for current conditions. Overall, the cattle model showed a fairly good fit to the current data (Fig.10), while sheep models did not perform well enough to be used for projections to 2050, even though several model configurations and parameterizations were tested. The reasons for such a poor fit may be related to the relative independence of livestock densities from broad environmental conditions and more to do with socio-economic drivers. However, the socio-economic variables we tested, based on available data (INEGI 2009, IBGE 2014, INE 2014) either did not improve the model fit or reduced it, and so were not included. The cattle model was then applied to future scenarios.

Results showed a net increase in areas available for grazing to 2050, while livestock density did not have a consistent response, displaying a patchy pattern across the whole range of ROBIN Countries, with a slight decrease overall. Livestock density was not influenced radically by different RCPs.

Concerning input explanatory variables, all were more or less equally influential, with rainfall regime prevailing slightly.

Uncertainty in model projections was high for cattle, mainly due to the difficulties of integrating extensive free range cattle farming with intensive livestock holdings, the latter being less dependent on climatic conditions. As a consequence, correlations among environmental conditions and livestock density were obfuscated during modelling by a higher variability in between them. This affected also model performance, in particular leading to progressive under-prediction at increasing livestock density.

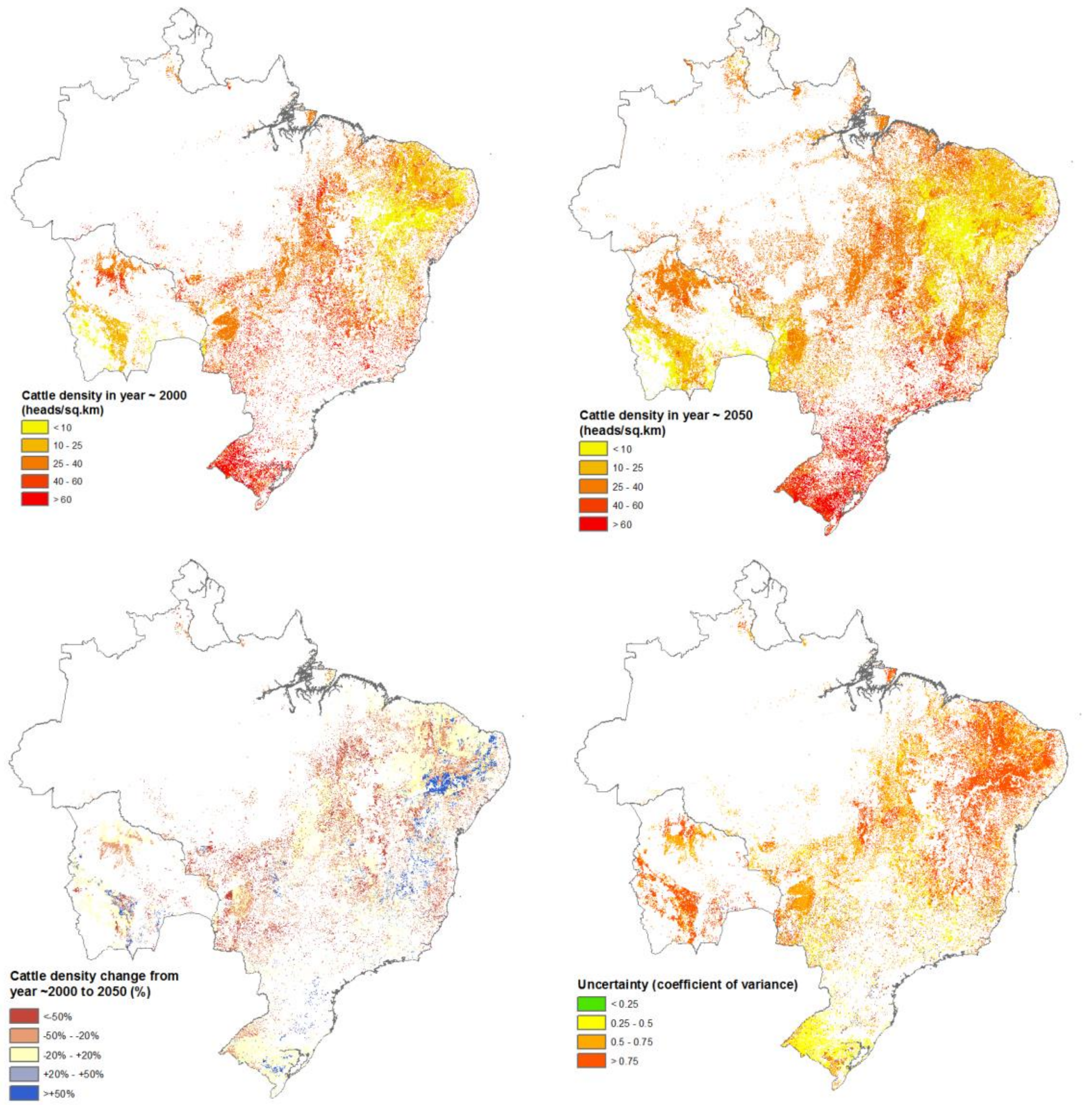


Figure 10. Upper panel, from left to right: cattle density for current day; cattle density under high climate forcing (RCP8.5). Bottom panel: percentage change from 2000 to 2050 under Conventional development scenario (SSP5) land use change and high climate forcing scenario (RCP8.5); Uncertainty of model projection expressed as coefficient of variance.

Global demand for livestock products is forecasted to be constantly increasing to 2050 (Alexandratos and Bruinsma 2012), so an overall increase in absolute production is very likely, whether through intensification of existing farms, exploitation of newly established pasturelands or both. Our model results seem to suggest both factors are operating, depending on geographical areas, i.e. a tendency to increasing the area of pastureland where land is available -and presumably convenient- for conversion, or crop intensification otherwise.

3.2.4 Models for GHG emissions

Authors: Jones L, Martorano L, Masante D, Thompson J, Smith R, Banin L., Skibe U. & Balvanera P.

3.2.4.1 Conceptual and methodological underpinning

The greenhouse gas emissions discussed here cover methane (CH_4) and nitrous oxide (N_2O) emissions. Carbon dioxide emissions and carbon storage are considered in Section 3. The modelling approach utilises components of the ARIES framework through Bayesian modelling tools.

The basis of the approach is to spatially allocate national IPCC Tier 1 inventories of emissions of methane and nitrous oxide from the Land Use, Land Use Change and Forestry (LULUCF) category using modelling techniques[1]. National LULUCF inventories of emissions are built up through upscaling emissions from a combination of different economic sectors and different land use activities. Emission factors are derived from look-up tables, with values scaled by land area, the numbers of livestock, or the scale of agricultural or industrial processes, as applicable. The numbers report the net emissions taking into account uptake as well as emissions. The main sources are: i) for nitrous oxide: N_2O –Fertilizer, crop residues and soil C losses (N_2O from soil N mineralisation); ii) for methane: CH_4–Biomass burning and waterlogged rice. As an example from Mexico, Table 2 shows national total emissions for the period 1999- 2002. In Brazil, agriculture and livestock have become key sectors for growth, leading to steady

[1] Note that this does not include emissions from other categories such as energy, industrial processes or waste – in Mexico, 2006, transport was the largest contributor to N_2O, while solid waste disposal on land was the largest contributor to national CH_4 emissions.

expansion. Marginal expansion induces conversion of native vegetation and deforestation has become the main GHG emissions source.

Table 2. Mexico National Greenhouse Gas Inventory. Emissions in the agriculture category (Gg of CO_2-equivalent) for the period 1990 – 2002. Mexico's Third National Communication to the UNFCCC.

	1990	1992	1994	1996	1998	2000	2002
CH_4	40,312.76	39,403.39	38,698.77	37,155.64	37,988.29	37,712.00	38,681.60
	85%	86%	85%	84%	84%	83%	84%
N_2O	7,114.81	6,646.09	6,805.10	6,921.06	7,456.43	7,814.76	7,464.49
	15%	14%	15%	16%	16%	17%	16%
Total	**47,427.57**	**46,049.48**	**45,503.87**	**44,076.70**	**45,444.72**	**45,526.76**	**46,146.09**

The conceptual framework to solve the how these emissions are spatially allocated (Fig. 11) includes predictor variables built up from knowledge of the main agricultural sources and land cover types which contribute to emissions. The data for these input variables come partly from other ecosystem service model outputs (e.g. spatial modelling of crop production and livestock numbers), from national data, and from global datasets of other explanatory variables such as soil type, temperature, rainfall and fertiliser application.

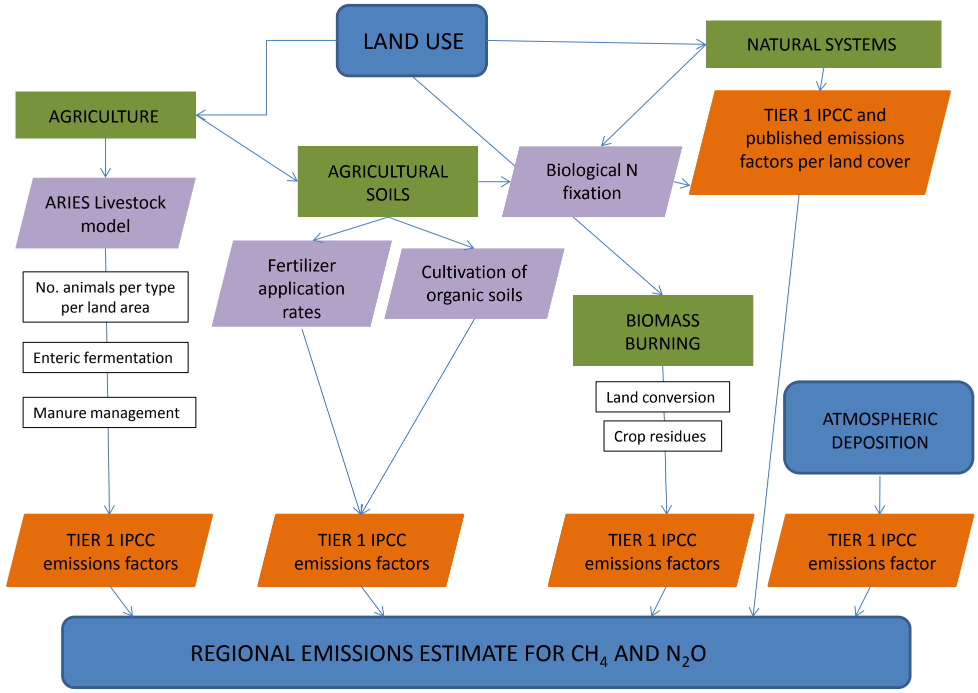


Figure 11. Conceptual model for CH_4 and N_2O emissions from the LULUCF category.

3.2.4.2 Implications for policy design at national scale

The model analysis of emissions across the study countries allows interpretation of trade-offs among ecosystem services to be undertaken within a spatial context. This can help answer wider questions on how combinations of ecosystem services change with increasing intensity of land use, and whether implementation of policies to protect biodiversity also safeguards ecosystem services. This has implications for how wider landscape management of non-forested areas, or of forest within a complex multi-functional landscape, might be considered within REDD+ schemes.

3.3 Models for disease regulation

Authors: Purse B., Masante D., Golding, N. Piggott, D., Day J., Ibañez-Bernal S., Kolb M. & Jones L.

3.3.1 Conceptual and methodological underpinning

Vector-borne disease impacts are sensitive to changing climate, land use and biodiversity and human exposure. The Leishmaniases, protozoan parasites transmitted by sandflies have high impact globally (1-2 million people infected each year) and in the Americas, and are ecologically complex (multiple Leishmania and sandfly species, mammal reservoirs and humans involved in transmission). Disease impacts in the Americas have been linked to deforestation, human marginalization and climate variability. Climate mitigation options that increase carbon storage (e.g. reforestation) may therefore have unforeseen impacts on biodiversity and disease incidence.

A correlative species distribution modelling approach (Boosted Regression Trees) was used to understand the relative role of climate (Worldclim) and land use (CLUE) variability as well as (wild) mammal biodiversity in constraining current occurrence patterns of Cutaneous Leishmaniasis (CL) and Visceral Leishmaniasis (VL) across the ROBIN study area. While VL cycles largely between people and domestic dogs, CL transmission can involve a range of wild mammal species. These disease-environment relationships were used to forecast future disease occurrence (2050) under different scenarios.

3.3.2 Results for current conditions

The two disease forms CL and VL had differential sensitivity to climate and land use factors (coloured yellow and green respectively on Table 3). Land use explained 49% of the variance in the occurrence of VL and 30% for CL, whilst CL was more sensitive to climatic effects. Temperature seasonality was the most important predictor affecting both pathogens. In addition to urban land cover (which affects VL most strongly), CL was sensitive to the amount of edge of perennial food crops in the landscape and forest cover and VL to cover of irrigated land as well as crops. These results are consistent with habitat fragmentation in crop-urban-forest matrices increasing human exposure to Leishmaniasis pathogens (Rogue & Jansen 2014).

Models that attempted to incorporate impacts of biodiversity on disease occurrence by including richness of all mammals or mammal orders alongside abiotic variables were not substantially more accurate (Area Under the Receiver Operator Curve - AUC values increased by between 0.002 and 0.006).

Table 3. Top ten predictors of current Leishmaniasis occurrence - relative contribution to variance explained.

Visceral Leishmaniasis	% contribution		**Cutaneous Leishmaniasis**	% contribution	
Predictor	mean	Sd	Predictor	mean	sd
Urban land class cover	36.9	4.4	Urban cover	12.2	2.1
Temperature seasonality	7.1	1.7	Temperature seasonality	10.0	1.1
Precipitation annual mean	6.4	1.4	Precipitation seasonality	8.2	1.2
Temperature annual mean	4.6	1.4	Max temp. warmest month	8.0	1.7
Irrigated land area	4.4	1.5	Precipitation annual mean	7.0	0.4
Max temp. warmest month	4.3	0.8	Cropland food perennial edge	6.2	1.6
Precipitation seasonality	4.1	0.7	Elevation	5.9	0.8
Elevation	4.0	0.8	Forest cover	5.8	1.0
Cropland foodPerennial edge	4.0	1.0	Precipitation driest quarter	5.1	0.6
Cropland FoodFeedFiber cover	3.4	0.4	Cropland FoodFeedFiber cover	4.9	0.3

When abiotic models were used to forecast occurrence into 2050, differential impacts of future climate pathways and socio-economic scenarios and policies on these two disease forms were predicted. CL occurrence was predicted to increase by 3.1 to 4.5 fold in spatial extent, and to the greatest extent under low climate forcing and under the Development Conventional development versus the Sustainability scenario (Fig. 12). VL occurrence was predicted to increase in spatial extent proportionally less than CL (2.8-3.4 fold) but to the greatest extent under high climate forcing and under Sustainability versus Conventional development scenarios (Fig.13). Overall climate pathways are having a dominant effect in causing the increased occurrence of the diseases, the extent of which is then modulated by the socio-economic land use change scenarios.

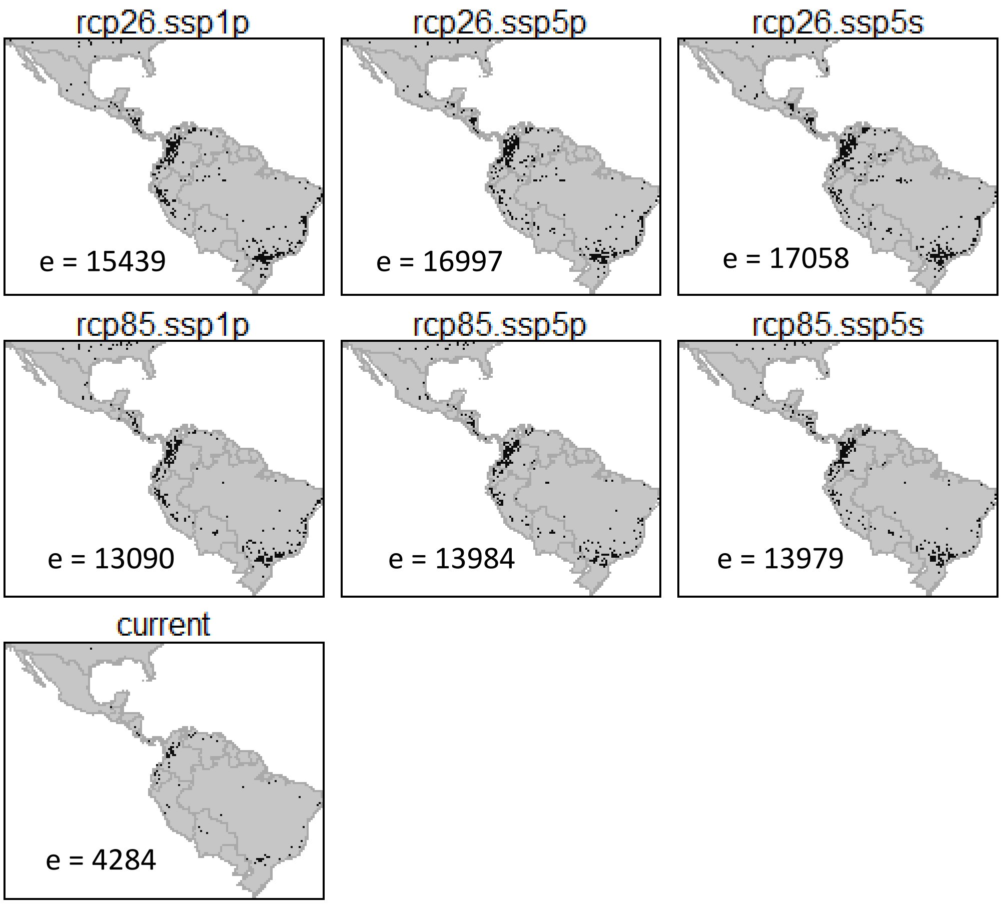


Figure 12. Predicted distribution of Cutaneous Leishmaniasis (CL) under six different future scenarios (Had-GEM2-ES model) and in the current day – colours depict predicted presence in black versus predicted absence in grey. Area of extent, e, refers to the number of 10km grid cells in which presence of CL is predicted (Had-GEM2-ES model). The increase in occurrence of CL is more pronounced under low climate forcing (RCP2.6 - top row) than high climate forcing (RCP8.5 - middle row) and more pronounced under Conventional development (SSP5) and 5s versus Sustainability (SSP1).

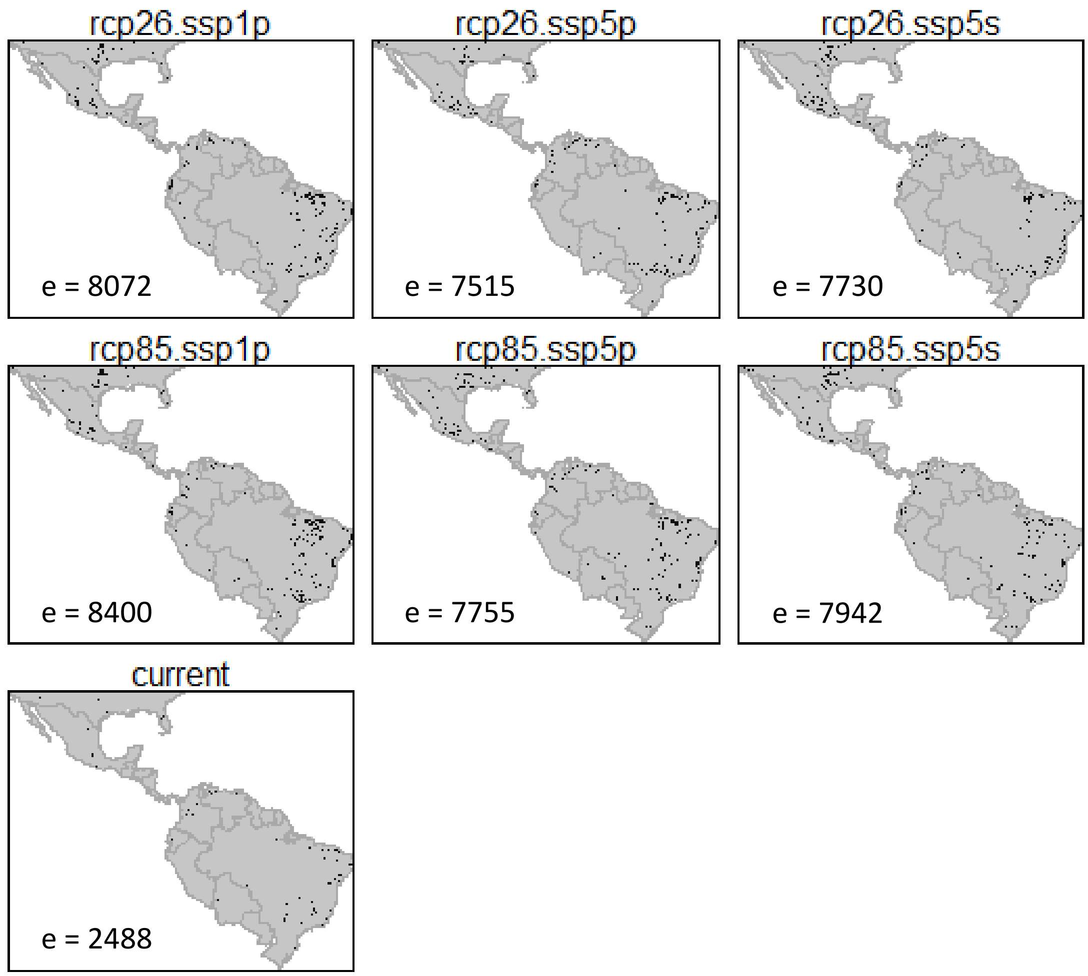


Figure 13. Predicted distribution of Visceral Leishmanaisi (VL) under six different future scenarios (Had-GEM2-ES model) and in the current day – colours depict predicted presence in black versus predicted absence in grey. Area of extent, e, refers to the number of 10km grid cells in which presence of VL is predicted (Had-GEM2-ES model). The increase in occurrence of VL is largely more pronounced under high climate forcing (RCP8.5 - middle row) than low climate forcing (RCP2.6 - top row) and slightly more pronounced under Sustainability (SSP1) versus Conventional development (SSP5) and 5s.

3.3.3 Validation of results

All models had high ability to discriminate between areas of disease occurrence and absence, indicated by Area Under the Receiver Operator Curve

(AUC) from internal cross-validation, always exceeding 0.95 for CL and 0.87 for VL models, giving us confidence in extending them into the future.

3.3.4 Implications for policy design at national scale

Considering CL first and the three focal areas (Mexico, Brazil and the Amazon), predicted impacts for disease in humans are worse in all areas under low climate forcing with Mexico and the Amazon undergoing 5-7 fold increases in extent. Under both climate pathways, the Amazon is predicted to be worst affected under the Conventional development scenarios, possibly due to high levels of fragmentation of the crop-forest-urban matrix. For VL, similar 5-7 fold changes in extent are observed in Mexico and the Amazon under both climate pathways, but for the Amazon the impacts are particularly bad under strong climate forcing. Bolivia is the least affected in terms of area by either disease form in the current day but also undergoes a ~ 3-fold increase in extent for both disease forms and both climate pathways. The increase in Leishmaniasis due to fragmentation of forest area has particular implications for design of REDD+ schemes, and illustrates the wider consequences of forest management for other components of human well-being, as well as carbon.

4 Trade-offs between biodiversity and ecosystem services

Authors: van Euten M., Pérez-Maqueo O., Equihua M., Simoes M., Ferraz R., Balvanera P., Quijas S., Jones L., Masante D., Zarco-Arista A.

4.1. *Conceptual and methodological underpinning*

The relationship between biodiversity and ecosystem services is complex: it is dependent on the scale at which it is analysed, on the way we define biodiversity, and on the type of services that are being considered (Reyers et al. 2012, Quijas et al. 2013). Win-lose relationships emerge from cutting diverse tropical forests to foster agriculture. Win-win opportunities are available for many ecosystem services that are highly dependent on the maintenance of the forest, as is the case of carbon stocks. Also win-neutral relationships can emerge.

One approach to assess these relationships is the use of dose-response curves, previously suggested within the context of the ROBIN project (Kolb et al. 2013). By assessing the existence of relationships (win-neutral vs. other options) and their direction (win-win or win-lose), and their shape (e.g. linear, asymptotic) the relationships between biodiversity and ecosystem services becomes more explicit making it easier to inform alternatives for policy design that deal with the hard choices between conservation and human needs.

Biodiversity was assessing using two indicators: ecosystem integrity and percent natural vegetation.

Ecosystem integrity, as an indicator of biodiversity, was defined as the ability of an ecosystem for auto-organization expressed by manifestations of biological diversity represented in five composite indicators used in ROBIN: structural diversity, functional diversity, compositional diversity, landscape level characteristics and human impacts. The first three are measures of biodiversity, while landscape is structural diversity on a broader scale and human impacts represent conditioning factors of the others indicators (Kolb et al 2013).Ecosystem integrity was calculated for Mexico and for the Amazon at a resolution of 1 x 1 km. For some of the analyses it was further averaged to have one value for each 50 x 50 km pixel. Ecosystem integrity data for Mexico was calculated for 2004, and for 2008 for the Amazon (Kolb et al. 2013).

The percentage of natural vegetation was assessed using the CLUE models for current and future land cover (van Eupen et al 2014). The land cover classes that were considered nature included forest, shrubland, grassland, desert, wetland and natural flooded forest. Data from current conditions (2005) and future conditions (2050) for the two development scenarios (conventional and sustainable) were used. Original data resolution was 1x1 km; it was averaged when needed to 50 x 50 km pixels.

Here we show some preliminary exploratory findings.

4.2 Links between biodiversity and ecosystem services under current conditions and into the future

Preliminary exploratory findings show that a few very clear and strong correlations were found between biodiversity indicators and ecosystem services (Fig. 14). Cattle production was negatively correlated with ecosystem integrity in Mexico, following a linear trend. This comes as no surprise given that negative impacts of cattle ranching on many ecosystems is well known and documented. Carbon storage was positively correlated with the proportion of natural vegetation cover in the three countries. This too, is not surprising given that increased carbon storage is tightly linked to increased aboveground vegetation biomass. Evaporation was negatively correlated with percent natural vegetation, following a linear trend (Fig. 14), likely due to reduced contribution of vegetation transpiration to the water balance.

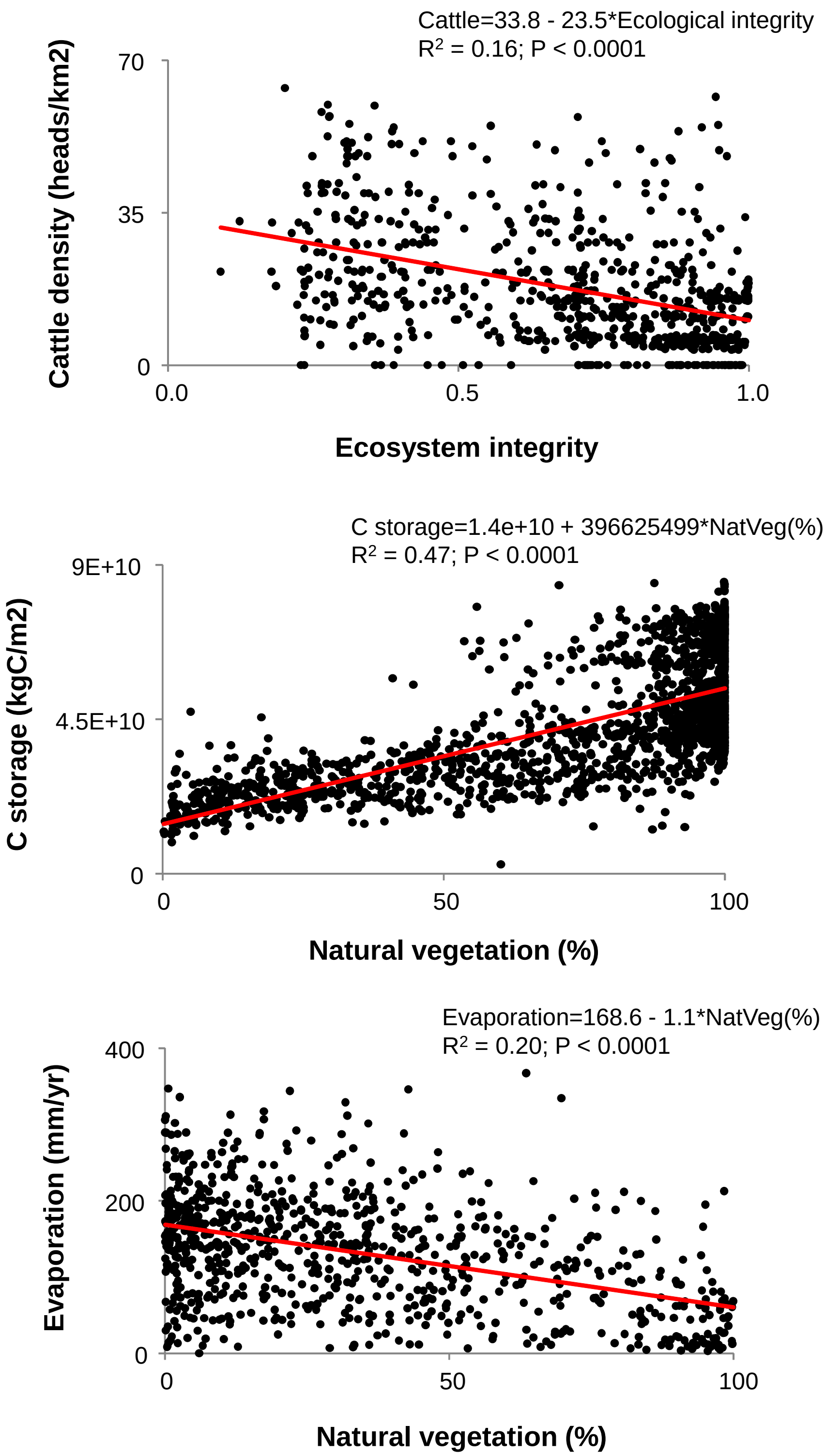


Figure 14. Nature of the relationships between two indicators of biodiversity conditions, ecosystem integrity and percent natural vegetation, and two ecosystem services, cattle (provisioning ES), carbon storage (regulating ES) and evaporation

(supporting ES) for the case of Mexico (cattle and evaporation) and the Amazon (carbon storage).

Correlations between ES and ecosystem integrity differ from those between ES and percent natural vegetation (Table 4). Also, the nature of the correlations change among countries suggesting that different processes underpin these trends. However, caution is needed in interpreting these preliminary results given the existing high spatial autocorrelation, and the large number of comparisons (i.e. avoid type II errors of over estimating significance).

Table 4. Relationship between two indicators of biodiversity, ecosystem integrity and percent natural vegetation, for three countries, for current conditions (2005) under low climate forcing (RCP2.6) and Sustainability (SSP1) land use scenario. Values are those obtained for Pearson Correlations, with N = 847 (for Mexico), 441 (for Bolivia), 1857 (for Amazon). Colors and number of asterisks indicate significance levels (*P < 0.05; **P < 0.01; ***P < 0.001). Red and yellow signifies negative correlations, blue signifies positive correlations, and white indicates no correlations. NA = not applicable.

Ecoystem services	**Mexico**		**Bolivia**	**Amazon**	
	Ecosystem integrity	% Nat Veg	% Nat Veg	Ecosystem integrity	% Nat Veg
C storage	-0.15***	0.30***	0.69***	-0.23***	0.69***
C sequestration	0.2***	0.04	0.38***	0.15***	-0.45***
Water Flow	-0.17***	0.02	0.11*	-0.02	0.31***
Evaporation	-0.17***	-0.44***	-0.41***	0.16***	-0.11***
Transpiration	-0.33***	0.18***	-0.11*	-0.18***	0.26***
Interception	-0.24***	0.10**	0.12*	0.15***	-0.07*
Maize	-0.08*	-0.19	-0.05	0.21***	-0.53***
Cassava	-0.23***	-0.03	0.1*	0.29***	-0.25***
Rice	-0.28***	0.06	0.001	0.24***	-0.49***
Soy	-0.22***	-0.09**	0.06	0.21***	-0.23***
Sugarcane	-0.12**	-0.02	0.05	NA	NA
Coffee	-0.24***	-0.02	-0.11*	0.08**	-0.25***
Cattle	-0.41***	-0.09**	-0.14*	0.23***	-0.67***
Cutaneaous Leish	-0.13**	-0.06	0.05	-0.01	-0.56***
Visceral Leish	-0.23***	-0.09**	-0.11*	-0.03	-0.22***

Very consistent relationships between ecosystem services and percent natural vegetation were found across future scenarios (Table 5). Carbon storage increases with increased percent natural vegetation while evaporation, interception, crops and cattle decrease with the same variable. These consistent correlations are clearly the result of the functional relationships assumed in the construction of the ecosystem service models and their dependency of CLUE inputs.

Table 5. Relationships between percent natural vegetation in scenarios and ecosystem services in 2050 for the Amazon. The scenarios considered two levels of climate change forcing conditions: low climate forcing (RCP2.6) and high climate forcing (RCP8.5); and two alternative socio-economic contexts: Sustainability (SPP1) and Conventional development (SPP5). Values are those obtained for Pearson Correlations, with N = 1857 (Amazon region). Colors and number of asterisks signifies significance levels (*P < 0.05; **P < 0.01; ***P < 0.001). Red signifies negative correlations, blue signifies positive correlations, and white signifies no correlations. (--) data no available.

Ecoystem services	**Scenarios**		
	RCP2.6P1	RCP2.6P5	RCP8.5P5
C storage	0.71***	0.78***	0.78***
C sequestration	-0.02	0.25***	0.05
Water Flow	-0.01	-0.02	-0.01
Evaporation	-0.79***	-0.83***	-0.77***
Transpiration	0.12***	0.13***	0.03
Interception	-0.69***	-0.73***	-0.74***
Maize	--	-0.62***	-0.63***
Cassava	--	-0.68***	-0.70***
Rice	--	-0.62***	-0.64***
Soy	--	-0.65***	-0.65***
Sugarcane	-0.48***	-0.44***	-0.44***
Coffee	--	-0.30***	-0.30***
Cattle	--	-0.53***	-0.53***
Cutaneaous Leish	0.003	0.03	-0.02
Visceral Leish	-0.26***	-0.25***	-0.30***

5 Trade-offs among services under alternative future scenarios at national scales

Authors: Balvanera P., Jones L., Quijas S., Boit A., Thonicke K., Ancarrunz N., Jones L., Masante D., Zarco-Arista A., Purse B., Banin L., Day J., Ibañez-Bernal., Simoes M. & Kolb M.

5.1. *Conceptual and methodological underpinning*

Synergies and trade-offs occur among ecosystem services across space and time. These interactions result from concurrent responses to similar drivers and from functional relationships among services (Bennett et al. 2009). Changes in the nature of these trade-offs among countries and alternative future scenarios can be the result of both changes in functional processes and those in socio-economic drivers. Trade-offs among ES will be assessed using Pearson Pair-wise correlations (Raudsepp-Hearne et al. 2010).

5.2. *Trade-offs among ES for contrasting countries*

Preliminary findings show that increased carbon sequestration, the service that will more directly relate to climate change mitigation, correlates negatively with carbon stocks, water flow, crop and cattle production and positively with the regulation (and thus negatively with its incidence) of cutaneaous Leishmaniasis under current conditions (Table 6). These patterns were expected to occur as a result of the functional relationships between these variables. The nature of the correlations among trade-offs differed among countries. 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. Explorations of changes in these correlations into the future are ongoing.

Table 6. Correlations among ecosystem services for current conditions (2000) for Mexico, under low climate forcing (RCP2.6) and Sustainability (SSP1) land use scenario. Values are those obtained for Pearson Correlations, with N = 847. Colors and number of asterisks indicate significance levels (*P < 0.05; **P < 0.01; ***P < 0.001). Red indicates negative correlations, blue indicates positive correlations, and white indicates no correlations.

	C storage	C sequestration	Water flow	Evaporation	Transpiration	Interception	Maize	Cassava	Rice	Soy	Sugarcane	Coffee	Cattle	Cutaneaous Leish
C sequestration	-0.48***													
Water flow	0.75***	-0.56***												
Evaporation	-0.22***	-0.14**	0.10**											
Transpiration	0.80***	-0.39***	0.72***	-0.20***										
Interception	0.67***	-0.33***	0.68***	-0.15**	0.79***									
Maize	-0.06	-0.04	-0.02	0.20***	-0.02	-0.07								
Cassava	0.37***	-0.41***	0.42***	0.12**	0.39***	0.31***	0.02							
Rice	0.47***	-0.26***	0.39***	-0.09*	0.52***	0.43***	0.15**	0.19***						
Soy	0.13**	-0.10**	0.14***	0.09*	0.18***	0.02	0.16**	0.12**	0.22***					
Sugarcane	0.23***	-0.16**	0.26***	0.04	0.24***	0.17***	0.04	0.05	0.31***	0.15**				
Coffee	0.40***	-0.42***	0.47***	0.15**	0.40***	0.42***	0.06	0.23***	0.28***	0.07	0.22***			
Cattle	0.45***	-0.42***	0.50***	0.15**	0.55***	0.37***	0.17***	0.37***	0.47***	0.21***	0.26***	0.45***		
Cutaneaous Leish	0.17***	-0.21***	0.20***	0.04	0.20***	0.21***	-0.006	0.14**	0.13**	-0.05	0.15**	0.08*	0.18***	
Visceral Leish	0.01	-0.02	0.05	0.09**	0.09*	0.09*	0.10**	0.03	0.11**	0.06	0.06	0.04	0.17***	0.29***

These preliminary results need to be further revised by taking into account spatial autocorrelation and the elevated number of comparisons, as well as biases resulting from differential data availability.

Nevertheless, these preliminary results already highlight the importance of taking into account the strong trade-offs among ecosystem services. Particular attention should be put to policies aimed at increasing climate change mitigation only at the cost of addressing other societal needs.

6. Trade-offs between biodiversity, ecosystem services and well-being at multiple spatial scales

6.1 Trade-offs at local spatial scales

Authors: Varela-Ortega C., Blanco I., Esteve P., Lazos E., Gerritsen P., Martorano L., Beltrão N., Lisboa L., Nascimento N., Manners R., Toledo M., Simoes M. & Ferraz R.

6.1.1. *Conceptual and methodological underpinning*

Ultimate decisions on how ecosystems are managed are taken at the local scale. There, actual land owners and/or land managers foster alternative ecosystem services in the context of the existing biophysical restrictions and in response to socio-economic, cultural and technological drivers operating at local to global scales. Thus trade-offs between biodiversity, ecosystem services and well-being are likely to be different at local scales.

The ROBIN project chose one study case per studied country. The study cases are: i) the southern coast of Jalisco, for the case of Western Mexico, ii) the province of Guarayos, in the Bolivian lowlands, and iii) the Tapajos National Forest, in the Brazilian state of Pará.

For all study cases governmental information as well as other type of information from varied stakeholders used to assess trends in biodiversity, ecosystem services and well-being. A series of stakeholder workshops were carried out to study the social-ecological systems in the project's local case study sites and to develop future scenarios.

This study focuses on the analysis of the current state of the environment and existing trade-offs between biodiversity conservation and human well-being in the three study cases (southern coast of Jalisco, Mexico, Guarayos, Bolivia, and Flona Tapajós, Brazil). The analysis was developed using Fuzzy Cognitive Mapping (FCM) in local stakeholder workshops (Varela-Ortega et al. 2014). FCM offers a proven method for modelling socio-ecological (complex) systems, and it can illustrate the functioning and interactions of factors within such systems. FCM can be fully participatory when they are developed by stakeholders using their knowledge and interpretation of the question or theme posed to them (Varela-Ortega et al 2013). In the following sections 6.1.3 and 6.1.4 we use the dynamic analysis of the FCMs to simulate the impacts of policy drivers on the social-ecological system of the Brazil and Bolivia case studies. The analysis illustrates the relations between human and environmental systems including the linkages and trade-offs between biodiversity, climate change, human welfare, and ecosystem services.

6.1.2 Southern Coast of Jalisco (Mexico)

Authors: Lazos E. & Gerritsen P.

During the last 50 years many socio-ecological transformations haven taken place in the Southern Coast region of Jalisco state in western Mexico. Six municipalities form the region: Casimiro Castillo, Cihuatlán, Cuautitlán, La Huerta, Tomatlán and Villa Purificación.

At the workshops we organized with local stakeholders, although the local authorities came from almost all the region, the farmers were mainly from two municipalities (La Huerta and Villa Purificación). With a similar surface (1,749.71 km^2 y 1,937.61 km^2), La Huerta extends from sea level to the 258 m; and Villa from

300 m up to 500 m. The population is highly dispersed: in La Huerta we find 153 communities and 168 in Villa. La Huerta has a population of 23,428 inhabitants with a low population density (13,38 in hab/km^2) and with a medium index of marginalization (20.4). Villa Purificación has a population of 11,623 inhabitants with a very low population density (5,99 hab/km^2) and a higher index of marginalization (26.97).

The transformations that have taken place in the Southern Coast region have complex origins and interrelations. Regional stakeholders understand the complexity of the transformation and identify a great number of causal factors with cultural, ecological, economic, political and social dimensions, understanding their interrelations. These causal factors have contributed to profound changes in the region. First, since the 90s, the timber production has decreased, especially in Villa, mainly due to the expansion of extensive cattle ranching (Fig. 15). On the contrary, timber production has increased in Autlán, Tomatlán and La Huerta (Fig. 15).

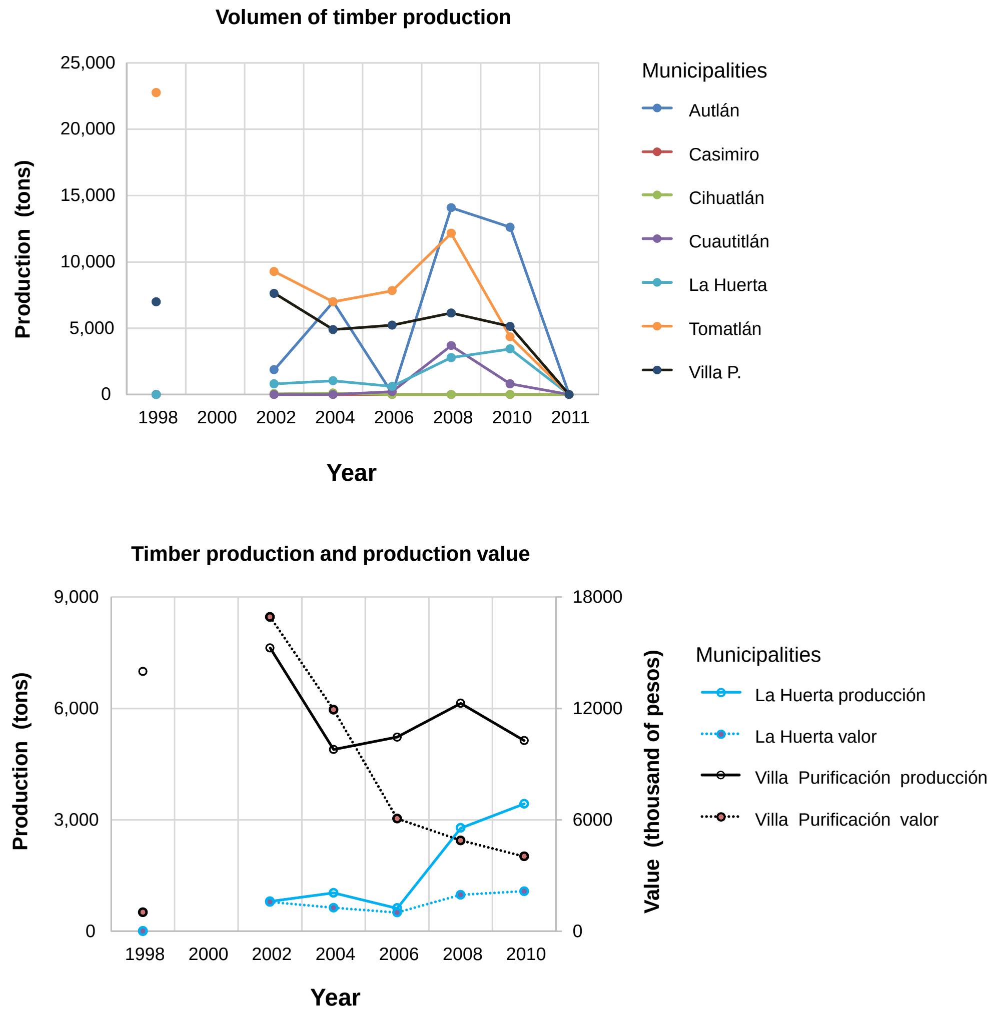


Figure 15. Timber production and value of timber in the Southern Coast of Jalisco.

A reduction of meat production was observed by the workshop participants from the mid 80s to the beginning of the 90s due to diseases and hence to the US market closure (Fig. 16). From the mid 90s, the production has oscillated but has stayed low (except in the case of Tomatlán). The value of the meat production has slightly increased (Fig. 16). At the same time, agricultural production has abruptly decreased (Fig. 17). The inhabitants remember 20 and 30 years ago full granaries of maize and its exportation to big cities, as Autlán and Guadalajara. Nowadays, the maize production has been reduced so much that they have to import maize during 4 to 7 months per year (Lazos, in press). At the beginning of the 90s, La

Huerta and Villa were producing each around 13,000 tones of maize per year; now, their joint production does not reach 5,000 tones. At the same time, the bean production has strongly diminished, especially in Villa and Cuautitlán, where bean was one of the main crops (Fig. 18). New problems, such as mining, unprecedented illegal forest exploitation and tourist entrepreneurial development along the coast have aggravated the current situation.

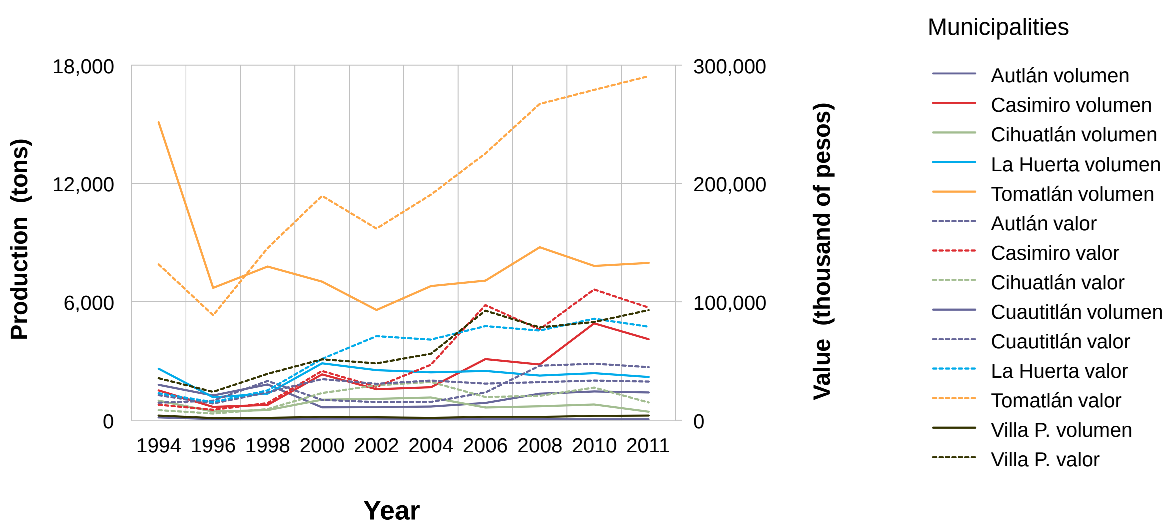


Figure 16. Bovine meat production and value of the production in the Southern Coast of Jalisco.

In the Southern Coast of Jalisco, important productive reductions of staple crops (maize, beans, rice, sugarcane) have taken place since the late 1980´s. As crops depend on the rainy season, there are good and very bad years due to drought or to inundation. Also, due to the same reason, there are big differences between the cultivated and the harvested agricultural surface. Even the farmers remember losing up to 80% of the maize production. Since the 1990´s, when Mexico signed the North American Free Trade Agreement, the maize prices have gone down, so the farmers have not been able to sustain their production. Regarding the meat production, it has oscillated with some upper peaks in the mid 90´s and some low peaks at the late 90s because of the cattle sickness and the fluctuating prices. Finally, the legal timber production has diminished, but the illegal timber extraction has increased. So, there is no distribution of benefits from the forests.

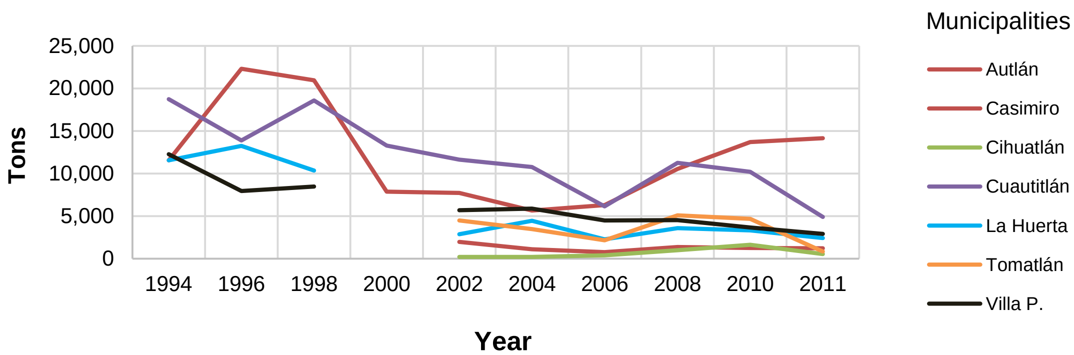


Figure 17. Maize production in the Southern Coast of Jalisco.

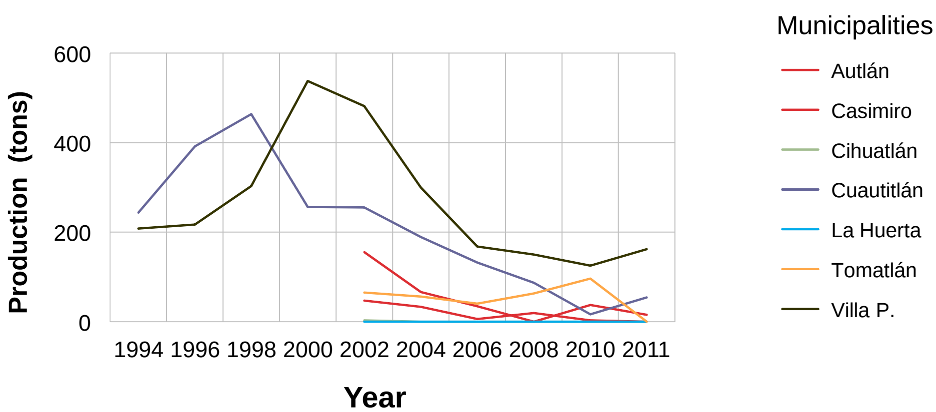


Figure 18. Bean production in the Southern Coast of Jalisco.

In other words, the socio-ecological problems that affect the region have had an impact on biodiversity, climate change mitigation and human welfare. First, stakeholders mention the loss of biodiversity. Secondly, stakeholders identify different manifestations of climate change (more frequent droughts and a longer period of the dry season). Finally, they state that human welfare is under threat. Regional stakeholders are aware that current land-use practices will lead to a more unsustainable future. However, they identify a great many solutions that also can be located in the different dimensions of sustainability (cultural, ecological, economic, political and social). Noteworthy in this respect is the fact that regional stakeholders mistrust the civil servants of the municipal, state and federal institutions, who make the implementation of new policies and programs difficult

In synthesis, the region is experiencing a tendency to replace crops that were essential for local food security for those with commercial importance. Also, the cultivation of staple grains is being replaced by fodder, pastures and bovine cattle. Labor is being expulsed from the region due to increased advanced technology availability.

Interestingly, workshop participants that manage land for agro-industrial agriculture do not worry about the impacts of extensification. Instead, those that manage for subsistence do see such a trend as a threat.

At the local level, many proposals exist to improve the welfare and to halt environmental deterioration. This means that attendees, apart from having environmental knowledge also displayed ways to recover sustainability. In other words, a regional potential exists.

It is important to note that all participants agree that the region and its people have not benefited from the changes. This explains the mistrust towards government agencies. In this sense, a first task in implementing new policies for mitigation of climate change is building trust between different actors, both local and external.

6.1.3 The Tapajós National Forest (Brazil)

6.1.3.1 General trends

Authors: Martorano L., Beltrão N., Lisboa L., Nascimento N. & Varela-Ortega C.

Total of losses of forest areas in the Legal Amazon reported in July 2014 was on the order of 355 km^2. This constituted a 134% increase from the figure reported in July 2013 of 152 km^2 of total deforestation for the same area. The state of Pará witnessed the most deforestation: 57% of the total from August 2013 to July 2014 (IMAZON 2014).

The most vulnerable areas are increasingly being preserved or conserved for the current and future generations. The state of Para has the biggest extent in protected areas, with about 22 million hectares added to the protected Amapa and Amazonas areas which form the largest biodiversity corridor on the planet (Barreto et al. 2007). Yet, these areas suffer greatly with the withdrawal of goods and services provided by the forest, such as illegal logging, fishing, hunting, small-scale agriculture, mining, land invasion, among others, which may cause the isolation and extinctions of small populations of species of flora and fauna (MMA 2003).

Brazil's Tapajós National Forest (Flona Tapajós) — a designated Conservation Unit (CU)(Rodríguez et al.) under Sustainable Use Group created by Decree No. 73,684 (February 1974) — measures approximately 527,000 hectares (ICMBIO 2012). This CU has undergone constant changes in usage patterns and ground cover, especially in its surroundings, due to activities related to agriculture, livestock and timber harvesting. In June 2012, Federal Law No. 12,678 reduced the area of Tapajós Flona by approximately 4% of its original size. These areas (Fig. 19) began to be called buffer zones.

In Flona Tapajós and its surroundings, between 1989 and 2005 there was a higher percentage of loss patterns in the Native Forest than occurred from 2005 to 2009 and the patterns remained stable. The spatiotemporal dynamics in Flona Tapajós and its surroundings indicates the importance of legally protected areas for the conservation of goods and services offered by the people as part of the Amazon Forest Strategy. In integration with other information and analysis, these dynamics may uncover possible threats to the maintenance of goods and services that sustain the biodiversity of the region.

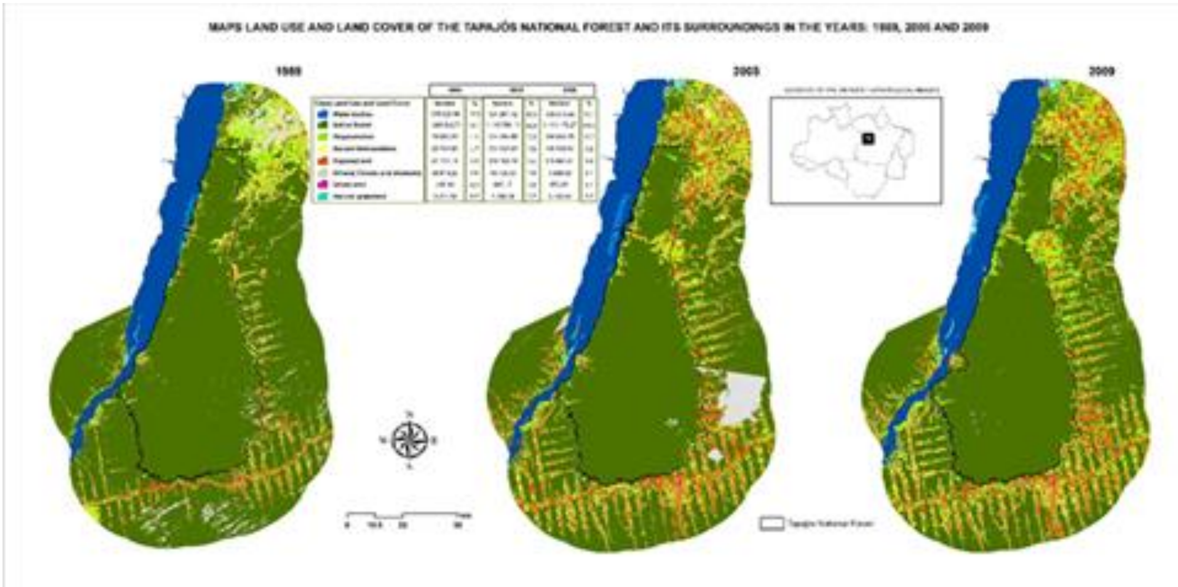


Figure 19. Mapping and quantitative analysis of the land use and cover in Flona Tapajós and its surroundings. Years: 1989, 2005, and 2009.

Further assessments of changes in land cover, biophysical conditions and ecosystem services from governmental statistics and remote sensing data are underway.

6.1.3.2. Results from the analysis in the Tapajos National Forest

Authors: Varela-Ortega C., Esteve P., Blanco I., Manners R., Martorano L., Simoes M. & Ferraz R.

The method of Fuzzy Cognitive Mapping (FCM) was used to analyse trade-offs between ecosystem services and human well-being. Fig. 20 shows the development of a FCM for the Tapajos National Forest in Brazil (Pará state).

Figure 20. FCM development for the Flona Tapajós case study.

The FCM for Flona Tapajós case study (see Varela-ortega et al. 2014) includes 32 factors, 9 of them drivers of the system: i) illegal mining, ii) lack of environmental awareness, iii) lack of governmental policy coordination, iv) international interest to conserve the Amazon, v) lack of efficiency of policies for subsistence agriculture, vi) lack of protection of traditional forest communities, vii) population increase in the Amazon, viii) opportunities to sell environmental services, and ix) technology supply for sustainable land use. The central issue in the map, which is the one linked to most factors, is deforestation.

The dynamic analysis of the map based on Varela-Ortega et al. (2014), allows for the interpretation of the effect of the different drivers on key elements in the system, such as the effect of key institutional and social drivers on deforestation or biodiversity loss. For the analysis of trade-offs between these key factors we focus on the analysis of the impacts of three selected drivers: 1) governmental policy coordination (inverse of the original driver in the system), 2) absence of environmental awareness, and 3) protection of traditional forest communities (inverse of the original driver in the system). Fig. 21 depicts the effects of these drivers on the system described by the original FCM (see Varela-Ortega et al. 2014).

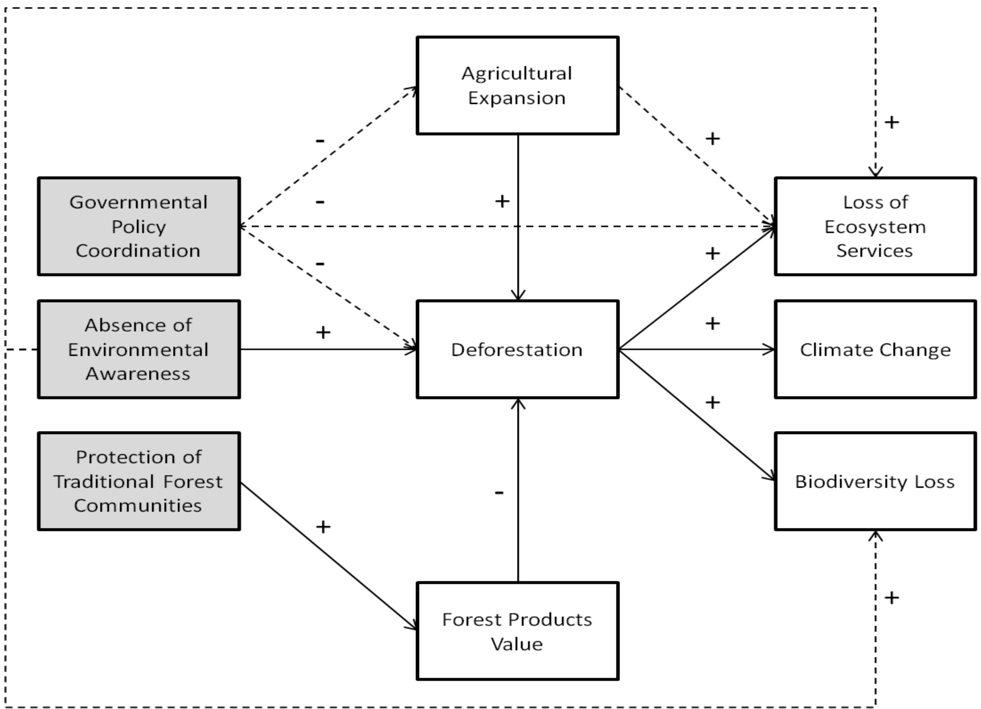


Figure 21. A simplified schematic representation of the causal relations between selected drivers (in grey) and key outcomes of the system represented by the Brazilian Tapajós Forest stakeholders. Dashed lines represent non-direct links, i.e. there are other factors involved in the causal relation (see Varela-Ortega et al. 2014) for a complete representation of the FCM)

As shown in Fig. 21 (FCM of Brazil), governmental coordination has an effect on ecosystem conservation and also on agricultural expansion. Environmental awareness is a driver that has significant impacts on ecosystems. Although agriculture is a major threat to forest conservation, government support to agricultural activity is not viewed as an important driver in the system's dynamics. Instead, the protection of traditional forest communities is considered a major driver that promotes other forest-related livelihoods.

The results of the relative effects of the three selected drivers on key selected variables are depicted in Fig. 22.

According to the FCM dynamic simulations in Fig. 22 we concluded that:

a) Governmental coordination (blue bars) can reduce biodiversity loss, deforestation and especially limits the loss of ecosystem services. It would also reduce the current contribution of deforestation to climate change. However, it would reduce agricultural expansion, though in a smaller proportion, which could have detrimental effects on agricultural income and rural livelihoods.
b) Agricultural expansion is, according to Brazilian stakeholders, partly triggered by the absence of environmental awareness. This driver produces the opposite effect (orange bars) than governmental coordination and in a very similar relative magnitude. This lack of awareness would contribute to increased biodiversity loss, deforestation, losses of ecosystem services and climate change, whilst agriculture would expand at a greater pace.
c) Finally, governmental actions to protect traditional forest communities (yellow bars) could contribute to halting the loss of biodiversity and deforestation while protecting ecosystem services and increasing the value of forest products.

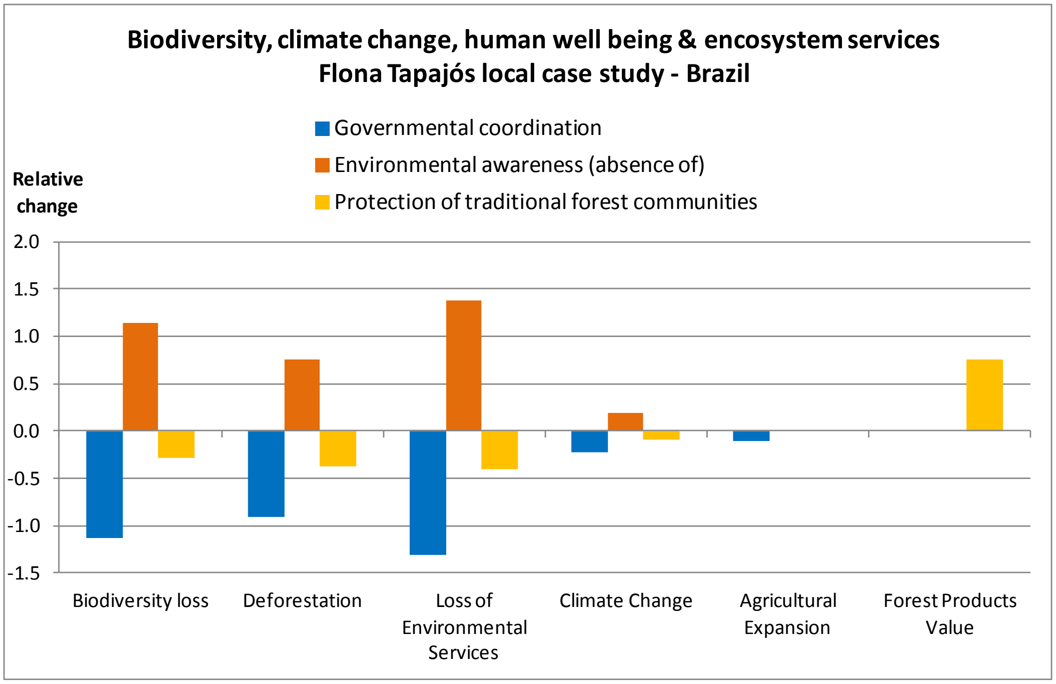


Figure 22. Impact of selected drivers on biodiversity, deforestation, ecosystem services, climate change, agriculture and forest products.

If we consider the joint effects of the different drivers, there are several relevant implications for policy making. First, the lack of environmental awareness would counterbalance and mitigate the positive environmental effects triggered by governmental policy coordination. Therefore, governmental actions addressing social environmental awareness are very relevant to enhancing the effects of environmental policies. Second, although governmental coordination may have detrimental effects on agricultural expansion, and consequently on agriculture-based livelihoods, if combined with policies that protect forest communities, beneficial effects on ecosystems would be maintained while, at the same time, the relatively small impact on agricultural livelihoods could be compensated by the promotion of forest-based livelihoods.

6.1.4 The Guarayos province (Bolivia)

Authors: Varela-Ortega C., Esteve P., Blanco I., Manners R. & Toledo M.

The Fuzzy Cognitive Mapping (FCM) method was used to analysing trade-offs between ecosystem services and human well-being. Fig. 23 shows the development of a FCM for the Guarayos case study in Bolivia.

Figure 23. FCM development for the Guarayos case study.

The FCM of the present situation in Guarayos includes 27 variables, of which 6 variables act as drivers of the system: i) implementation of the INRA (National Institute of Agricultural Reform) law, that reduces the development of traditional agriculture law, ii) lack of understanding, application and coordination of policies, iii) lack of environmental awareness, iv) illegal mining, v) land trafficking, and vi) poor administration by community leaders (Varela-Ortega et al. 2014, and Varela-Ortega et al.). Similarly to the Brazilian case study of the Tapajós National Forest, deforestation is the central issue in this map.

In this case, we selected two drivers of the system to look at the relations between biodiversity, climate change, human well-being and ecosystem services. These are: the implementation of the INRA law, and coordination and implementation of policies (inverse of the original driver in the system). The INRA law has developed agrarian reforms in Bolivia, establishing different types of private ownership of land and guaranteeing land property rights to peasants and indigenous communities. This law, while providing these people with access to land, is also having significant impacts upon forests. The causal relations of those selected drivers with key outcomes in the system are represented in Fig. 24.

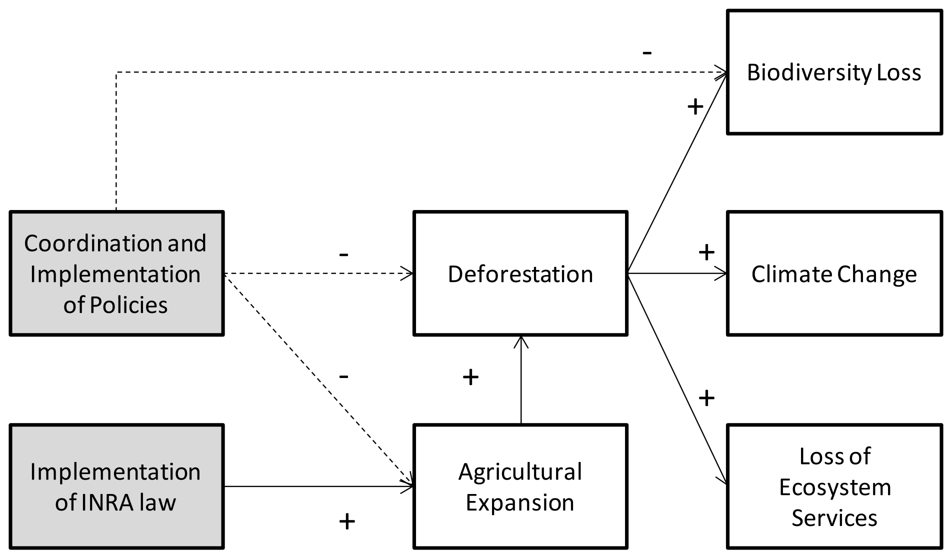


Figure 24. A simplified schematic representation of the causal relations between selected drivers (in grey) and key outcomes of the system represented by Bolivian stakeholders. Dashed lines represent non-direct links, i.e. there are other factors involved in the causal relation (see Varela-Ortega et al. 2014) for a complete representation of the FCM)

The results of the FCMs dynamic simulations are depicted in Fig. 25.

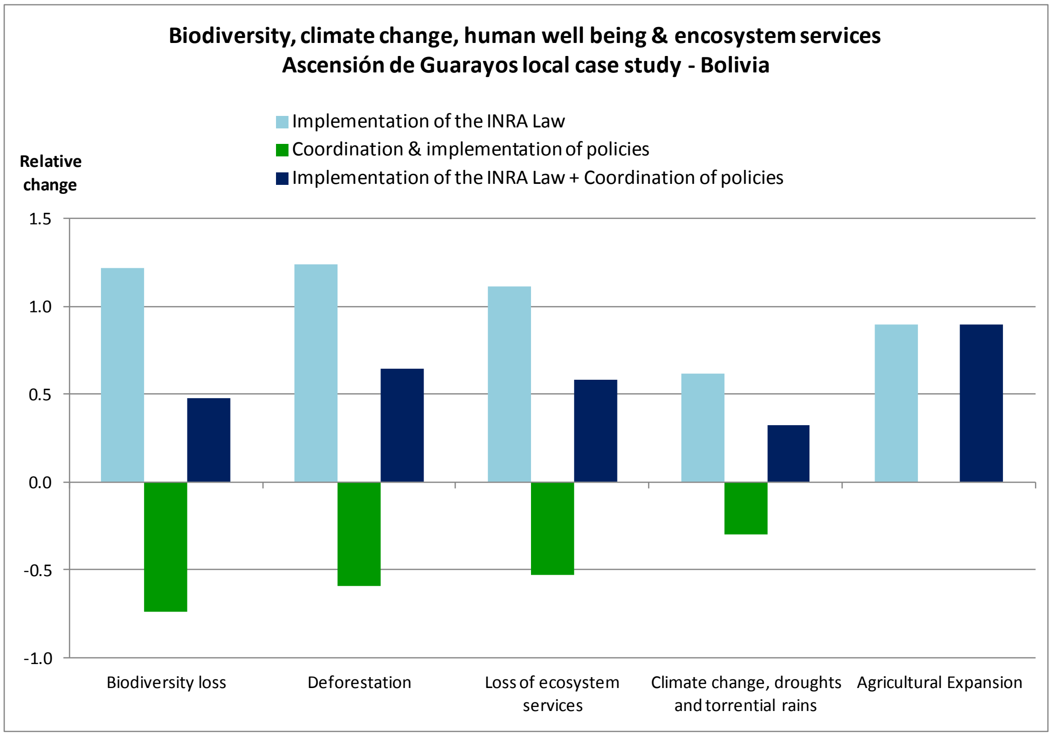


Figure 25. Impact of selected drivers on biodiversity, deforestation, ecosystem services, climate change and agriculture.

The results of the relative effects of the three selected drivers on key selected variables are shown in Fig. 25, and can be summarized as follows:

a) The implementation of the INRA law (pale blue bars) has a clear negative effect on forest ecosystems, showing a significant effect on biodiversity loss, deforestation and ecosystem services. This impact on forests results also in a change in climate, including more frequent drought and torrential rains. Nonetheless it has a positive effect on agricultural expansion, which is used as an indicator for agricultural income and support of rural livelihoods.
b) The coordination and implementation of policies (green bars) refers to the effective implementation of forest protection laws and the strengthened coherence between agricultural and environmental policies. This driver produces less biodiversity loss, reduced deforestation and losses of

ecosystem services and limits climate change, without an impact on agricultural expansion.

c) The analysis of the joint effect of both drivers (dark blue bars), shows that agricultural expansion is possible with a lesser negative impact on ecosystems and climate change. This means that policies and institutional elements, such as the coordination of different administrations and policies, can play a key role in balancing the trade-offs between biodiversity protection, climate change mitigation and the development of the agricultural sector and rural livelihoods. In this case, the coordination and effective implementation of policies would represent a win-win solution in which, without halting agricultural development, environmental targets would be more easily attained.

Comparing the results of the two Amazonian case studies (Brazil and Bolivia), we can conclude that coordination and effective implementation of policies at local level are key for guaranteeing a balanced provision of ecosystem services. It can contribute to more sustainable socio-economic development and to maintain rural livelihoods while protecting forest ecosystems and biodiversity. Therefore, supporting and building institutional capacities can be essential in the context of the development and implementation of REDD+ policies. This also underlines the relevance of policy actions taken at local scale. Downscaling policy perception to the local level is decisive as deforestation and climate change policies (e.g. REDD+) are taken globally, but effects and actions are perceived locally. Therefore local perceptions of deforestation pressures and biodiversity conservation can help to identify the main drivers of deforestation and key social-ecological interactions. In turn, participatory cognitive mapping have proven to be a valuable tool for supporting policy development at the local scale by identifying key elements and processes upon which policy makers and institutions can take actions.

6.2 Using a Bayesian approach to exploring the links between biodiversity, climate mitigation, ecosystem services and human well-being at multiple scales

Authors: Pérez-Maqueo O, Equihua M, Equihua J, Díaz P, García-Alaniz N, Kolb M, Schmidt M.

6.2.1. Mexico

6.2.1.1. Conceptual and methodological underpinning

Ecosystem Integrity (EI) can be understood as a dynamic state of natural ecosystems that has the maximum capacity of resilience and self-organization of its original components that maintains many ecosystem processes related to most terrestrial biogeochemical cycles.

Conceptually the baseline EI state would cover balanced natural systems with optimal values of functional, structural and taxonomic biodiversity (BD). In this way, somehow, biodiversity can be regarded as an indicator of this supposed ecosystem integrity state, and on the other hand, EI can be considered as a proxy of biodiversity and of all ecosystem services in general

Humans depend on the conservation of ecosystems both by our use of materials harvested from them and by the environmental conditions of where we live. Biodiversity is paramount for the structure and function of ecosystems, so documenting its status is deeply connected to measuring the status of ecosystems. However, in many cases biodiversity data are not available and furthermore it is not always clear how to actually measure it (Kolb et al. 2013). On the other hand, different structural and functional attributes of ecosystems that can be obtained from various data sources such as remote sensing, and field, expert opinion and even models, can inform us about the status of an ecosystem (Equihua et al in prep.; Pérez-Maqueo et al. in prep). Under the framework of ecosystem integrity and the Bayesian networks approach, we have developed an indicator that allows, through the measurement of different attributes (i.e. tree height, leaf area, biomass and also including biodiversity) to evaluate the degree of integrity of ecosystems which also relates to the ecosystem services that they provide (Equihua et al in prep.; Pérez-Maqueo et al. in prep). This way, the Bayesian approach we are developing makes it possible to couple Ecosystem Integrity and Ecosystem Services provisioning in the same mathematical structure. We can produce either an “ecological mapping” or a “socio-ecosystem mapping” with the same model network (Equihua in prep.).

6.2.1.2. Bayesian networks linking biodiversity, climate mitigation, ecosystem services and human well-being

Ecosystem services are defined as the benefits that people obtain from ecosystems and are basic to human life. Using Bayesian networks makes it more or less easy to link some of the variables that accounts for integrity in terms of ecosystem services (such as carbon capture and storage, water provision and disease regulation, for instance). Given the capacity of Bayesian networks to make inference in both “mapping” directions described above, we can evaluate relationships between ecosystem services and integrity (Fig. 26) (Equihua et al. 2014, Pérez-Maqueo in prep.). Indirectly, we can have an estimate of the human wellbeing that could be associated with the management of these ecosystems.

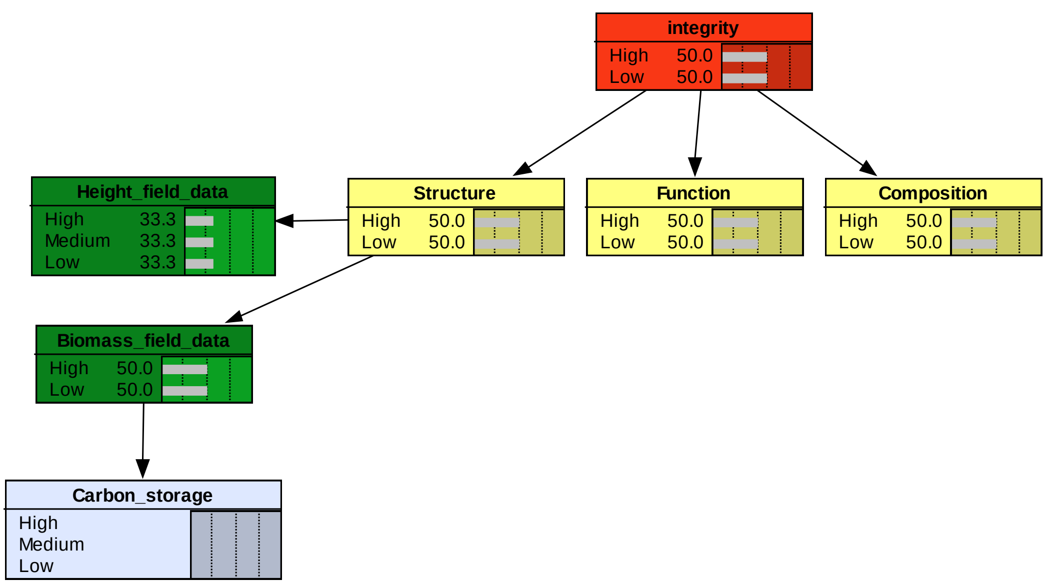


Figure 26.Bayesian network used for modelling ecosystem integrity and ecosystem services (e.g. carbon storage).

6.2.1.3. Implications for policy design at national scale

It is possible to have a diagnosis of the integrity of ecosystems at different scales (local, national and regional). We can evaluate the environmental cost in terms of integrity loss and ecosystem services provisioning changes resulting from those decisions made while managing a landscape. Given this potential of the approach we are developing, it seems worthwhile to consider improving the data base from which the estimates are derived through suitable monitoring systems for those variables that account for the state of ecosystem integrity.

The results of the proposed analysis will be useful for the design of REDD +. In one hand, they will assess the impact of REDD + on the integrity of different environmental units and on the other it will make possible to estimate the trade-offs on the supply of other environmental services. The approach can also be applied in the implementation of other public policies such as payment programs for ecosystem services, proposals of conservation areas and even policies for the development of infrastructure (roads, dams, etc.) or crops, livestock, etc.

6.2.2. Brazilian Amazon

Authors: Simões M., Ferraz R. & Pereira S.

6.2.2.1. Conceptual and methodological underpinning

Land use changes (LUC), within extended geographic areas and presenting high degree of intensity, are intrinsically related with biodiversity loss and integrity decrease of natural systems, and at the same time the decrease of their ecosystem services (ES). Landscape patterns can be correlated with different levels of ecosystem integrity (EI) and consequently, with the potential environmental services provision. Therefore, relating land-use patterns with ecosystem integrity makes it possible to predict environmental services provision in the future, based on the assessment of different LUC scenarios (Fig. 27).

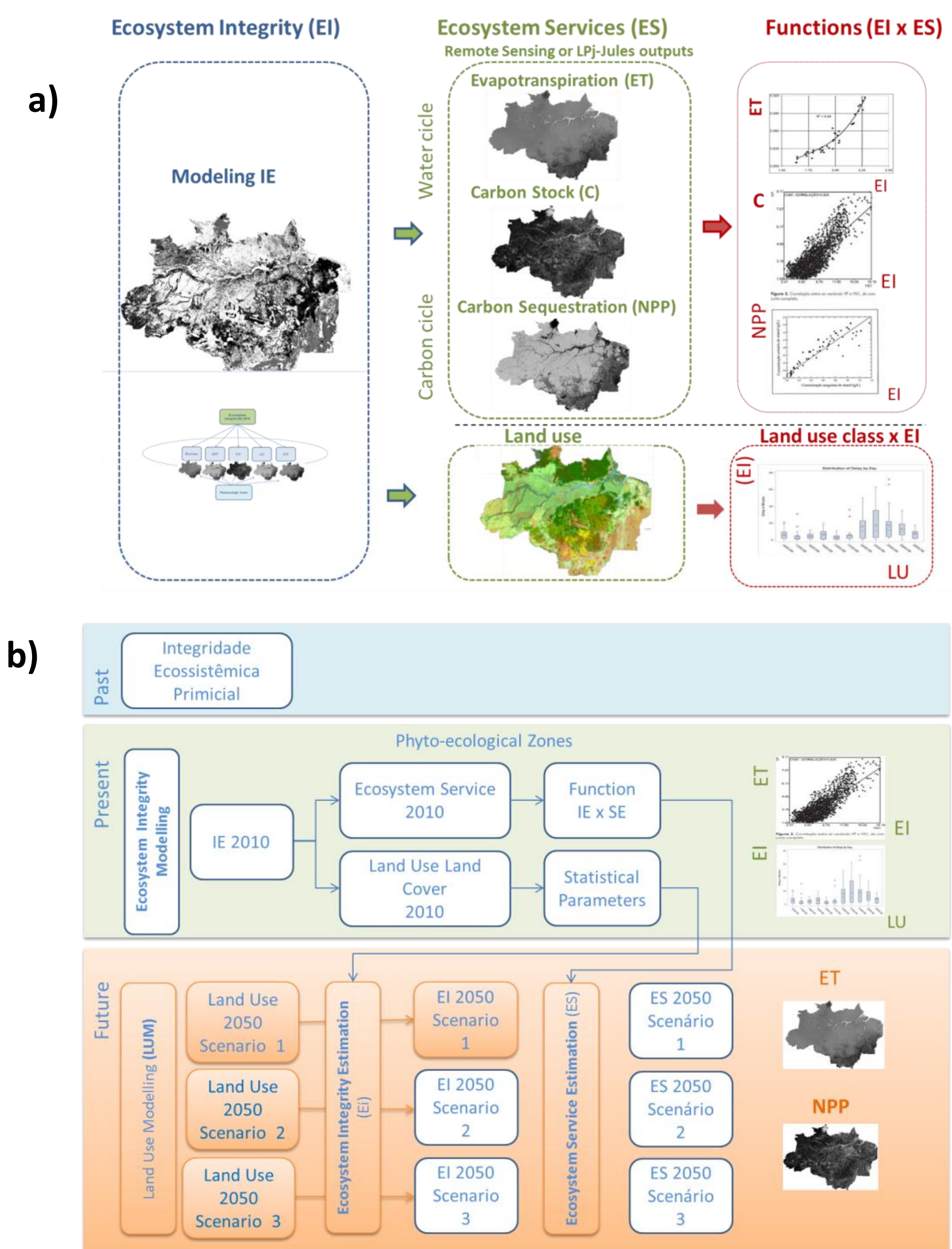


Figure 27. General methodological approach, from past to future (b), modelling and linking land use changes, ecosystem integrity (EI) and climate related ecosystem services (a) in the legal Brazilian Amazon.

In Brazil and other Latin American countries, where there is low field data availability - geographically distributed and periodically updated - a viable approach is the use of Remote Sensing (RS) data (Fig. 28a). The RS approach allows, not only monitoring the temporal variations of EI/BD and SE, as well as, spatial variations, using smaller or larger spatial resolutions satellite data, making it possible to model those variables in different spatial-time levels.

a)

b)

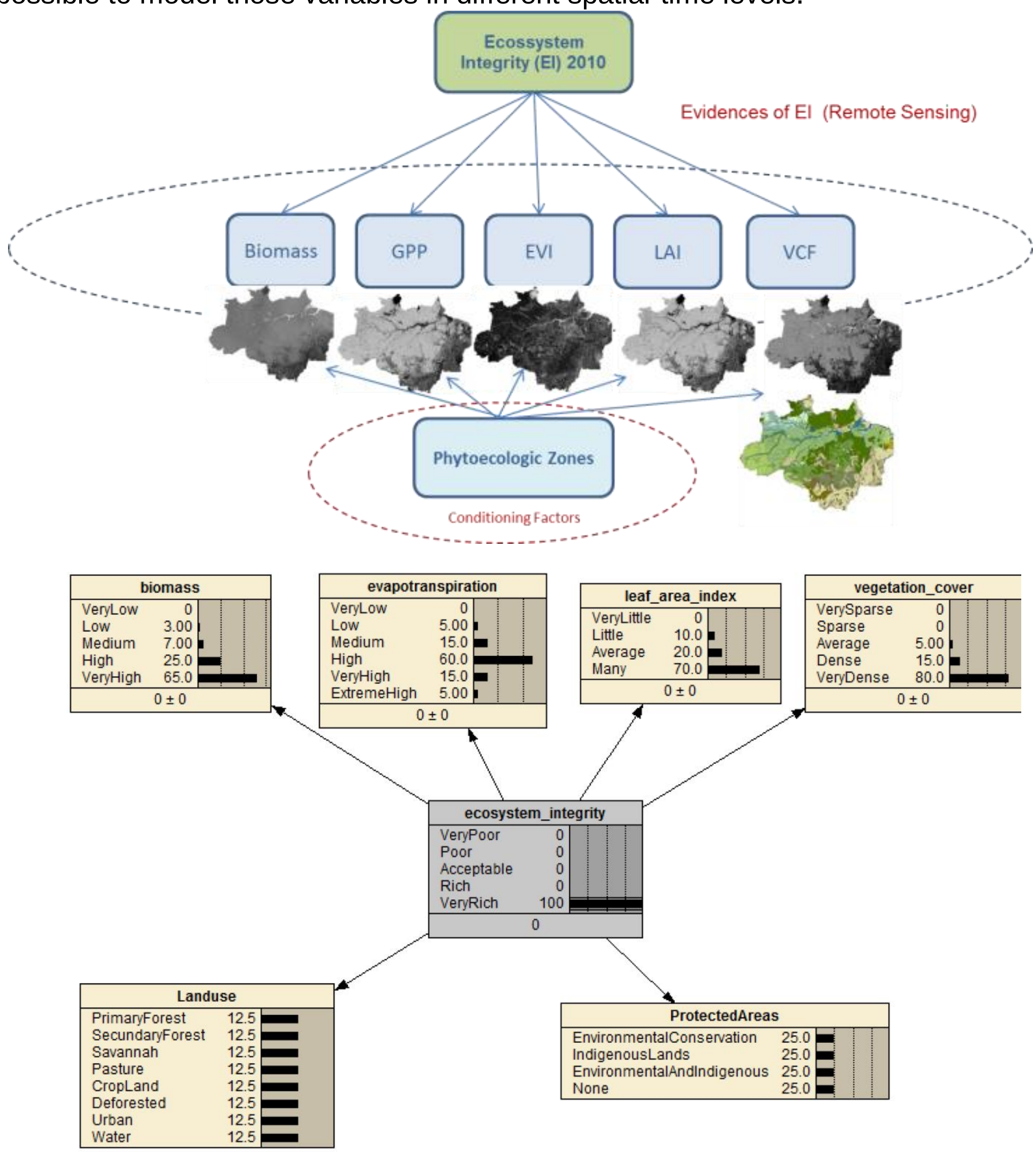


Figure 28. Methodological approach: Conceptual (a) and operational/Netica (b) Bayesian network applied to Ecosystem Integrity estimation for the Brazilian legal Amazon.

Initially, the EI mapping, at 1km^2 pixel, was performed in order to capture the intrinsic differences of the different phyto-ecologic landscape patterns of the Brazilian Amazon. Considering that the huge Brazilian Amazon region is environmental and socio-economically diverse, this resolution (1 x 1 km), while continuing to meet the ROBIN Project goals, respond more adequately to the expectations of decision makers within the Brazilian Government regarding the proposition of regional policies for sustainable development.

It was proposed to develop an integrative methodological approach (Fig. 27) able to establish the relationship between the Ecosystem Integrity, Ecosystem Services and Land Use Changes in time (Fig. 30), mainly based on Remote Sensing data that allows monitoring the environmental dynamics in different spatial and temporal scales.

The methodological integrated approach (Fig. 27) consists of the following steps: (i) Ecosystem Integrity Spatial Model: generation of an Ecosystem Integrity spatial model, on a regional scale, for the Brazilian legal Amazon region, based on probabilistic distribution of evidences based on learning process (*data-driven models*) through the Expectation Maximization algorithm (Buntime, 1994). A Bayesian network (Fig. 28b) has been established from an expert conceptual model that related different spatial data (Remote Sensing data):

i. Biomass (MODIS/ USGS – NASA); (ii) EVI; (iii) LAI - Leaf Area Index (MODIS/ USGS – NASA); (iv) Tree Cover (MODIS/ USGS – NASA); (v) GPP- Gross Primary Productivity (MODIS/ USGS – NASA). The validation of the model is being held through the specific knowledge and some control-areas which there are available forestry and biodiversity data inventories;
ii. LUC-SSPs scenarios: generation of a Land Use Changes Model (Clue Model) for the Brazilian legal Amazon region based on SSPs scenarios but adapted to the sectorial policies reality currently in Brazil;
iii. Correlation of Ecosystem Integrity Spatial Model (Fig. 29) and Ecosystem Processes/Services Models: (*a*) Evapotranspiration fluxes ecosystem service*:* estimated from MODIS Surface Resistance and Evapotranspiration (MOD

16), data developed by Numerical Terradynamic Simulation Group (NTSG), College of Forestry & Conservation - University of Montana. (Mu et al., 2007); (*b*) Carbon stocks spatial model: estimated from aboveground carbon stocks spatial model developed by Baccini *et. al*. (2004) within the Pantropical National Level Carbon Stocks Project held by the Woods Hole Research Center – WHRC, Boston University and the University of Maryland (MA, USA). The methodology was based on ground data, MODIS 500m imagery and GLAS LiDAR data;

iv. In view of the modeling integration, at regional scale, proposed by the ROBIN project, we have also established the correlations between EI and LPJmL and ARIES models ES outputs, from the resampling of EI outputs pixels of 1 km ^{2} to 50 km^2;

v. Establish the statistics parameters about LU patterns and EI.

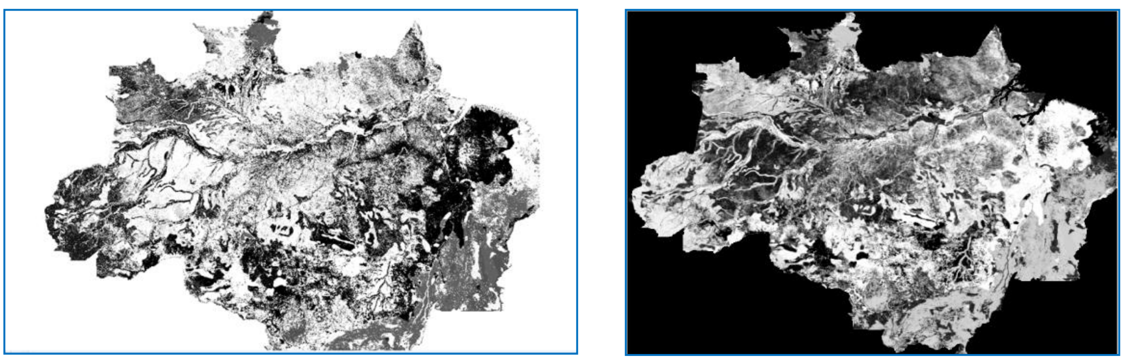


Figure 29. Ecosystem Integrity estimation for the Brazilian legal Amazon: (i) Left: EI present (Range between white and dark = high to low EI; (ii) Right: Loss on EI =▲IE = IE present – IE pristine (Range between white and dark = high to low Loss on EI). *Note: Models are still in validation.*

6.2.2.2 Implications for policy design at national scale

Land use changes (LUC), in large regions with high degree of intensity, are intrinsically related with *biodiversity loss* and *integrity decrease* of natural systems, as well as *ecosystem services* (ES). *Landscape* patterns can be correlated with different levels of *ecosystem integrity* (EI) and consequently with the potential environmental services provision. Relating land-use patterns with ecosystem integrity from different LUC scenarios, makes it possible to predict future environmental services provision (Table 7).

Providing a real management tool with direct application to the proposal of national policies for biodiversity conservation and natural resources management, territorial planning and ordering, makes it possible to establish targets of reducing greenhouse gas emissions and so on.

Table 7. Land Use change scenarios with and without Policies

Scenario	Demand	Contextualization
First scenario: Amazon untouched development		
SSP1P (Policies C3+BD+ES) – Maximization of deforestation prevention & protection of currently known protected areas.	Harmonization of 6 macro-economic scenarios (per Amazon state).	Forest do not convert to agriculture or to pasture (after 10 years) – no deforestation Conversion of pasture to: agriculture, reforestation and secondary vegetation – pasture area decreases Secondary vegetation grows 1% year (in grazing areas).
Second scenario: food security “Brazil feeds the word”		
(SSP5S – conventional development without policy) – Changes considering the maximum allowed for deforestation – legal milestones (policies).	Significant increase (full economic development) 20% forest are converted to agriculture and pastures	Scenario of food security (the need to feed the population over the coming decades) – would the economic situation be more important than global warming and biodiversity conservation worries; e.g. China importing meat.
Third scenario: sustainable development		
SSP5S (policiesC3+BD+ES) – Development but considering full application of all	Compatibility of 6 macro-economical scenarios for each Amazon State	National forest code Conversion of forest to agriculture and pasture Conversion of pasture to agriculture, reforestation and

Scenario	Demand	Contextualization
sustainable development policies		secondary vegetation – pasture area decreases Recent deforested areas will be converted to agriculture, pasture and reforestation (1000 ha/yr) Secondary vegetation grows 1%/yr (in grazing areas) Maintenance of conservation units (UCPI-integral protection, UCUS-sustainable use, PI) Agriculture new frontier in Brazil will be Maranhao Tocantins, Piaui, Bahia (irrigated savannah areas)

7 Links between ecosystem services and well-being indicators at regional and local scales.

Authors: Díaz J. & Lazos E.

7.1 Conceptual underpinnings

Well-being is a description of the state of individuals' life situation´ and it should be treated like a multi-dimensional phenomenon that captures peoples' life circumstances (Mcgillivray,2006; Summers et al. 2012). Because the multi-dimensional character of welfare and complexity between social-natural interactions that distribute benefits differentially, linking services to well-being necessarily involves assessing interactions and trends between the sustainability trilogy (biodiversity, ecosystem services and human well-being). Indicators used to measure welfare are focused in different dimensions and used for different purposes. The Millennium Ecosystem Assessment (MEA 2005), has tried to link these indicators to ecosystem services, which has led to the measurement of welfare under the umbrella of ecosystem services framework, therefore, it has been focused on measuring physical and human capital as well as provisioning services and not in valuing implicit-indirect benefits like climate regulation (Table 8).

Table 8. Linking existing measures of well-being, ecosystem services and welfare components.

Human well-being measure	Potential Indicator	Ecosystem Services †	Well-being component ‡
Human Development Index	A long and healthy life	P,R	P,H
	Being knowledgeable		S,P
	Decent standard of living	P, R	F
OECD Better Life Initiative	Community		S
	Education		H
	Environment	P,R,C	N
	Governance		S
	Health	P,R	H,P
	Housing	P	P
	Income	P,R	F
	Jobs	P	F
	Life satisfaction		H
	Safety		S
	Work-life balance		H
QOL Index for Development Countries	Affective autonomy		H
	Conservatism	R	N
	Egalitarian commitment		H
	Harmony		H
	Hierarchy		H
	Intellectual autonomy		H
	Mastery		H
The Economist Intelligence Unit´s QOL Index	Climate and geography	R,C	N
	Community life	C	S
	Family life	C	S
	Gender equality		H
	Health	R,P	H
	Job security	P	F
	Material well-being	P	F
	Political freedom		S
	Political stability and security		S
Gallup Healthways Well-Being Index	Basic access		
	Emotional health	C	H
	Healthy behaviour		H
	Life evaluation		H
	Physical health	R,P	H
	Work environment	R,C	N
Gross National Happiness	Community vitality		S
	Culture	C	S
	Ecology	C,R	N
	Education		S
	Good governance		S
	Health	R,P	H,P
	Living standards		
	Psychological well-being	C	H
	Time use		
Happy Planet index	Ecological footprint	P,R	N
	Experienced well-being	C	
	Life expectancy		H

ǂ Ecosystem Services: P=Provisioning; R=Regulating; C=Cultural, ǂǂ well-being Components: H=Human Capital; S=Social Capital; F=Financial Capital; P=Psychical Capital; N=Natural Capital. Source: OECD (http://www.undp-globalfund-capacitydevelopment.org/); (www.oecdbetterlifeindex); (www.happyplanetindex.org/); (www.grossnationalhappiness.com); Smith et al. (2013); Meijer & Van Beek (2011); Leisher et al. (2013); Diener et al.(2006). **Note:** Table 8 was constructed to link welfare indicators most commonly used with the analytical framework of ecosystem services.

7.2 Links between services and well-being indicators for the state of Jalisco

The exploration of these links was performed for the state of Jalisco, Mexico, where one of the ROBIN study cases is found, as a pilot for analogous explorations in other study cases.

Analysis of conventional ways for measuring welfare, reveal there is a clear correlation between the Human Development Index (HDI) components (income, employment and education) associated with urban areas; however, high marginality and migration rates are present in rural areas where pressure on natural resources is higher (Table 9). During the last thirty years there is a clear trend for reduced percent natural vegetation while population and welfare indices have increased (Fig. 30). It is also clear that pressure on natural resources is high, despite a decrease in the maize planted area, that was offset by the increase in yields (Fig. 31), due to the increase use of inputs and therefore with effects on increased salinization, erosion and pesticide pollution. Although there are many factors that explain the ecosystems degradation, evidence shows how human well-being has increased despite large global decline in most ecosystems. Fig. 32A shows a negative trend between Remaining Natural Vegetation (RNV) and HDI while the latter increases, RNV decreases in an exponential way. It is important to see in Fig. 32D how agricultural productivity has declined as the RNV decreases, possibly to the fact that increases in yield have not offset the decrease in production.

Table 9. Correlation matrix between conventional human well-being indicators for the State of Jalisco

Indicator	Population	Marginality	Health	Migration	Education	Income	Employment	Infrastructure	Forest Area	Urban Area
Marginality	-0.359									
Health	0.067	**-0.590**								
Migration	-0.400	0.158	0.099							
Education	**0.575**	**-0.755**	0.254	**-0.428**						
Income	**0.646**	**-0.732**	0.288	**-0.364**	**0.881**					
Employment	**0.948**	-0.300	0.064	**-0.333**	**0.490**	**0.564**				
Infrastructure	-0.074	0.509	**-0.500**	-0.109	-0.274	-0.243	-0.098			
Forest Area	-0.249	**0.536**	-0.206	0.021	-0.316	**-0.354**	-0.206	0.229		
Urban Area	**0.959**	**-0.412**	0.081	**-0.423**	**0.637**	**0.690**	**0.841**	-0.060	-0.252	
HDI	0.439	**-0.868**	**0.664**	-0.232	**0.868**	**0.838**	**0.380**	**-0.444**	**-0.317**	**0.486**

Source: INEGI (http://www.inegi.org.mx/).

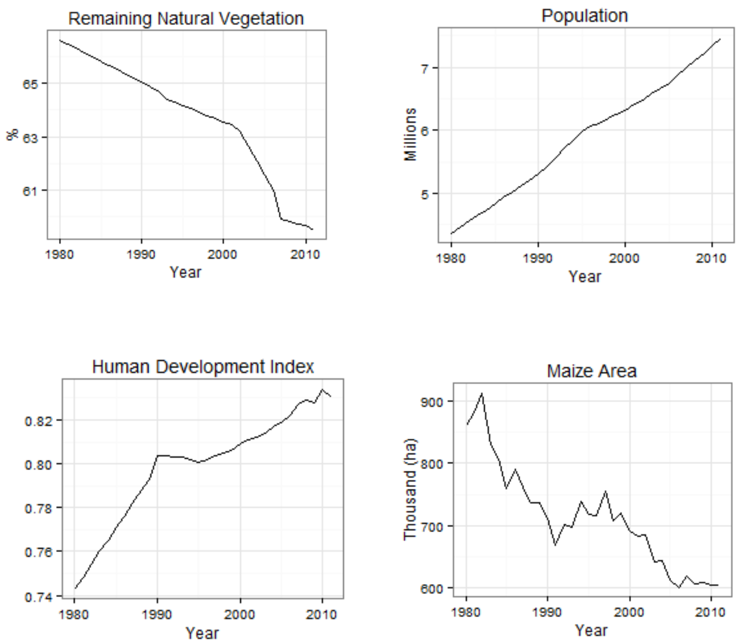


Figure 30. Trends for different indicators in Jalisco, México (1980-2011)
Source: SEMARNAT (www.semarnat.gob.mx/temas/estadisticas /snia/Reportes-de-Indicadores); SIAP (http://www.siap.gob.mx/); INEGI (www.inegi.org.mx/), UNDP (www.mx.undp.org/).

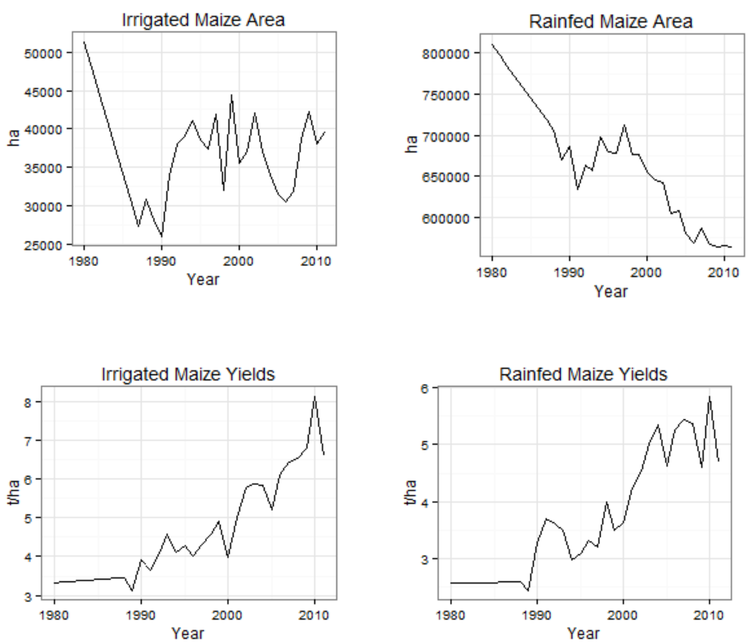


Figure 31. Comparing different maize production trends in Jalisco, México (1980-2011). Source: Sistema de Información Agroalimentaria de Consulta (SIACON).

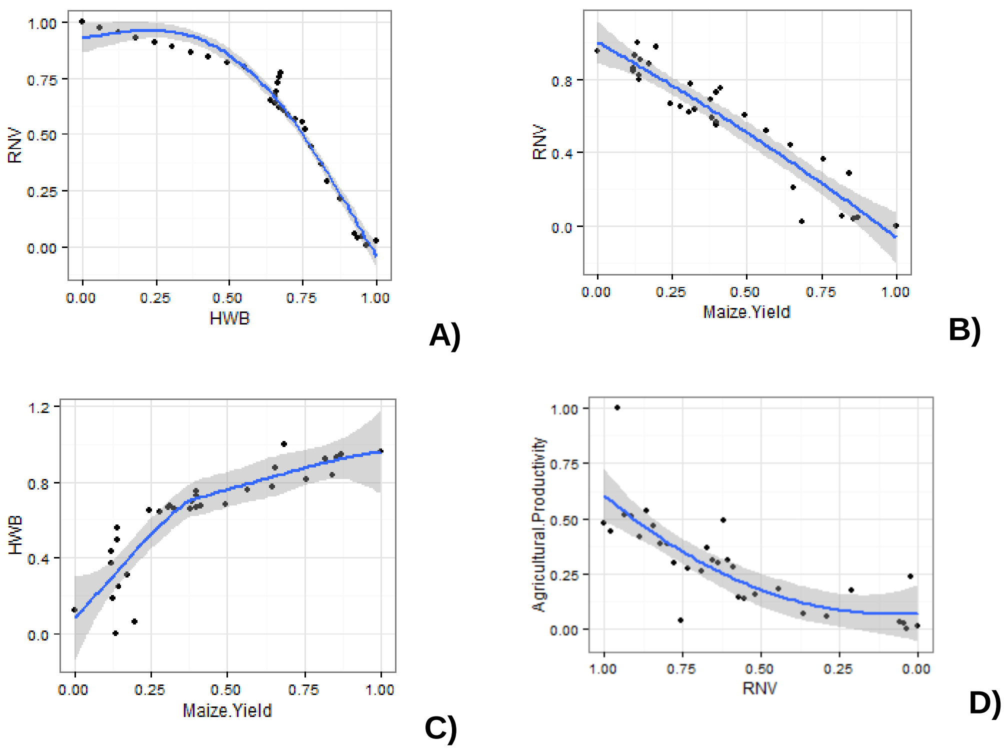
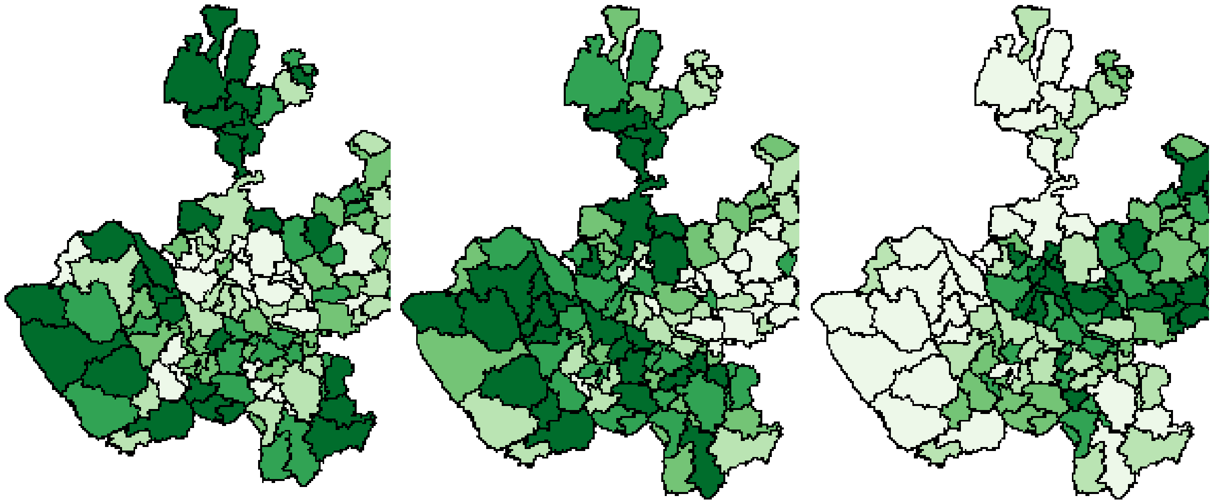


Figure 32. Comparing curve trends between land cover indicators, provisioning services and human well-being in Jalisco, Mexico.
Note: **RNV**: Remaining Natural Vegetation in Jalisco 1980-2011; source (SEMARNAT , INEGI); **Maize Yield**: 1980-2011, source: SIAP; **HWB**: 1980-2011, Human Development Index Series (≤ 1989 estimated based on similar criterion) source: UNDP; **Agricultural Productivity:** Estimated based on maize area and yield during 1980-2011, Source: SIACON.

7.3 Implications for sustainability

The spatial patterns of well-being, biodiversity (forest area in this case) and ecosystem services (agricultural area in this case) cannot easily be correlated; complex links between them need to be further explored (Fig. 33).

People perceive and evaluate the direct benefits provided by nature (provisioning services such as food and water) and not those indirect benefits e.g. like pollination and erosion. Therefore, the greatest challenge is to align a work framework where people can value what is intangible or invisible to them (Fig. 34).



Marginality Index **Forest Area** **Agricultural Area**

Figure 33. Linking spatial indicators of well-being, natural resources and ecosystem services. Source: CONAPO (2013); INEGI (2012); SIAP (2012).
Note: High Values Low Values

This study reveals that an oversimplified notion of well-being should be avoided. The analysis reveals that while conventional welfare indexes increase, natural resources decrease. Although the assessment of food, water and shelter is a good starting point, measuring benefits from ecosystems through new indicators are necessary. This study will propose a framework for analyzing ecosystem services and human well-being e.g. the importance of valuing indirect benefits and subjective indicators of well-being that will provide useful information to study ecosystems and society as well as the policy design.

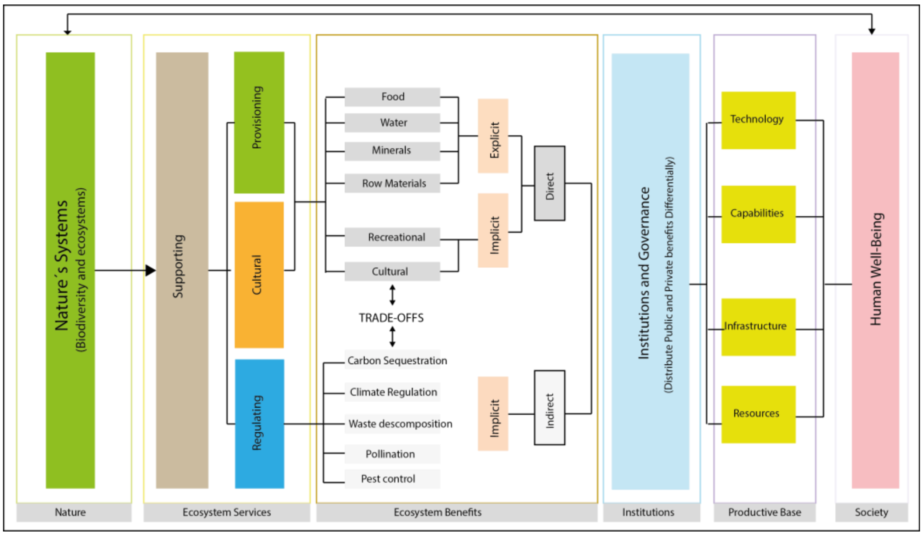


Figure 34. Links between nature, ecosystem services and human well-being. Source: adapted from MEA 2005, Mainka et al. 2008, Duraiappah et al. 2014).

8. Spatial patterns of bundles of ecosystem services and their links with biodiversity

Authors: Jones, L., Balvanera, P. Masante D., Quijas S., Boit A., Thonicke K., Ascarrunz N., Zarco-Arista A., Purse B., Banin L., Day J., Ibañez-Bernal., Simoes M & Kolb M.

8.1 Conceptual and methodological underpinnings

Ecosystem services are delivered by ecosystems, and therefore have a fundamental spatial (and temporal) component. In general, land is managed directly for provisioning services, or is protected for biodiversity. Land managed for both these primary aims also provides indirect benefits in the form of regulating and cultural services (there is increasing recognition of these benefits, and increasing policy initiatives which focus land management to consider these services, e.g. Payments for Hydrological Services (PSAH), 2003 in Mexico, and the Proambiente national program 2000 – 2010 for PES in Brazil. The spatial patterns of these ES are complex and may be influenced both directly and indirectly by socio-economic context and by policies at national and at sub-national levels.

We hypothesized that: a) there is spatial variability in the way services are co-located, b) this spatial variability can partly be explained by socio-economic context and by underlying biophysical constraints on land-use, c) the nature of co-located bundles of services will also differ between countries due to national-level drivers such as policy implementation and historical socio-economic context, and d) these bundles may change in the future due to climate change and altered socio-economic context. We will explore these relationships broadly following methodologies described by a number of recent studies (Mouchet et al. 2014).

Analysis to develop and analyses bundles of services first needs to solve disaggregation problems for LPJml data at 0.5° resolution. The spatial resolution to which LPJmL can be applied to allow for regional application, e.g. the Amazon basin, is constrained by the availability of the climate data input which additionally provide monthly values at annual resolution for 200 years for climate change application. Respective climate scenarios are usually provided at a spatial resolution of 0.5°x0.5° longitude-latitude (roughly 50x50 km at the equator) which already presents a downscaling from the original spatial resolution of the climate models, e.g. HadGEM2 computes climate originally at 3.75° x 2.5° grid cell size. Therefore, climate scenarios are bias-corrected and downscaled to 0.5°x0.5° using historical climate data sets. This puts a challenge to the projection of ecosystem services which is usually done at finer spatial resolution, as in our case 1x1 km. We therefore have to use a hybrid approach by downscaling LPJmL output at its original output grid size.

There are a number of sophisticated downscaling techniques available, e.g. entropy methods (You et al. 2009; Howitt & Reynaud, 2003; Chakir, 2009) and kriging, but these involve considerable work and there was not the time to explore these options within the ROBIN project. A rather simpler alternative was to make use of additional variable outputs from the LPJmL model. These have been explored for disaggregating the carbon outputs, but not for the water outputs as these operate at larger scales where it is difficult to separate the role of land cover from other important variables such as rainfall and hydrological routing.

In the case of carbon, LPJmL gives a number of outputs for component Crop Functional Types (CFTs) and for Plant Functional Types (PFTs). Not all of the required outputs are split by PFT and CFT however. For carbon stocks in vegetation, soil and litter, only a grid-average value is given. However, it is possible to separate out the natural vegetation and the crop component by considering the difference between outputs for potential natural vegetation and actual vegetation. The natural vegetation can be further separated into grassland and forest carbon by considering the location of these classes from the CLUE land use maps, the foliage projective cover of the PFTs from LPJmL output, and a rough proportion of above-ground carbon in these vegetation types from the literature. Crop carbon can be calculated by the sum of harvested and residual carbon per crop. Therefore we can achieve a partially disaggregated output at 1 x 1 km resolution for carbon stocks.

8.2 Results for current conditions

Identifying relationships between ecosystem services and land use intensity, and bundles of ecosystem services. A complementary method to the Ecosystem Integrity index which can be used for future scenarios and where EI data are not available is to allocate CLUE land-cover classes to an Intensity gradient (Table 10 below). At coarser spatial scales (e.g. 10 x 10 km grid), a continuous index can be developed from these five classes (Fig. 35). Relationships between ES and the Land Use Intensity index can be plotted and modelled and using GAM models (Fig. 36). Following a normalization between 0 and 1, relative ES provision can be compared across the LUI gradient defined (Figure 37).

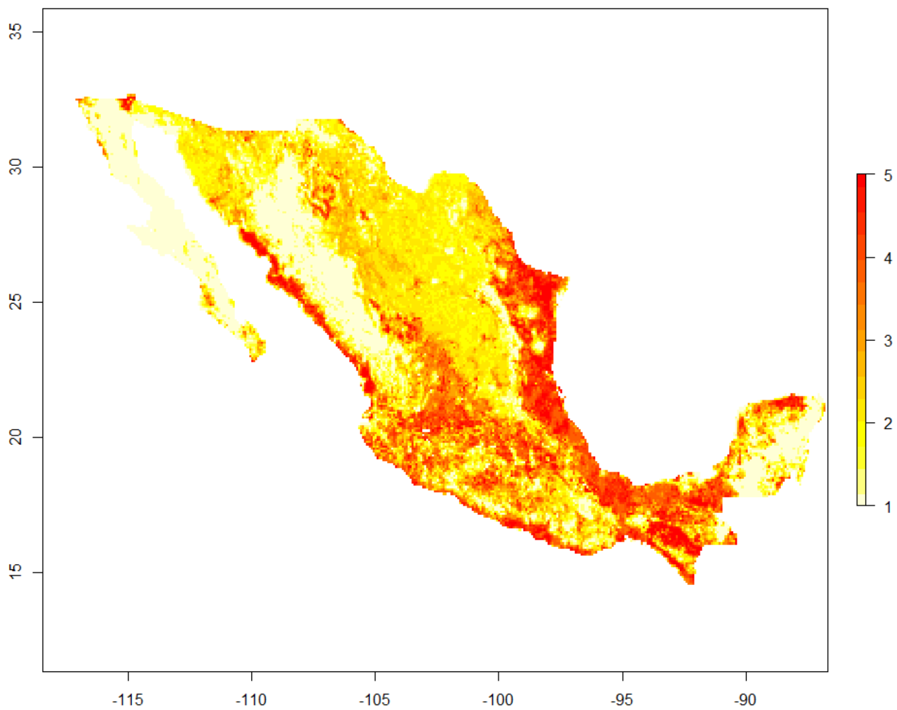


Figure 35. Intensity of land use at ~10 km resolution, accordingly to Table 10.

Table 10. Allocation of CLUE land use classes to Land Use Intensity gradient

Intensity class	Description	CLUE land use classes
1	Natural	Forest, shrubland, grassland, sparse vegetation, bare or desert, flooded/wetland forest
2	Low intensity	Grazed shrubland, grazed sparse vegetation
3	Moderate intensity	Grazed grassland, Abandoned agricultural land
4	High intensity	Cropland food perennial, cropland energy
5	Very high intensity	Cropland food feed fibre, Urban
0	Not considered	Water, wetland, ice & snow

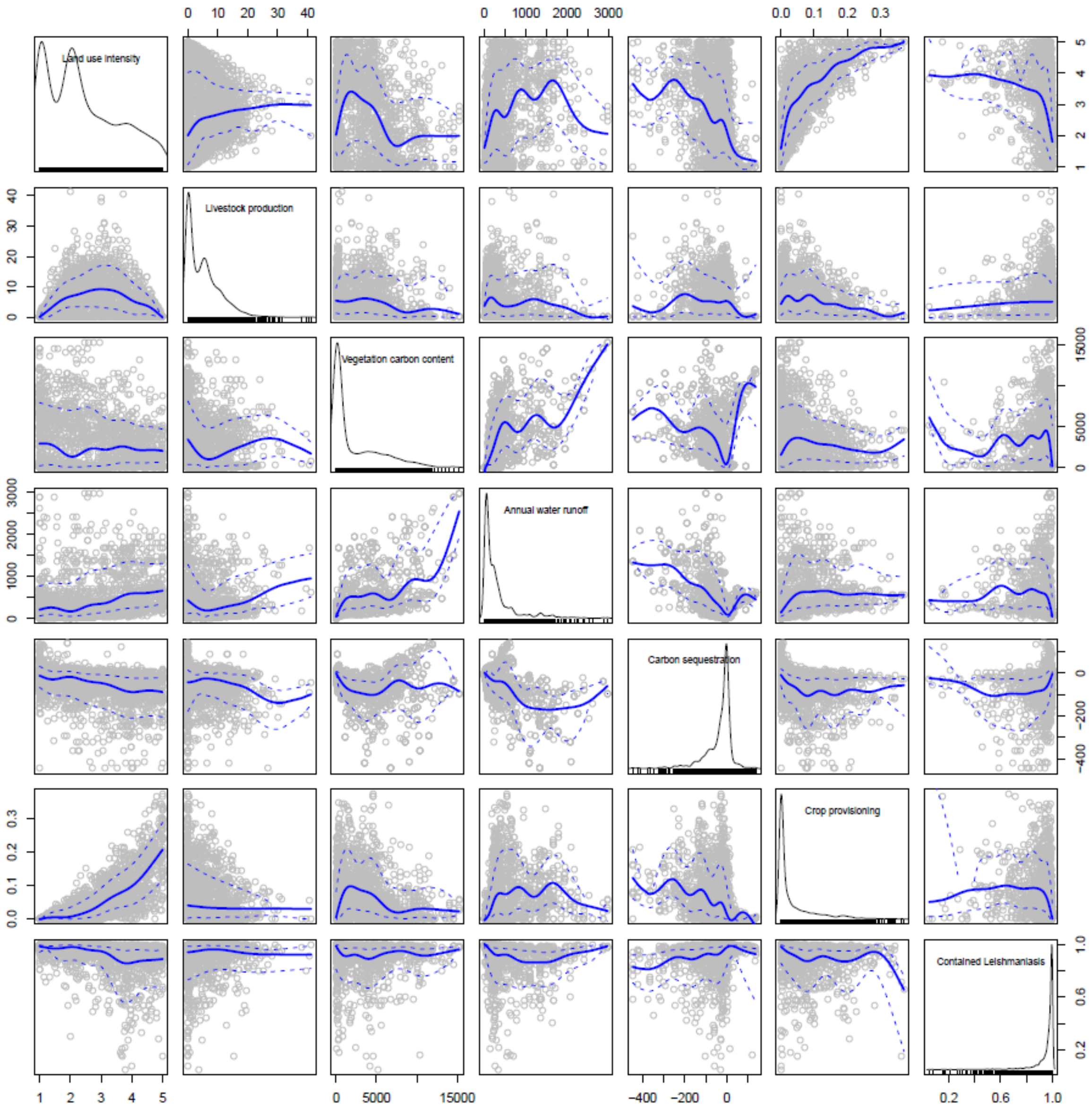


Figure 36. Matrix of cross-scatterplots among ES and land use intensity, with fitted generalised additive model (blue line) and spread (dashed lines).

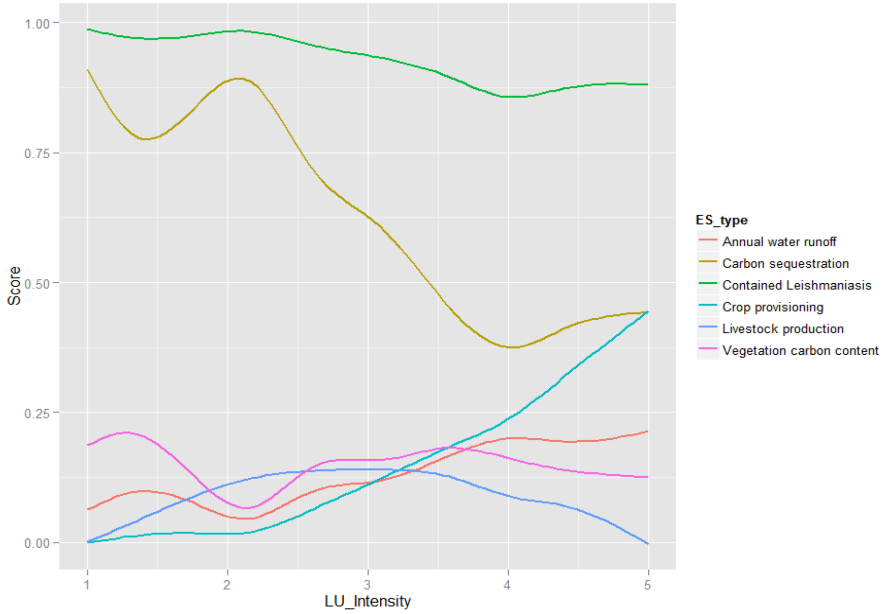


Figure 37 Provisioning of ES and correlations with land use intensity. Services are normalized between zero and one for ease of comparison.

A classification procedure (k-means) was used to separate bundles of similar services based on their spatial co-location. Five bundles were defined, shown spatially for Mexico in Fig. 38. These bundles will form the basis of subsequent analysis.

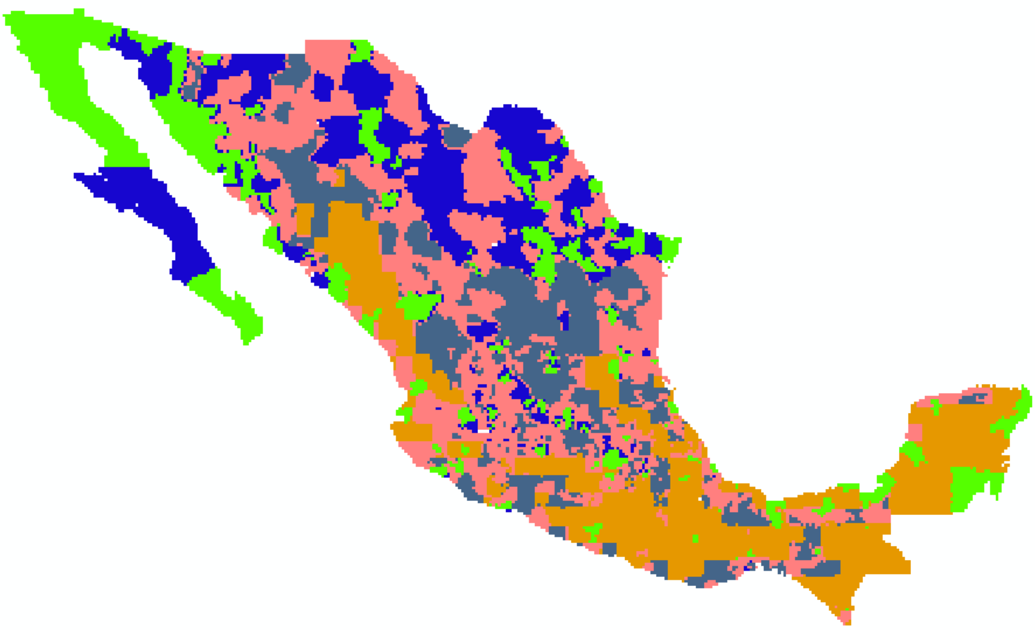


Figure 38. Spatial pattern of five groups from classification, according to services provided and socio-economic variables identified for Mexico.

8.3 Implications for policy design at national scale

This analysis will reveal the types of services that are co-located in space, and whether these optimal groups of services differ spatially, and according to which socio-economic contexts. The analysis into the future will reveal to what extent they are impacted by climate change, and by policies designed to safeguard both biodiversity and ecosystem services. Analysis of the impact of the future policy scenarios will show to what extent REDD+ type policies can influence ecosystem service provision and well-being.

9. Implications for sustainability and integration across scales

Authors: Balvanera P., Jones, L. Masante D., Quijas S., Boit A., Thonicke K., Ascarrunz N., Zarco-Arista A., Purse B., Banin L., Day J., Ibañez-Bernal., Simoes M., Kolb M., Ortega-Varela C., Blanco I., Lazos E., Simoes M., Ascarrunz N. & Toledo M.

The information presented above will be integrated using a recently developed framework to assess sustainability (Cavender-Bares et al. 2015, King et al. In press). The effects of the biophysical constraints on trade-offs between bundles of services and with biodiversity will be assessed by evaluating the “efficiency frontier”, drawn by the conditions where the highest possible values of two trading off bundles of services and biodiversity indicators can be obtained. These curves will be drawn at the national scale from any readily available data for biodiversity, climate mitigation and ecosystem services. They will be also drawn at the local scales from data derived from field assessments in the same study cases.

Conflicts among different federal policies for the three countries and among local stakeholders for the three study cases will be summarized into utility curves that highlight the areas along such efficiency frontier that are preferred by different stakeholders or fostered by different policies. The shape of these utility curves will be inferred from readily available literature review and stakeholder workshops for the three countries and the three study regions.

Obstacles towards attaining the efficiency frontier and the opportunities for solutions that reduce the intensity of the hard choices among the different environmental, social and economic agendas will be identified from readily available data at federal and local levels.

Changes in the nature of the efficiency frontier, in those of the utility curves, and those of obstacles and opportunities across scales (federal to local) will be assessed under the alternative climate change and development future scenarios described above.

Preliminary results show that the general patterns of the trade-offs are shared across scales. Development of policies to foster food production, specially that of agricultural commodities aimed at global markets, are at least partially trading-off with those linked to the maintenance of biodiversity and the associated regulating services. At the national scales we were able to show how these trade-offs change through time into alternative future scenarios, while at the local scales we were able to identify how they have evolved from the past into the current conditions.

10. Conclusions

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. We were able to show how the approach used here can be used to better design payments towards carbon stocks and ecosystem level (and not just aboveground uptake) carbon balance. Future scenarios predict severe reductions in water availability, although yield and areas available for grazing could be increased under some scenarios. Increased fragmentation lead to increased human exposure to Leishmaniasis.

At national scales, ecosystem integrity was negatively correlated with cattle production but positively correlated with carbon storage. Increased carbon sequestration increased the regulation of Leishmaniasis but decreased carbon stocks, water flow, agricultural production. At local scales, similar trends were observed and policies driving these patterns, such as those for the promotion of commercial intensive agriculture, was shown.

Integration across scales and across approaches is still underway.

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