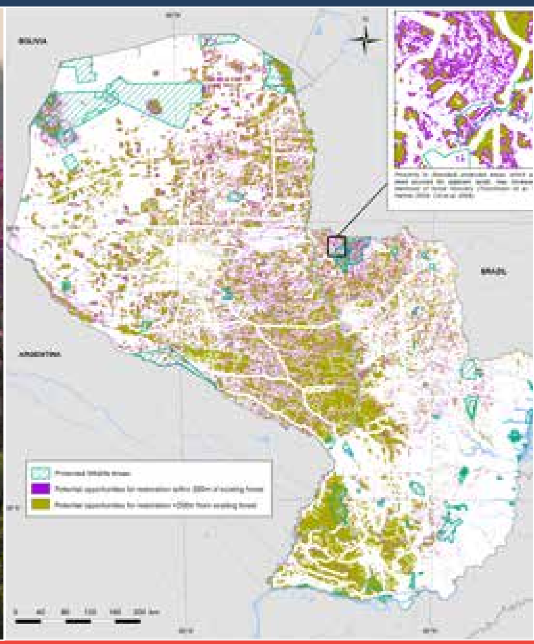
Mapping multiple benefits of REDD+ in Paraguay: using spatial information to support land-use planning



PROGRAMA
ONU-REDD+
PARAGUAY

PROGRAMA ONU-REDD+ PARAGUAY

The UN-REDD Programme is the United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries. The Programme was launched in September 2008 to assist developing countries to prepare and implement national REDD+ strategies, and builds on the convening power and expertise of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP).

The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is the specialist biodiversity assessment centre of the United Nations Environment Programme (UNEP), the world's foremost intergovernmental environmental organization. The Centre has been in operation for over 30 years, combining scientific research with practical policy advice.

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Judith Walcott, Julia Thorley, Valerie Kapos, Lera Miles,
Stephen Woroniecki and Ralph Blaney

Acronyms

ASP	Protected Wildlife Areas
CATIE	Centre for Tropical Agricultural Research and Education
CBD	Convention on Biological Diversity
CONAM	National Environmental Council
FAPI	Federation for the Self-Determination of Indigenous Peoples
FFPRI	Forestry and Forest Products Research Institute
FIRMS	Fire Information for Resource Management System
GEF	Global Environment Facility
IBA	Important Bird and Biodiversity Area
INFONA	National Forestry Institute
IUCN	International Union for Conservation of Nature
MAG	Ministry of Agriculture and Livestock
MOBOT	Missouri Botanical Garden Database
PNC ONU-REDD+	UN-REDD National Joint Programme on Reducing Emissions from Deforestation and forest Degradation in Paraguay
PRODERS	Sustainable Rural Development Project
ROAM	Restoration Opportunities Assessment Methodology
SEAM	Ministry of the Environment
SFN	National Forest Service
SINASIP	National System of Protected Wildlife Areas
UNA	National University of Asunción
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
UPAF	Upper Paraná Atlantic Forest
WRI	World Resources Institute

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Map of Potential forest restoration opportunities and proximity to existing forest and protected areas, UNEP-WCMC.
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1. Introduction

The Paraguay River runs from north to south through the centre of Paraguay, dividing the country into two regions with geographic, demographic and climatic distinctions. Paraguay's subtropical eastern region is home to the Upper Paraná Atlantic Forest (UPAF), among the most biodiverse and threatened ecosystems in the world. The western (or Chaco) region has 60% of Paraguay's total land area, but only 3% of the 6 687 000 total population (World Bank 2014); it is part of one of the world's last large contiguous extensions of dry tropical forest (Kernan et al. 2010) and is home to most of Paraguay's remaining intact forest (approximately 84%; PNC-ONU REDD+ Paraguay 2011). While the eastern region has experienced large-scale deforestation and forest degradation over the last few decades, due to population and infrastructure expansion and the conversion of land for growing soya and for cattle grazing, forests in the Chaco are now under increasing pressure from the expansion of agriculture. Deforestation and forest degradation in Paraguay not only threaten the traditional livelihoods of forest-dependent communities and the provision of key ecosystem services, such as climate regulation (as forests serve as carbon stores and sinks for carbon dioxide from the atmosphere), protection against soil erosion, and food, medicine and other non-timber forest products, but may also increase the country's vulnerability to climate change. Retaining and restoring forests in both parts of the country will help to protect and enhance the benefits forests bring to society, and to reduce the rate and effects of climate change (Kernan et al. 2010).

Indeed, forest loss plays a crucial role in climate change. Deforestation and forest degradation represent a significant contribution to anthropogenic CO_2 emissions, with land-use change estimated to provide a net contribution of around 10% of global emissions (IPCC 2013). Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are preparing to address this issue through REDD+, with the aim to significantly reduce emissions from deforestation and forest degradation, and increase removals of CO_2 from the atmosphere, while promoting sustainable development. REDD+ is expected to provide incentives for countries to implement actions relating to five main activities (Figure 1).

REDD+ also has the potential to deliver additional social and environmental benefits, sometimes called "multiple benefits". Social benefits from REDD+ implementation can include improved forest governance and increased local participation in decision-making on land use, and in some cases financial improvements to livelihoods. Environmental

Figure 1: REDD+ activities agreed under UNFCCC

REDD+ =

Reducing Emissions from
Deforestation and forest Degradation

+

Conservation of forest carbon stocks
Sustainable management of forests
Enhancement of forest carbon stocks

Lapacho, Paraguay's national tree, is found in the eastern region and lower Chaco. It is widely valued for its medicinal properties.
Photo by Andrea Ferreira https://flic.kr/p/ahqEKT (CC BY-NC-ND 2.0).

benefits from securing the many ecological functions of forests can include biodiversity conservation and the provision of ecosystem services that people depend on. However, REDD+ also carries potential risks, for example if pressures on forests were merely displaced from one area to another, or if local communities' access rights to forests were reduced as part of REDD+ implementation. The UNFCCC asks countries to promote and support the Cancun safeguards, which have been specifically developed to encourage benefits and address potential risks of REDD+. A REDD+ programme that delivers multiple benefits and avoids social and environmental risks can therefore contribute to a range of policy goals beyond climate change mitigation.

2. Planning for multiple benefits of REDD+ in Paraguay

The government of Paraguay joined the UN-REDD Programme (United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries) in 2008, with the aim of implementing REDD+ in alignment with the country's conservation and development objectives, and developing capacities for integrated environmental management, with particular attention to forest-dependent communities and indigenous peoples. Paraguay was the first UN-REDD Programme partner country to have its National Programme document signed by indigenous peoples representatives (from FAPI, the Federation for the Self-Determination of Indigenous Peoples). Paraguay's National Joint Programme on Reducing Emissions from Deforestation and forest Degradation (PNC ONU-REDD+) was formed in 2011, with collaboration between the Ministry of the Environment (SEAM), the National Forestry Institute (INFONA), FAPI and UN-REDD partners. The institutional arrangements for REDD+ implementation in Paraguay are still under design, but there are plans for a comprehensive, multidisciplinary structure of national coordination to support sustainable development.

Paraguay is currently in the process of developing a national REDD+ strategy, which, as in other countries, will likely involve reconciling different demands for land use; identifying the potential for a range of benefits that can be achieved through REDD+ implementation; planning to avoid or minimize possible risks; and prioritizing REDD+ activities to be addressed (and identifying suitable actions related to the activities selected). The suitability of areas for different REDD+ actions (such as forest restoration, or actions aimed at retaining forest cover), as well as benefits and risks, vary according to location. For example, forest pressures, carbon stocks and areas with high biodiversity and other forest values, are unevenly distributed throughout the country. Spatial analysis can be a useful tool to support REDD+ strategy development, helping decision-makers to plan for REDD+ actions in a way that enhances potential benefits and reduces possible risks.

Table 1: Potential benefits and risks of REDD+ actions in Paraguay, as identified and prioritized in 2011 and 2013 national workshops

Potential benefits of REDD+ actions in Paraguay
Climate change mitigation
Biodiversity conservation
Soil erosion control and hydrological services
Provision of timber and non-timber forest products (firewood, medicinal plants and forest foods)
Livelihood benefits for local communities
Maintenance of natural beauty and potential for supporting tourism
Preservation of sacred sites
Potential risks of REDD+ actions in Paraguay
Decreased access to traditional forest products for indigenous and forest-dependent communities
Loss of livelihoods due to closures in the timber industry and reduced investment in the agricultural sector
Problems identifying carbon ownership
Displacement of pressures to other areas
Increase in price of primary materials
Conversion of natural forest to planted forest as part of forest restoration efforts
Potential for arson and land-grabbing if compensation is provided for restoration of degraded areas

The benefits and risks included in this report reflect, as far as possible, the priorities of national stakeholders in Paraguay. UN-REDD stakeholder consultation workshops were held in Paraguay in 2011 and 2013, with participation from government agencies, NGOs, indigenous peoples organizations, local communities and research and academic institutions; the benefits and risks prioritized in both workshops are presented in Table 1. The benefits of REDD+ that were prioritized include, among others, the conservation of biodiversity; the preservation of sacred sites; soil protection and hydrological services; and the provision of medicinal plants and firewood. Potential risks of REDD+ actions discussed include decreased access to traditional forest products for indigenous communities and loss of livelihoods due to closures in the timber industry. The importance of individual social and environmental benefits and risks may vary according to the priorities of different stakeholder groups. For example, those whose income depends on farm productivity may see soil protection and hydrological regulation as key services to be secured by maintaining forests, while indigenous communities may value forests for their spiritual importance, or as sources of medicinal plants.

The sections that follow aim to support land-use planning for REDD+ in Paraguay by exploring the spatial distribution of social and environmental benefits and risks associated with actions to reduce deforestation and enhance carbon stocks. The spatial analyses presented here can be used as a basis for further discussion, refinement and exploratory work; they are based on the data that is currently available, but should be updated as better or more recent data becomes available. Preliminary versions of several of the maps in this report were developed at a joint GIS working session held at SEAM in April 2014, with participants from SEAM, INFONA and the Department of Forest Engineering at the National University of Asunción (UNA). These maps, as well as preliminary versions of other maps shown here, were jointly reviewed with national stakeholders during a 2014 UN-REDD workshop in Asunción.

3. Forests in Paraguay

Paraguay naturally features warm temperate moist forest in the eastern region, which has periods of substantial rainfall (1 700 mm annual average), and warm temperate dry forest in the Chaco, with arid and semi-arid conditions (500 mm per year average precipitation). Most of the eastern region features low rolling hills, with elevation ranging from 50 to 750 m above sea level, while the Chaco is largely a flat plain, with an average elevation of 130 m.

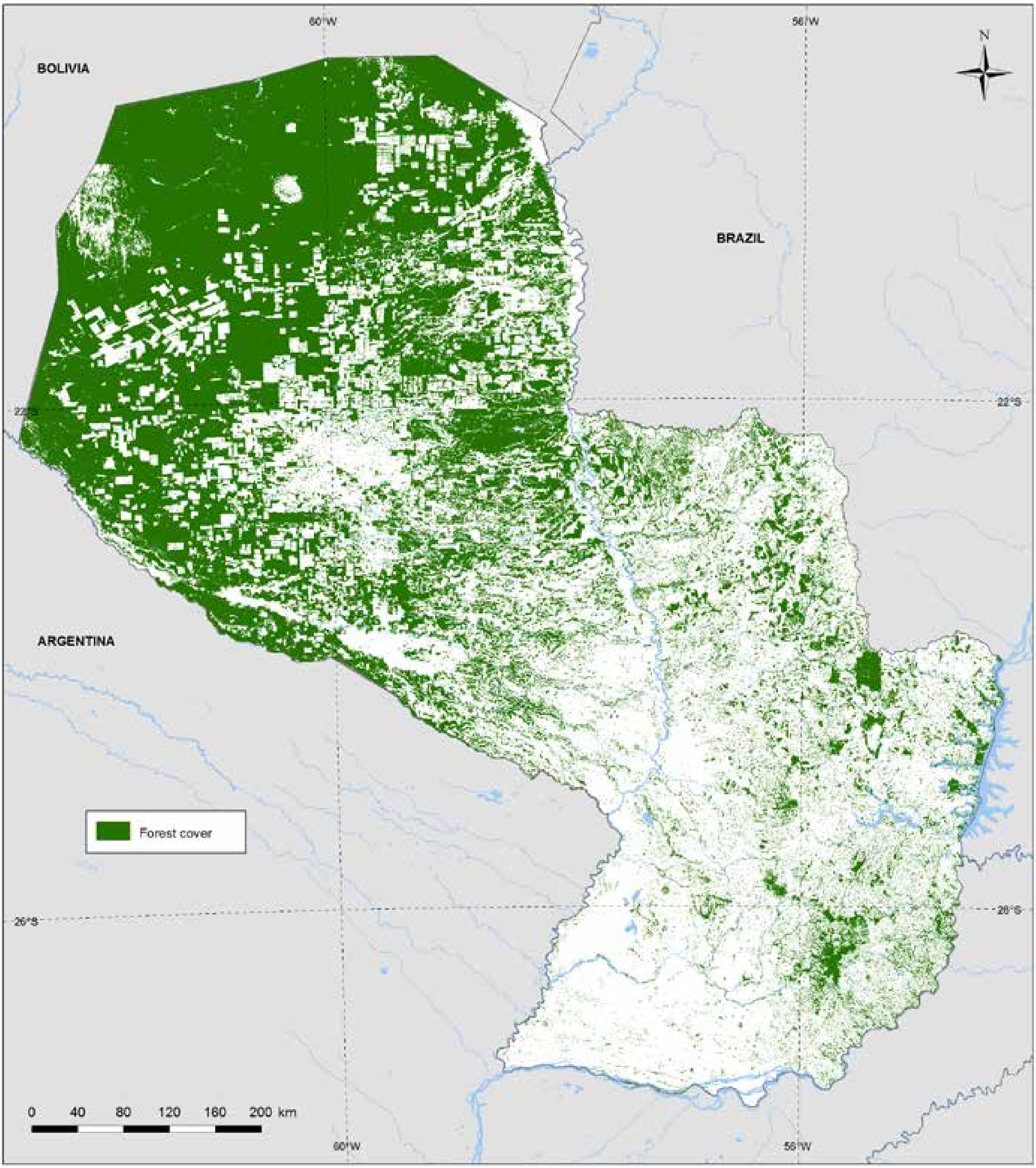
Paraguay's eastern region supports the Upper Paraná Atlantic Forest (UPAF), a sub-tropical humid semi-deciduous forest, with a wealth of flora and fauna. Nearly 65% of the soils in Paraguay's eastern region are fertile and well-drained, making them suitable for agriculture and pasture, which are the predominant land uses in this area. Where the land is level and fertile, forest has often been cleared and replaced by pasture or cropland, leaving most of the remaining forest in the eastern region on less fertile, rocky sites that are more steeply sloped (Kernan et al. 2010).

The Chaco region has low marshy plains, which are prone to seasonal flooding near the Paraguay River, and dry forest and thorny scrub through the rest of the region. Its sandy soils may become saline when cultivated. The forests of the Chaco have diverse species composition, varying from xerophytic forests in the driest Western portion to taller forests with hardwood Chaco species mixed with UPAF species along portions of the Paraguay River; its *quebracho*

Approximately 84% of Paraguay's remaining forest cover is located in the Chaco region. *Photo by LLosuna http://commons.wikimedia.org/wiki/Gran_Chaco#mediaviewer/File:Chaco_Boreal_Paraguay.jpg (CC BY-NC-ND 1.0).*

Map 1: Forest cover (2011)

Approximately 40% of Paraguay currently has forest cover.



Method and data sources:
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.

All map analyses presented in this report have used the following projection: WGS84 / UTM Zone 21S.

colorado trees have traditionally been used to produce tannin for industrial applications, while *copernicia* palms have been used in construction (Salas-Dueñas and Facetti 2007). As the Chaco's forests have often been seen as "brushland" with no financial value, when forest is cleared for pasture, instead of being used, trees are often bulldozed into windrows for compost, burned or left to rot (Kernan et al. 2010).

According to the 2011 map of forest cover in Paraguay, which has been developed by the UN-REDD National Joint Programme (PNC ONU-REDD+ Paraguay 2011), approximately 40% of Paraguay is currently forested (Map 1).

3.1 Forest pressures and drivers of land-use change

From the 1960s and 1970s, expansion of the agricultural frontier in Paraguay has led to extensive changes in land use, and a significant reduction in forest cover, as well as resulting loss of biodiversity, particularly in the Atlantic Forest in the eastern part of the country (R-PP 2014). Preliminary national analyses indicate that more than 60% of land-use change in Paraguay's eastern region is due to expanding soya cultivation; the preparation of land for livestock production and population growth have also led to deforestation (R-PIN 2008). Nearly three million hectares of forest have also been lost from the Chaco between 1990 and 2011 (PNC ONU-REDD+ Paraguay 2011), due largely to agricultural expansion[1]. Driven in part due to China and Europe's demands for cattle feed and biofuels, Paraguay is now among the world's top ten exporters of soya and beef, which comprise nearly 50% of Paraguay's total exports (World Bank 2014b).

Construction of the Itaipú Dam in 1975 also affected the landscape and local wildlife in the eastern region of Paraguay, as large areas of forest and other ecosystems were submerged under water in order to build the Dam. In addition, the resulting expansion of road networks and bridges made forests in this region easier to access, leading to widespread deforestation in the area (Kernan et al. 2010).

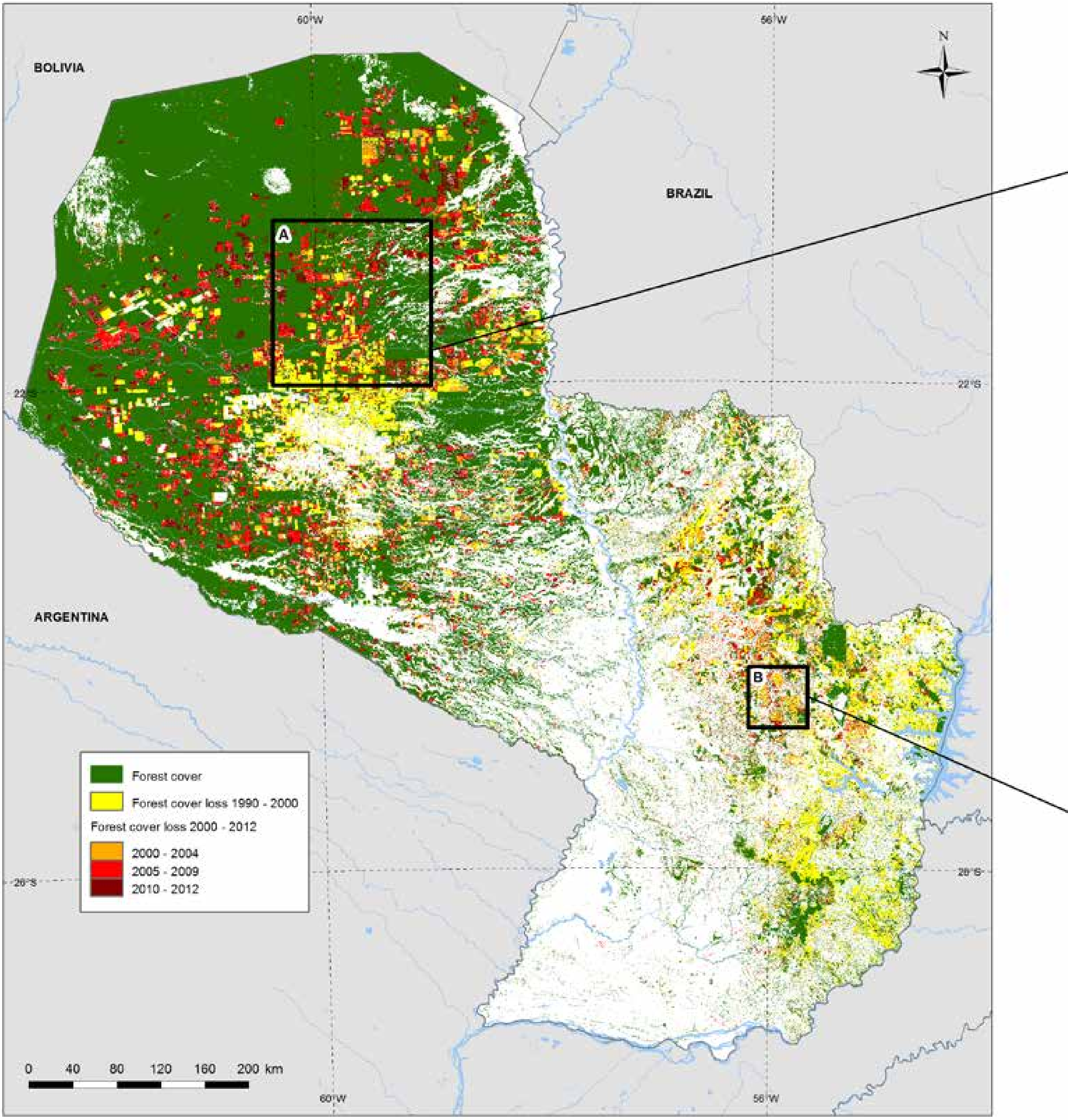
Preliminary results from Paraguay's National Forest and Carbon Inventory show that Paraguay has lost an estimated 24% of its forest cover between 1990 and 2011 (PNC ONU-REDD+ Paraguay 2011; R-PP 2014). According Hansen et al.'s (2013) recent data on global forest cover change, the tropical dry forests of South America had the world's highest rate of tropical forest loss between 2000 and 2012, due to deforestation in the Chaco of Paraguay, Argentina and Bolivia (Hansen et al. 2013). Map 2 combines spatial information from Hansen et al. (2013) with data from Global Land Cover Facility (2006), which highlights where deforestation occurred in Paraguay between 1990 and 2000, to show deforestation in Paraguay between 1990 and 2012. This map can be used to assess land-cover change quantitatively and to help determine processes and patterns of forest cover loss. Maps of land cover and land use are currently being developed in Paraguay, and once available,

[1] Agriculture, which is largely based on soya, beef, cotton and timber, contributes around 20% to Paraguay's GDP (CIA 2014), while the forest sector (which in addition to logging also includes wood processing, pulp and paper production) contributes around 2.4% to GDP (FAO 2014).

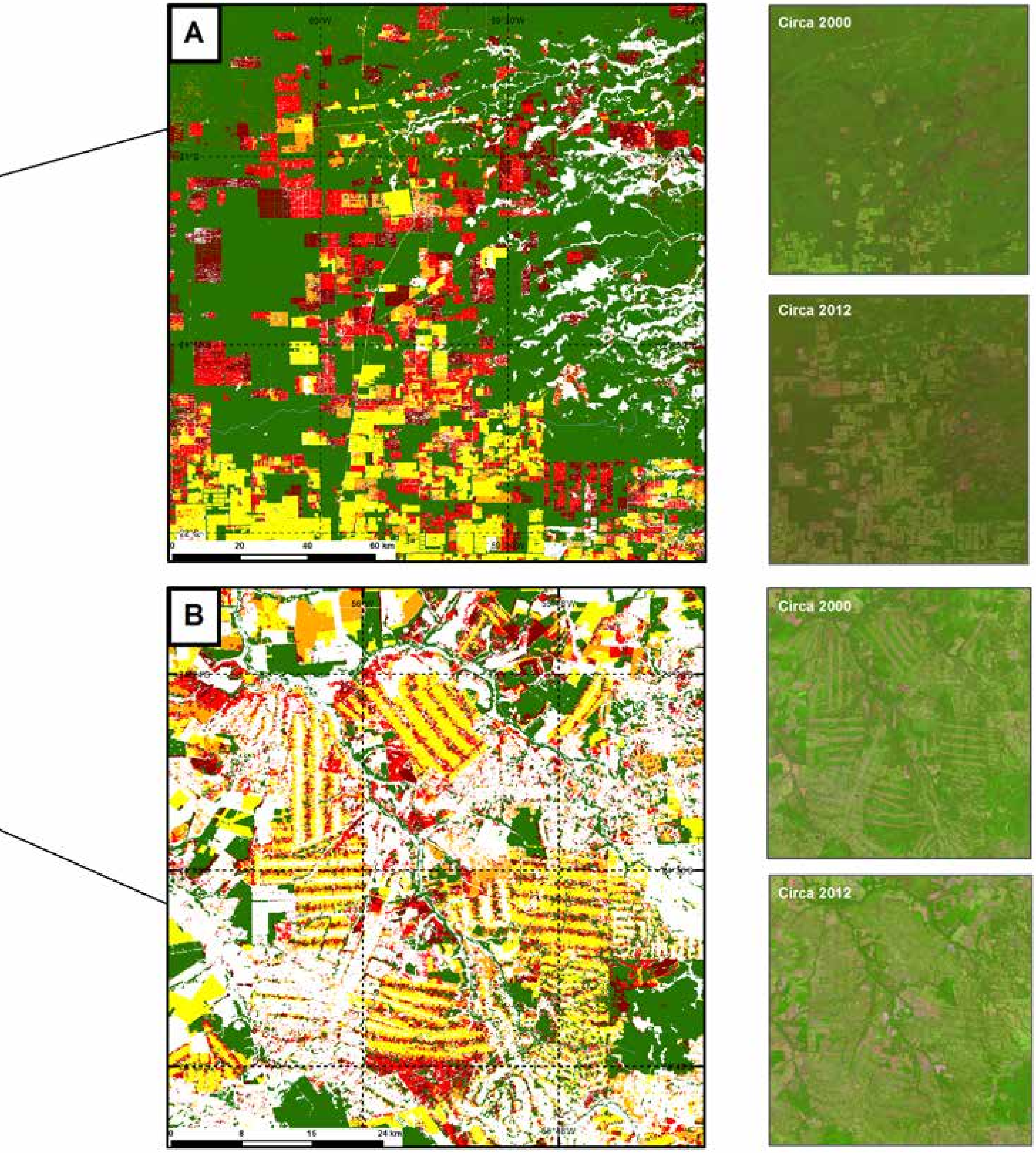
Cattle ranching has led to the loss of large areas of forest in the east of Paraguay, and now represents one of the most significant threats to the Chaco's forests. *Photo by Andrea Ferreira https://flic.kr/p/fHyHhU (CC BY-NC-ND 2.0).*

Map 2: Forest cover loss (1990-2012)

This map can be used to assess land-cover change quantitatively and help determine processes and patterns of forest cover loss in Paraguay.



Method and data sources:
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.
Forest cover loss 1990 - 2000: This product shows where deforestation occurred in Paraguay between 1990-2000. It is derived from Landsat TM and ETM+ imagery at a resolution of 28.5 meters for the two time periods. The Global Land Cover Facility (2006), Forest Cover Change in Paraguay, Version 1.0, University of Maryland Institute for Advanced Computer Studies, College Park, Maryland, 1990-2000.
Forest cover loss 2000 – 2012 and Landsat images:
Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest. Forest loss during the period 2000–2012, defined as a stand-replacement disturbance, or a change from a forest to non-forest state.



A: Patterns of loss of forest cover in the Chaco, where the majority of change is attributed to agricultural expansion (RPP 2014).

B: Patterns of loss of forest cover in eastern Paraguay, associated with agricultural development along roads. Most of the land use change in eastern Paraguay is attributed to the expansion of soybean cultivation and the preparation of land for livestock production (R -PIN 2008).

Landsat images showing the areas inside boxes (A) and (B) for 2000 (top) and 2012 (bottom). Forest cover is in the darker green. Areas in orange and red on the map correspond to forest loss between the two images.

The expansion of agricultural commodities such as soya represents one of the biggest threats to Paraguay's forests. *© Pro Cosara.*

will help to show where and what the key pressures are that are leading to forest cover loss, as well as where current land use may make an area particularly appropriate for forest restoration.

In addition to forest loss, Paraguay has suffered extensive forest degradation, largely due to biomass extraction and the unsustainable mining of secondary forests for fuelwood and charcoal, which are the main energy sources for more than 51% of Paraguayan households (R-PIN 2008). The UPAF provides more than 50% of the charcoal and fuelwood used in Paraguay for household and industrial energy sources (Kernan et al. 2010), as well as most of Paraguay's timber for export. Timber extraction was once an important economic activity in Paraguay's eastern region, but over-exploitation has caused forest degradation over the last several decades. The highest quality stems of the most valuable species were first exploited for timber; lower quality stems and less valuable species were then extracted for lower-quality timber and poles. The remaining forest is currently being used for poles, firewood and charcoal. However, unsustainable extraction has prevented most of these forests from regenerating.

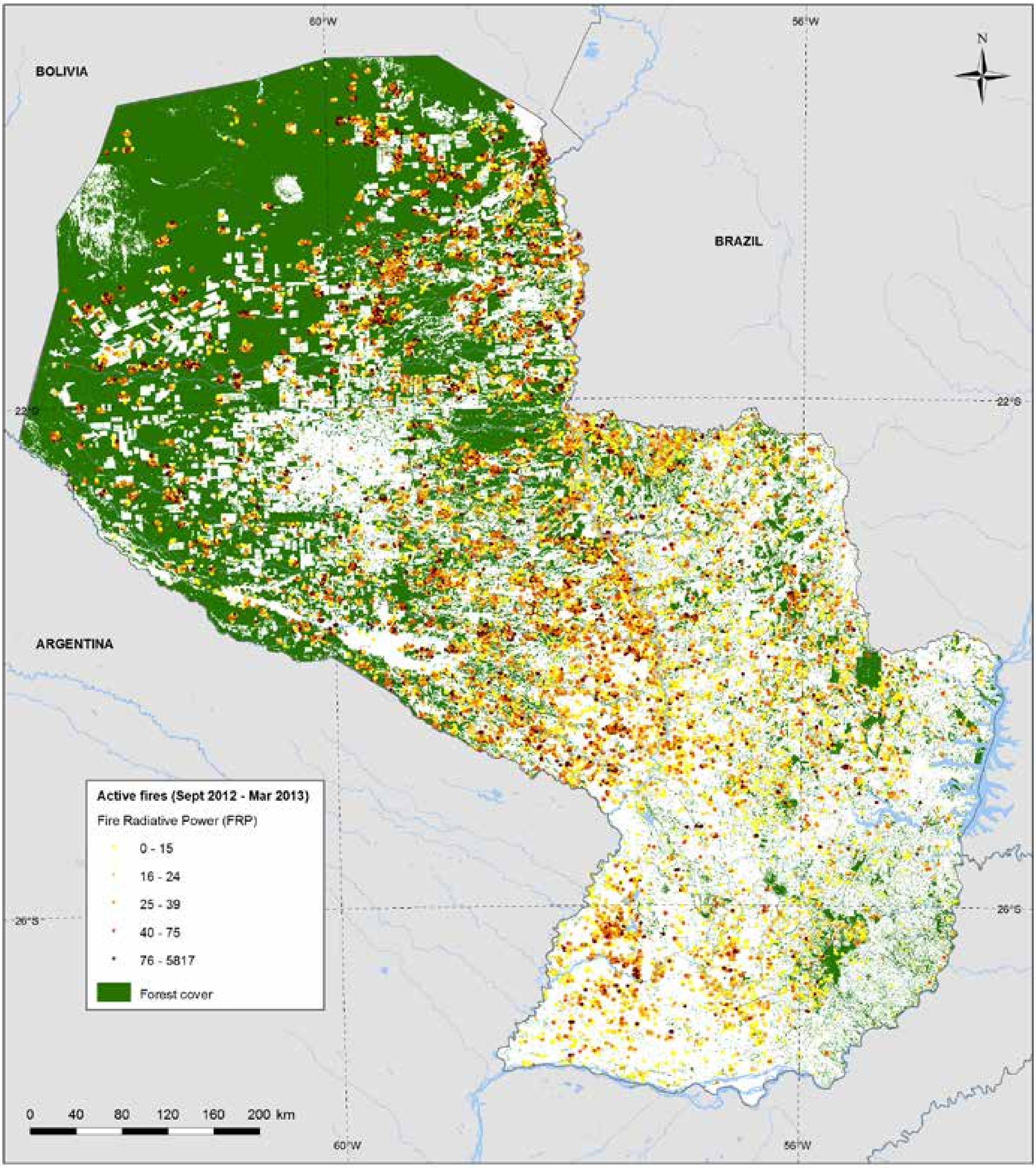
Fires have also been a large-scale cause of forest loss, degradation and fragmentation, and associated carbon emissions[2], as well as loss of biodiversity, in both regions of Paraguay. They may originate from land being cleared for agriculture, accidental fires that spread through forests, increased human settlement and even arson, and are most intense during periods of high temperature and low precipitation, characteristic of Paraguay's dry season. As most tropical forest fires are caused by agricultural fires spreading to surrounding vegetation, fire may be a problem even in areas with little deforestation; however, controlling fire is difficult, as it is an established practice for clearing land for agriculture and pasture (Kernan et al. 2010). Map 3 shows the incidence of fire between

The burning of natural forest to clear land for agriculture is a significant cause of forest loss and degradation in Paraguay. *© Pro Cosara.*

[2] Direct and indirect carbon emissions from fires are higher in areas that are already heavily degraded (Holdsworth and Uhl 1997 and Cochrane 2003 in Kapos et al. 2012).

Map 3: Active fires during the dry season (September 2012-March 2013)

Fire is a significant cause of forest degradation and associated carbon emissions in Paraguay, and has negative impacts on biodiversity. Reducing forest fires may therefore help to achieve multiple REDD+ objectives.



Method and data sources:
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.
Active fires: MODIS Active Fire Product, Fire Information for Resource Management System (FIRMS). Active fires September 2012 - March 2013. Fire Radiative Power depicts the pixel-integrated fire radiative power in MW (MegaWatts). FRP provides information on the measured radiant heat output of detected fires. This uses FIRMS data and imagery from the Land Atmosphere Near-real time Capability for EOS (LANCE) system operated by the NASA/GSFC/Earth Science Data and Information System (ESDIS) with funding provided by NASA/HQ. Downloaded December 2013. See: https://earthdata.nasa.gov/data/near-real-time-data/firms/active-fire-data.

September 2012 and March 2013 (during Paraguay's dry season), based on satellite estimates of radiant heat output from fires, using the MODIS Active Fire Product (Annex I provides further methodological detail). Particularly high frequencies of fire can be observed near to remaining forest cover in the eastern region, as well as on both sides of the Paraguay River.

3.2 Legal framework

The government of Paraguay has developed national legislation to protect natural forests, prevent deforestation and restore forests in certain areas, as well as to reform the regulatory framework of the forestry sector. SEAM, in consultation with CONAM, the National Environmental Council, is charged with general environmental oversight and regulation, while INFONA, the National Forestry Institute created in 2008 to replace Paraguay's National Forest Service (SFN), implements forestry law.

The main legal framework for the forestry sector in Paraguay is set out in Forestry Law 422/73 (1973), which establishes incentives for reforestation; designates forestland as reserves, production forest or semi-protected forest; and sets up regulations to protect forest resources. One example of this is the requirement that 25% of forest on properties larger than 20 ha is left in one or two continuous blocks. However, as properties are not required to register their 25% reserves, the land can be partitioned from the original property, and subject again to requiring only 25% forest cover (R-PIN 2008).

Paraguay's Zero Deforestation Law came into effect in November 2004, prohibiting land-use change or conversion of areas with forest cover in the eastern region. This has contributed to slowing the rate of deforestation in eastern Paraguay from over 110 000 ha per year prior to 2004 to about 20 000 hectares in 2005, 6 400 hectares in 2006, 5 600 hectares in 2007 and 9 500 hectares in 2008 (Kernan et al. 2010). There is concern that when the Zero Deforestation Law is no longer in place (it has been extended to 2018), deforestation will again increase. Although the Zero Deforestation Law has reduced the conversion of forest for agricultural use, the degradation of forests in the eastern region has continued, at times caused by arson to purposefully degrade forests to make land exempt from this law. In addition to causes related to the relatively lower prices of land in the Chaco region, and worldwide increases in the prices of beef, the Zero Deforestation Law could be considered a contributing factor to the displacement of deforestation from the eastern region to the Chaco (where the Zero Deforestation Law is not applicable).

The effectiveness of Paraguay's legal framework has at times been hampered by difficulties related to compliance and oversight. There is also often a lack of clarity in the application of the legal framework as related to forest products used by indigenous communities, as well as weak institutional implementation and enforcement of international conventions on forestry and environmental issues (R-PP 2014).

In order to facilitate the integrated management of land, water and other natural resources in a way that promotes conservation and the sustainable and equitable use of biological diversity, and in recognition of the natural variation between regions, SEAM's Resolution 614/13 established 6 ecoregions in the eastern part of Paraguay, and 5 ecoregions in the Chaco in January 2013. The ecoregion distinctions were decided in technical consultation with academic specialists and civil society, and will serve as the basis for decision-making on land use, for example within SEAM's Payment for Environmental Services Programme. A number of the maps in this report show Paraguay's ecoregion boundaries (Map 4), which may also be useful in national planning for REDD+.

Map 4: Ecoregions

Ecoregions were established by SEAM in 2013 to facilitate environmental decision-making and the integrated management of land, water and other natural resources in Paraguay.

Methods and data sources:
Ecoregions: La Secretaria del Ambiente (SEAM), Paraguay 2013.

3.3 Future deforestation scenarios

Successful REDD+ efforts that focus on conserving forests at high risk of deforestation are likely to have the greatest climate change mitigation impacts. Identification of areas at risk of future deforestation, particularly when combined with information on social and environmental benefits provided by areas of forest at risk, may thus have an important role in REDD+ planning.

The Centre for Tropical Agricultural Research and Education (CATIE), as part of Paraguay's PNC ONU-REDD+ work, has used scenario-based modelling to identify areas at risk of future deforestation. The scenarios are based on observed land-use change between 1990 and 2000, which was then validated for the 2000-2011 period (an off-sample approach) (CATIE 2014). Determinants of deforestation from 2000, as well as information on infrastructure, population density and other socio-economic and environmental characteristics, were used to calibrate and validate various simulations of two models (DINAMICA-EGO and econometric techniques) that estimate land-use transitions through an assessment of the probability that a given pixel will make a transition to another form of use. The best performing simulations were then used to project the distribution of deforestation to 2031, under both low- and high-impact scenarios of future socio-economic development. The results of the four possible combinations of models and scenarios, low- and high-impact scenarios for the DINAMICA-EGO model, and low- and high-impact scenarios for econometric techniques, were used to produce Map 5. The areas where the models and scenarios used show agreement in the probability that a given pixel will be deforested vary spatially; the lightest shading indicates that only one of the model and scenario combinations project deforestation, while the darkest shading indicates that all four possible model and scenario combinations project deforestation.

4. Mapping multiple values of forests in Paraguay

The primary aim of REDD+ is to contribute to climate change mitigation by maintaining and enhancing the amount of carbon stored in forests. However, in making decisions on where to implement REDD+, it is useful to consider not only where biomass carbon stocks are located, and what land-cover change pressures are anticipated, but also which areas are likely to offer social and environmental benefits from REDD+ implementation. The multiple values of forests discussed in this section – climate change mitigation potential; support for biodiversity; and the role of forests in reducing soil erosion and regulating hydrological flows – were all prioritized during stakeholder consultations in Paraguay.

4.1 Biomass carbon

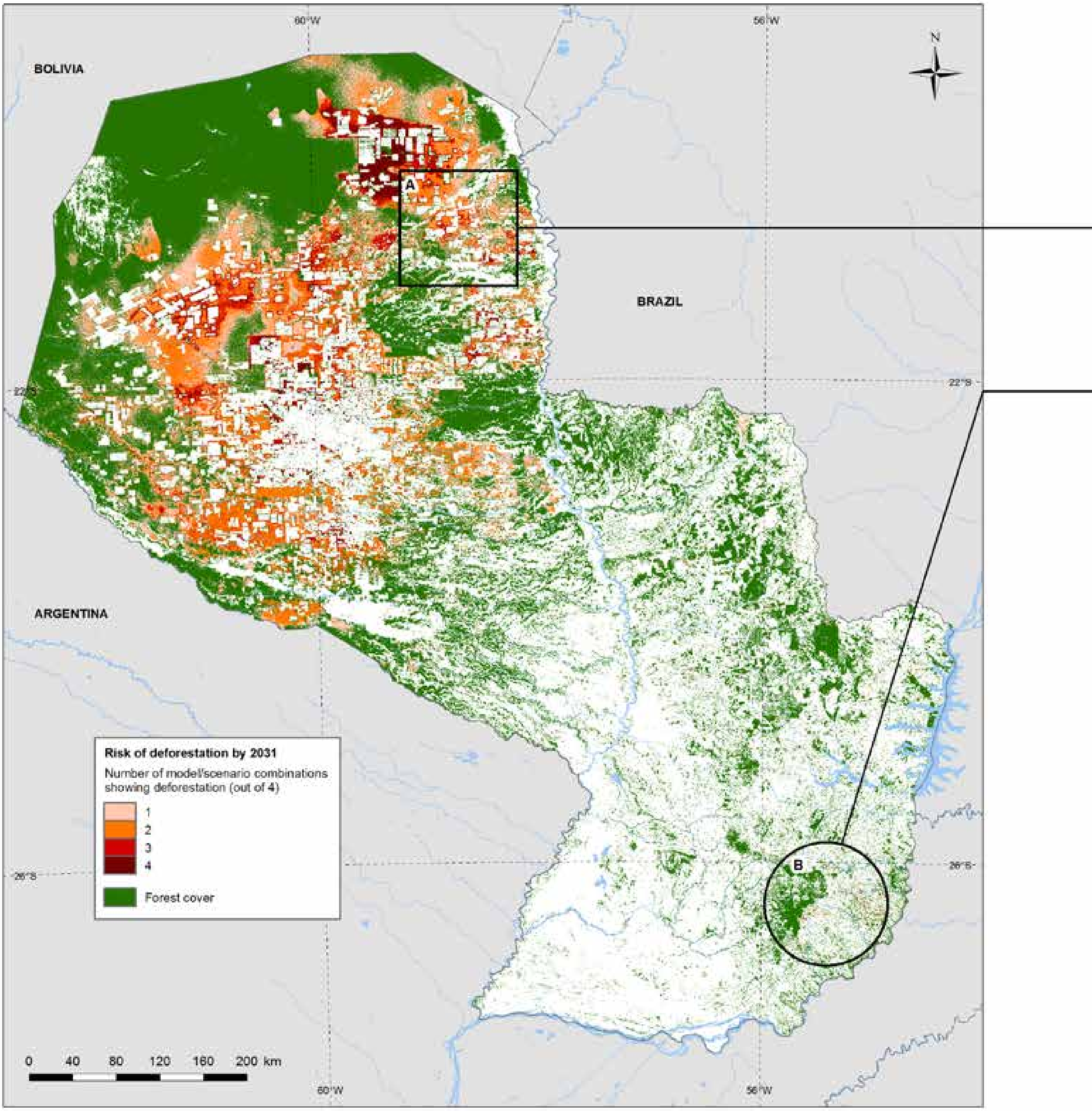
Forests, in particular tropical forests, are vast carbon stores and sinks (Trumper et al. 2009), immobilizing carbon in their biomass both above-ground (in leaves, branches and stems) and below-ground (in roots) (Walker et al. 2011). The biomass of forests varies considerably, depending on local conditions and land-use history. An understanding the distribution of biomass carbon stocks in relation to other forest values and to land-use pressures is important for effective REDD+ planning.

Information on the distribution of carbon stocks can be obtained from maps based on field data and/or remote sensing. Several global and regional scale maps provide information on biomass carbon based on different data sources and methods (e.g. Ruesch and Gibbs 2008; Baccini et al. 2012; and Saatchi et al. 2011), but nationally specific data are likely to be more relevant for supporting decision making. The maps in this report use data on forest carbon stocks in tropical regions from Saatchi et al. (2011). It will be important to update these maps as national data becomes available. The Department of Forest Engineering at the National University of Asunción has been working with the Forestry and Forest Products Research Institute (FFPRI) of Japan to develop national carbon maps for Paraguay; this and other national data, such as that which will be made available through Paraguay's National Forest and Carbon Inventory, will better reflect carbon content in Paraguay's forests.

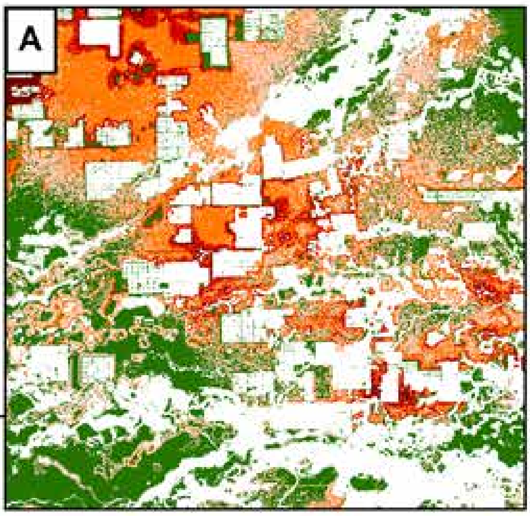
The way that data is classified can lead to vastly

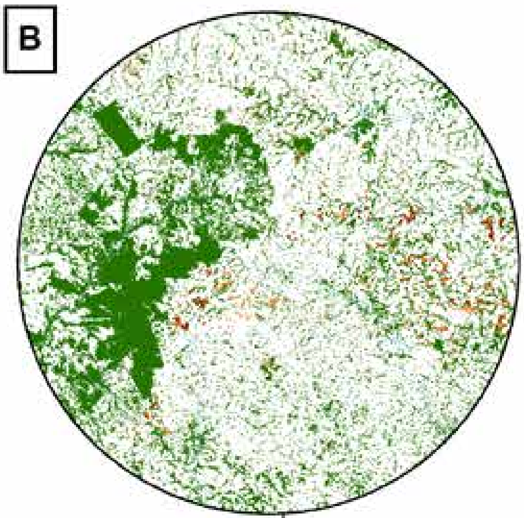
Map 5: Areas at risk of future deforestation

This map shows areas at risk of deforestation by 2031, according to the results of low- and high-impact development scenarios that have been used for two models (DINAMICA-EGO and econometric techniques) (CATIE 2014). The lightest shading indicates that only one of the model and scenario combinations project deforestation, while the darkest shading indicates that all four possible model and scenario combinations project deforestation.



Method and data sources:
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.
Projected deforestation: CATIE (2014). Análisis de cambio de uso de la tierra (1990-2011) y formulación de escenarios de deforestación futura (2031) de los bosques del Paraguay. Turrialba, Costa Rica CATIE. Deforestation probability is based on observed land-use change between 1990 and 2000, which was then validated for the 2000-2011 period (an off-sample approach).





different maps, which can in turn affect decision-making. Maps 6a and 6b demonstrate the differences between two approaches to classifying biomass carbon stocks. In Map 6a, data has been divided into six quantile classes, using an area-based classification scheme, in which each class covers approximately one-sixth of the land area of Paraguay. Using this method, the highest class reflects the sixth of the land area that has the highest carbon density. In Map 6b, the same data is presented using an equal-interval classification. In this method, biomass carbon values are divided into six equal sized sub-ranges. Map 6b shows that the majority of the carbon values are part of the lowest classes; however, it is difficult to distinguish the range of values in this map. As a result, all analyses of biomass carbon in this report use the classification scheme shown in Map 6a.

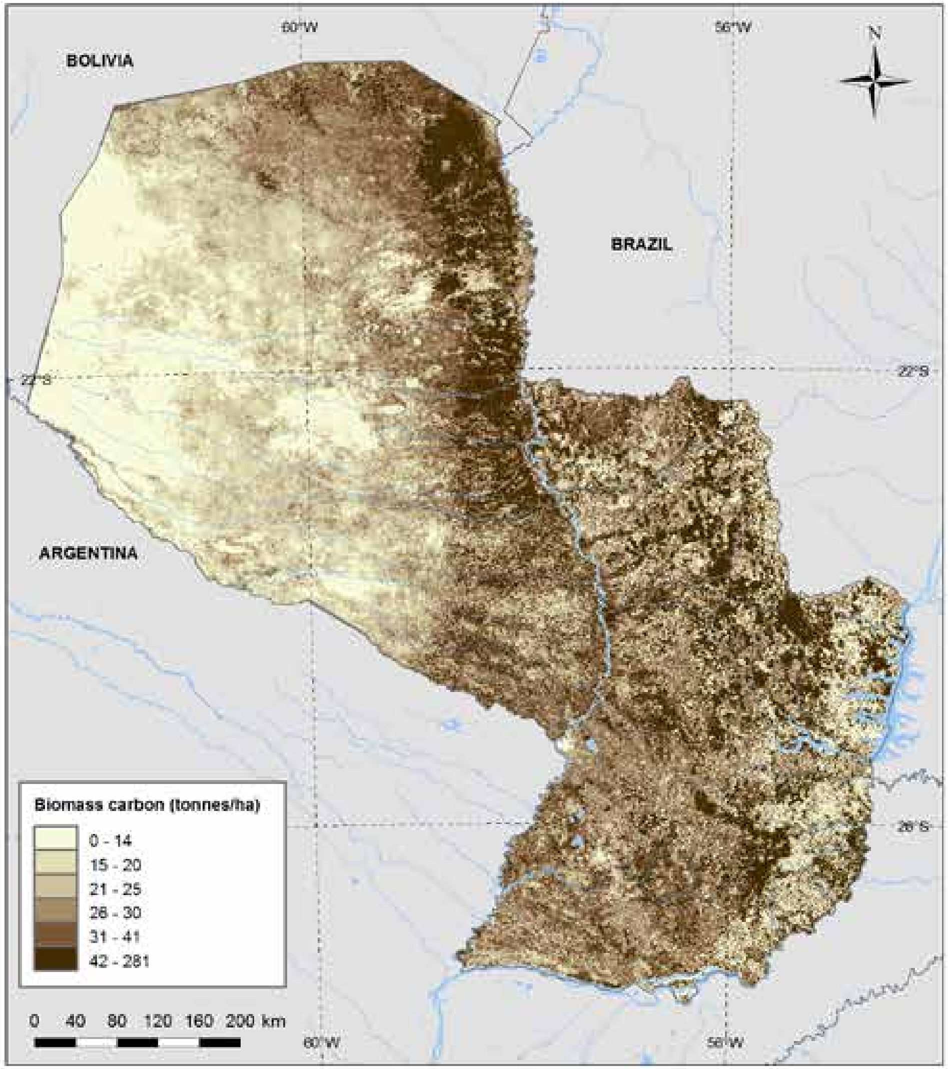
Map 7a shows biomass carbon within and outside of Paraguay's forests. Approximately 43% of Paraguay's biomass carbon is located within forests. The climate change mitigation effect of conserving forests depends on the carbon stocks of the forests in question. To identify areas where forests with high biomass carbon are at risk from deforestation, Map 7b combines data on biomass carbon (Map 7a) with modelling results in terms of the spatial variation in the probability of future deforestation (Map 5), derived from low- and high- impact development scenarios of the DINAMICA-EGO model and econometric techniques (CATIE 2014). Areas with high carbon stocks that are subject to risk of future deforestation may be priorities for implementing REDD+ actions designed to reduce deforestation. The extent and location of areas highlighted by such an analysis depend on models and scenarios used, as well as the quality of the carbon data, so careful consideration of a range of factors is needed to support effective decision making.

A limitation of this analysis is the lack of information about the condition of forests and the location of degraded forests. Due to the multiple factors involved, it can be difficult to collect and analyze information on forest degradation; however, the development of indicators on biodiversity, biomass carbon and other productive and protective forest areas can provide useful information (FAO 2011).

As Maps 6a and b and 7a show, the Chaco has considerably lower average carbon content in forests than the eastern region of Paraguay, due in part to differences in rainfall and soil type (Bonino 2006). However, the lower average content is offset by the relatively larger size of the Chaco, and the amount of remaining forest in the Chaco as compared to the eastern region of Paraguay. Conserving forests in the Chaco is also important because recent research has found that the effects of deforestation and climate change on forest ecosystem services are greater in certain soil types, such as the sandy soils typical of the Chaco (Crowther et al. 2014). Sandy soils, which retain less nutrients and have larger particles with less surface area, are more likely to release excess carbon when disrupted (as through deforestation), than muddy, clay-like soils (more typical of Paraguay's eastern region), which retain more nutrients and organic matter through their particles, and which have a greater surface area to bind nutrients and water (Crowther et al. 2014). Sandy soil therefore tends to lose the nutrients that microbes rely on for food (into the atmosphere, into rivers or through rain), while nutrients remain trapped in muddy clay

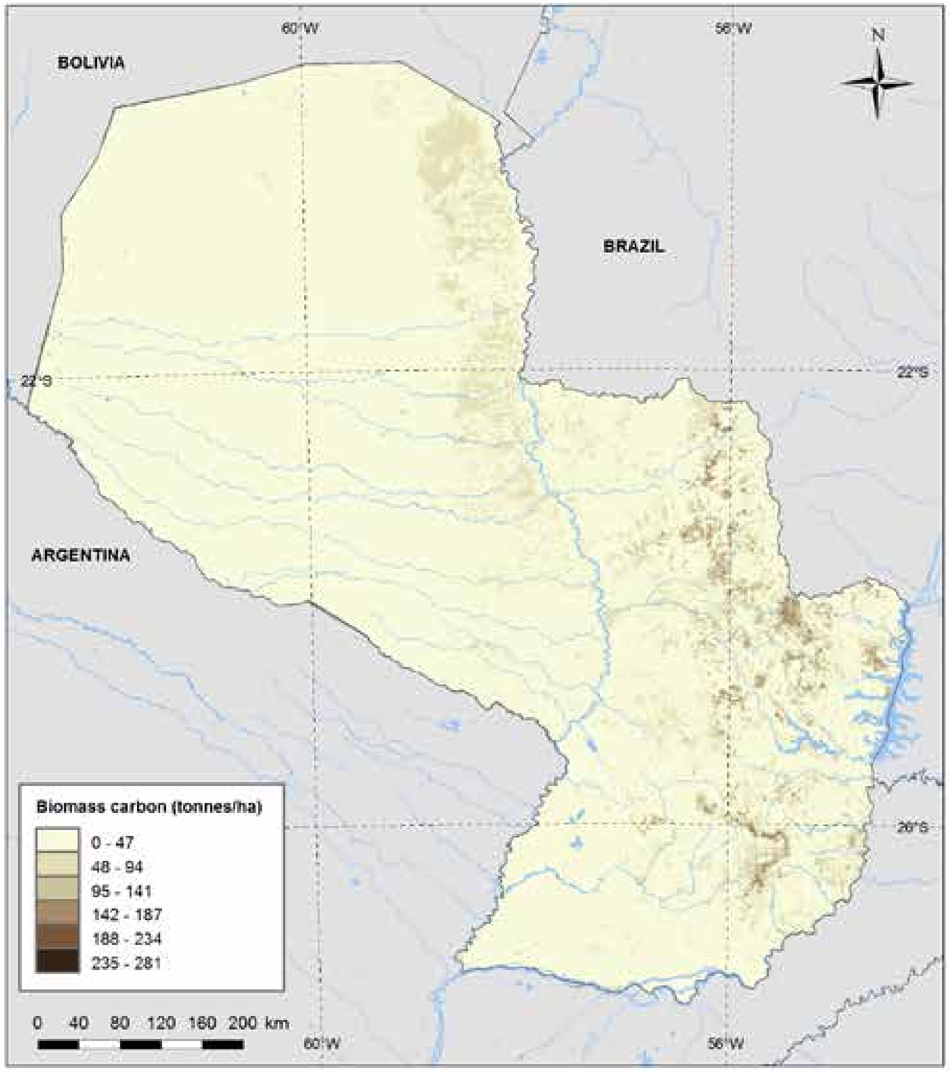
Map 6a: Biomass carbon (area-based classification)

This map uses Saatchi et al.'s (2011) data on forest carbon stocks in tropical regions to show the variation in Paraguay's biomass carbon. Carbon density classes have been defined by area; each class contains approximately one-sixth of the land area of Paraguay.



Map 6b: Biomass carbon (equal-interval classification)

This map uses the same data as in 6a, but presents it using an equal-interval classification, in which biomass carbon values are divided into six equal sized sub-ranges.



Method and data sources:

Map 6a:

Biomass carbon: Saatchi, S. et al. (2011) "Benchmark map of forest carbon stocks in tropical regions across three continents", PNAS, 108. 24: 9899-904. Data has been split into 6 quantile classes using an area-based classification; i.e. each class covers approximately one-sixth of the land area of Paraguay.

Map 6b:

Biomass carbon: Saatchi, S. et al. (2011) "Benchmark map of forest carbon stocks in tropical regions across three continents", PNAS, 108. 24: 9899-904. Data has been split into 6 classes using an equal-interval classification.

when the forest is cut down; these effects were found to be consistent despite of period of time following deforestation (Crowther et al. 2014). This may lead to greater effects on biodiversity when deforestation occurs in sandy soils.

4.2 Biodiversity

An increasing body of evidence indicates that species diversity can promote ecosystem functioning (Gamfeldt et al. 2013); in addition, biodiversity is valued in its own right, as recognized through the Convention on Biological Diversity (CBD). While Paraguay does not have a complete inventory of flora and fauna, national estimates include 13 000 plant species, of which 69% are regionally endemic. There are approximately 1 233 to 1 336 vertebrate species; 250 are fish; 76 amphibians; 135 reptiles; between 645-685 birds; and 167 mammals. There are 279 threatened plant species as well as 8 reptile, 86 bird and 38 mammal species at risk (CBD 2014).

Both the Chaco and east of Paraguay have biodiversity of regional and global importance. The Paraguayan Chaco comprises an important part of the Gran Chaco, which also includes southern Bolivia and northern Argentina, a region with over 3 400 plant species, 500 bird species and 150 types of mammals (Salas-Dueñas and Facetti 2007). More than 52% of the tree species and 92% of the amphibians in the Atlantic Forest are not found anywhere else in the world (WWF 2014). However, due to habitat loss, an estimated 102 plant and animal species in the UPAF are currently considered endangered, threatened or vulnerable (Kernan et al. 2010). The conversion of Paraguay's forests to pasture and croplands is the greatest current threat to Paraguay's biodiversity, but there are also important effects from urban and infrastructure expansion, over-exploitation, contamination, aggressive exotic species and climate change (Kernan et al. 2010).

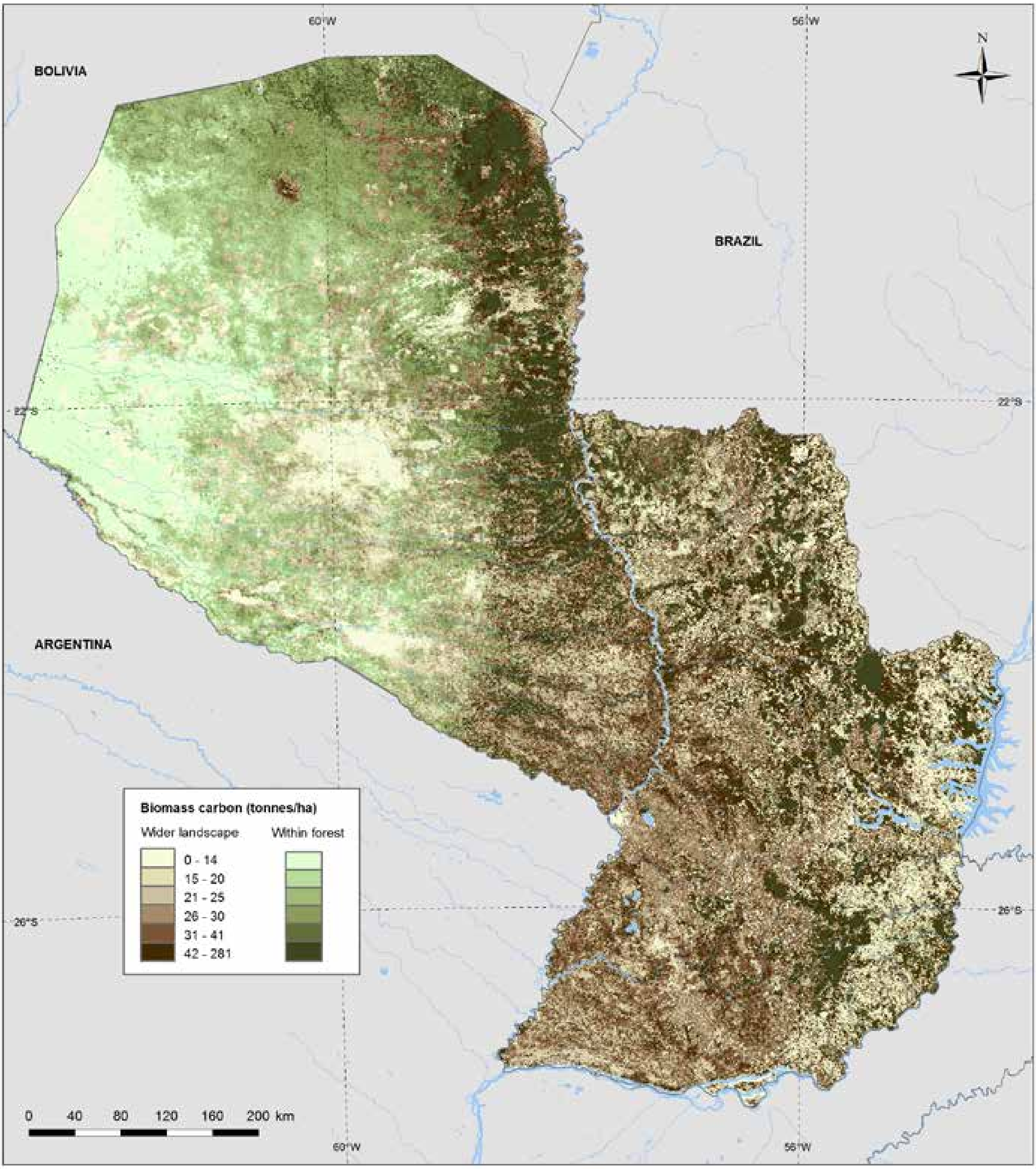
REDD+ actions can provide additional benefits for biodiversity conservation if efforts to maintain forest are prioritized in areas of high biodiversity value and/ or in their surroundings, where they can contribute to providing buffer zones or maintaining connectivity with other forests. Restoration of degraded forest in such areas, using appropriate methods such as natural regeneration or enrichment planting with mixed native species, may also provide significant benefits for biodiversity conservation, as well as for climate change mitigation. Information on areas that are important for biodiversity can therefore help to inform decisions on where to locate REDD+ actions in order to achieve such benefits.

By its very nature, biodiversity is complex and difficult to quantify or capture in a single indicator. As a result, a range of approaches and metrics may be used to measure and map a country's biodiversity and to

The Chacoan peccary, considered Endangered by the IUCN Red List, is endemic to the dry Chaco of western Paraguay, south-eastern Bolivia and northern Argentina. *Photo by ZakVTA https://flic.kr/p/6epKXz (CC BY-NC-ND 2.0).*

Map 7a: Biomass carbon within/outside of forest

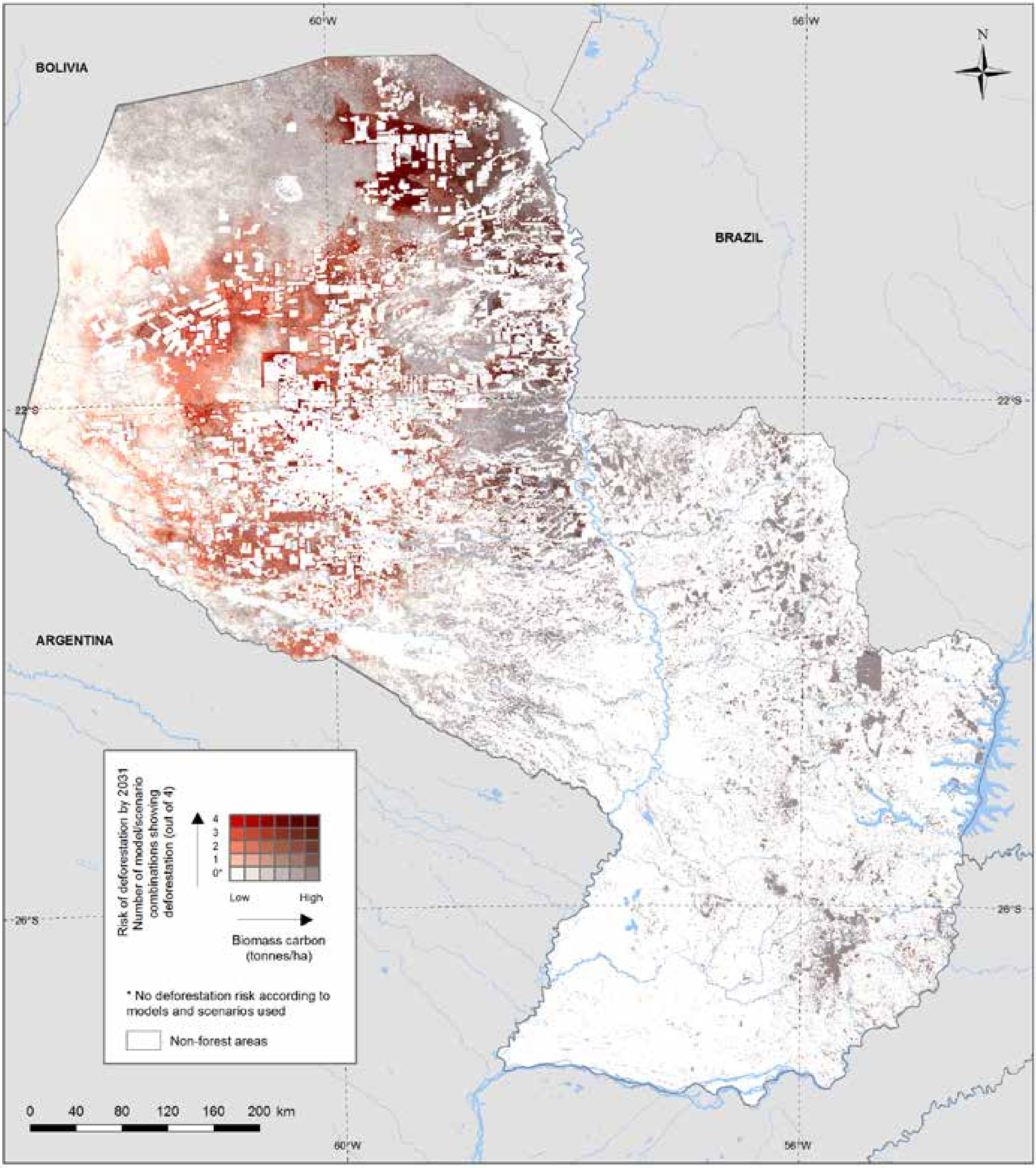
Approximately 43% of Paraguay's biomass carbon is located within forests.



Method and data sources:
Biomass carbon: Saatchi, S. et al. (2011) "Benchmark map of forest carbon stocks in tropical regions across three continents", PNAS, 108, 24: 9899-904.
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.

Map 7b: Biomass carbon at risk of future deforestation

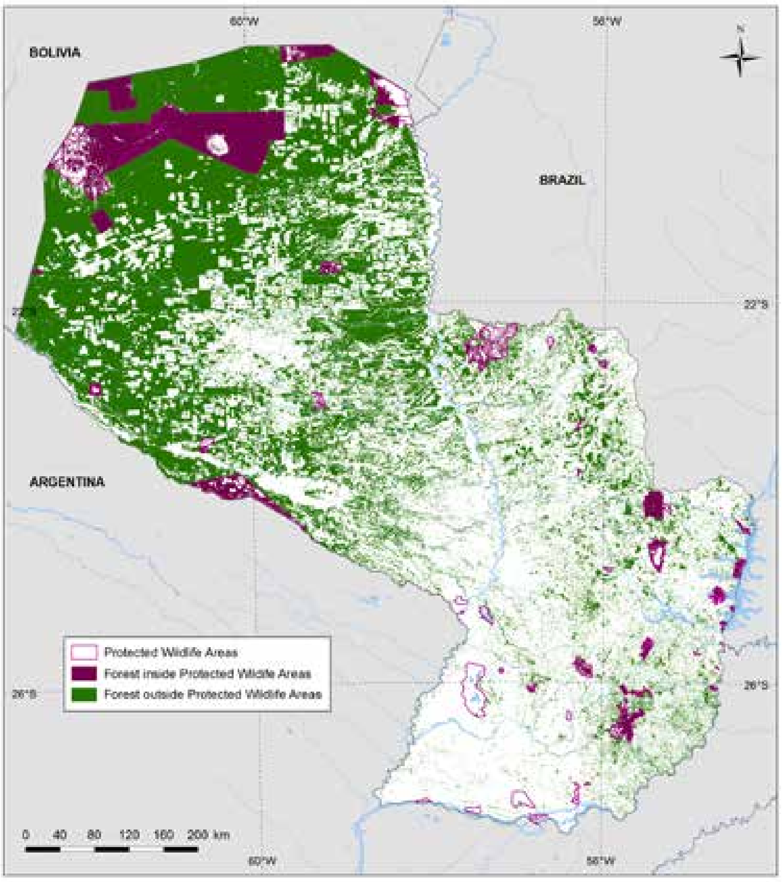
The climate mitigation effect of conserving forests at risk also depends on their carbon stocks. This map shows where carbon stocks may be at risk by combining biomass carbon (Map 7a) with the deforestation risk (Map 5), derived from low- and high- impact development scenarios of the DINAMICA-EGO model and econometric techniques (CATIE 2014). Areas of high biomass carbon that are also potentially at high risk of deforestation are shown in dark brown. Areas at high risk of deforestation but which contain low carbon stock are shown in bright red. Areas of high carbon stock with a low risk of deforestation are light brown. Areas where high carbon stocks are subject to high risk (dark brown), such as those in the Pantanal and Cerrado ecoregions in the Chaco, may be priorities for REDD+ actions designed to reduce deforestation.



Method and data sources:
Biomass carbon: Saatchi, S et al. (2011) "Benchmark map of forest carbon stocks in tropical regions across three continents", PNAS, 108, 24: 9899-904.
Projected deforestation: CATIE (2014). Análisis de cambio de uso de la tierra (1990-2011) y formulación de escenarios de deforestación futura (2031) de los bosques del Paraguay. Turrialba, Costa Rica: CATIE. Deforestation probability is based on observed land-use change between 1990 and 2000, which was then validated for the 2000-2011 period (an off-sample approach).
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.

The risk of deforestation, according to agreement between model/scenario combinations, was combined with biomass carbon (which was split into 6 quantile classes).

Map 8: Protected areas and forest cover



Method and data sources:
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.
Protected Wildlife Areas: Dirección General de Protección y Conservación de la Biodiversidad de la Secretaria del Ambiente (SEAM) 2011.

Information about the location of protected areas may help to determine where certain REDD+ actions are possible (as certain uses of the forest are prohibited in protected areas), and also where REDD+ actions that prevent deforestation or restore forest outside of protected areas may help to conserve biodiversity, supporting or enhancing the effectiveness of existing conservation areas by buffering them from land-use change.

Approximately 12% of Paraguay's forest cover is located in protected areas. *© Pro Cosara.*

identify areas important for its conservation and management. These approaches may focus on areas that have been protected, particular ecosystems, overall measures of species richness or species of conservation concern.

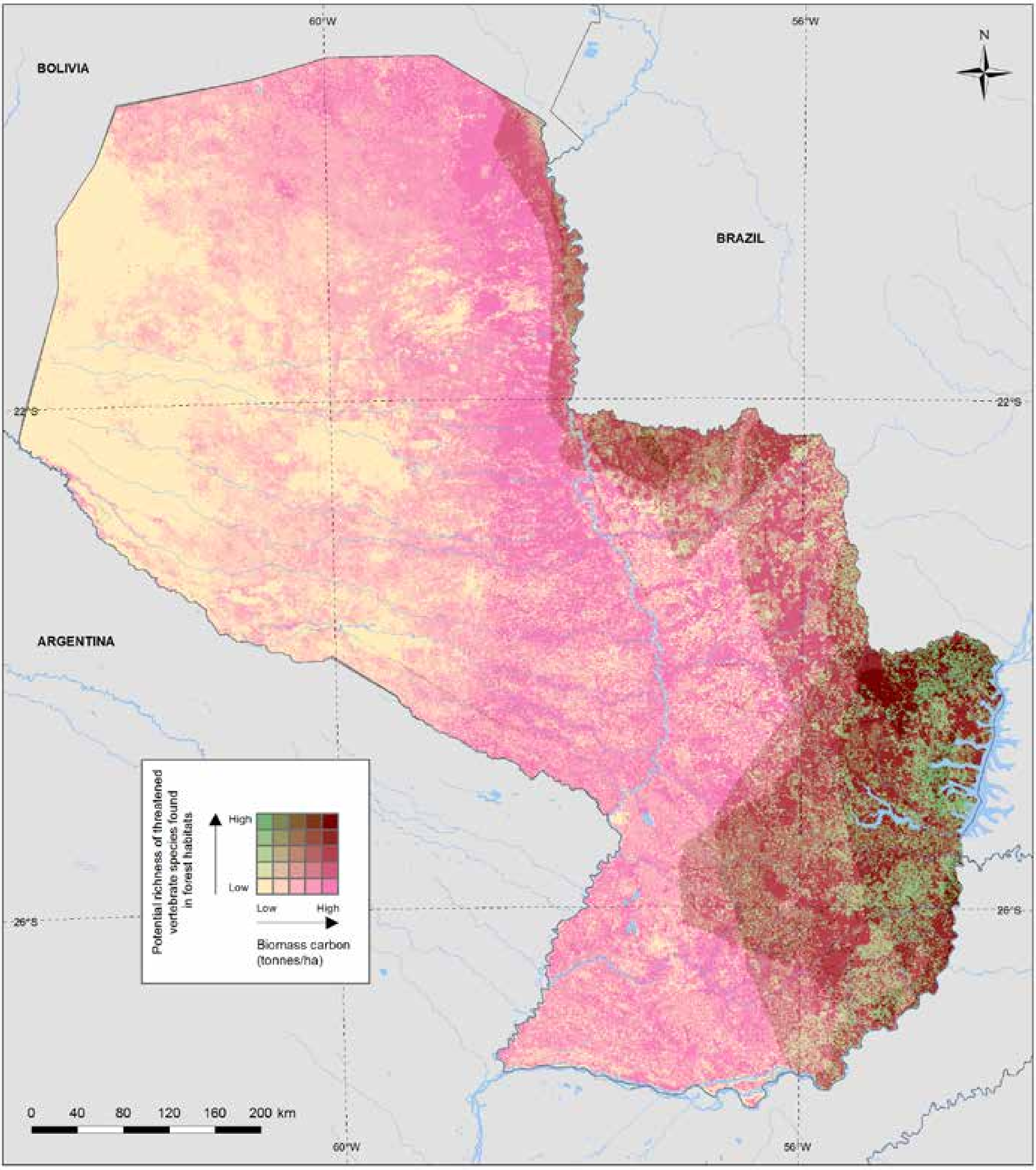
Protected areas are, by definition, important for the conservation of biodiversity. In protecting forests from land-use change pressures and human impact, protected areas may help to achieve REDD+ objectives. REDD+ actions that prevent deforestation outside of protected areas may also help to conserve biodiversity, supporting or enhancing the effectiveness of existing conservation areas by further buffering them from land-use change. Paraguay's National System of Protected Wildlife Areas (SINASIP) includes ten different categories of Protected Wildlife Areas (ASP), which currently cover 15% of Paraguay (R-PP 2014). However, management of protected areas in Paraguay is complicated by the fact that some public protected areas encompass private land (Kernan et al. 2010). Map 8 shows Paraguay's protected areas in relation to forest cover; approximately 12% of Paraguay's forest cover is located in protected areas.

The International Union for Conservation of Nature (IUCN) Red List of Threatened Species uses taxonomic, conservation status and distribution information to determine relative risk of extinction, cataloguing and highlighting those plants and animals that are facing a higher risk of global extinction (those listed as Critically Endangered, Endangered and Vulnerable) (IUCN 2013). Paraguay is home to 39 vertebrate species considered by IUCN (2013) to be globally threatened, 20 of which are found in forest habitats. Map 9 provides an initial basis for identifying priority areas in relation to biodiversity benefits, showing potential richness of threatened species that are found in forest habitats in relation to biomass carbon stocks. REDD+ actions in areas with high carbon stocks and where a greater number of threatened species are concentrated may support biodiversity conservation, in addition to providing climate change mitigation benefits.

Important Bird and Biodiversity Areas (IBAs) provide another basis for identifying areas where reducing the risks of adverse impacts of deforestation and forest degradation through REDD+ could deliver additional benefits for biodiversity. IBAs are sites needed to ensure the survival of viable populations of bird species (BirdLife 2014). As birds have been shown to be effective indicators of biodiversity in other animal groups and plants, the conservation of these sites

Map 9: Potential richness of threatened vertebrate species (mammals, birds and reptiles) found in forest habitats and biomass carbon

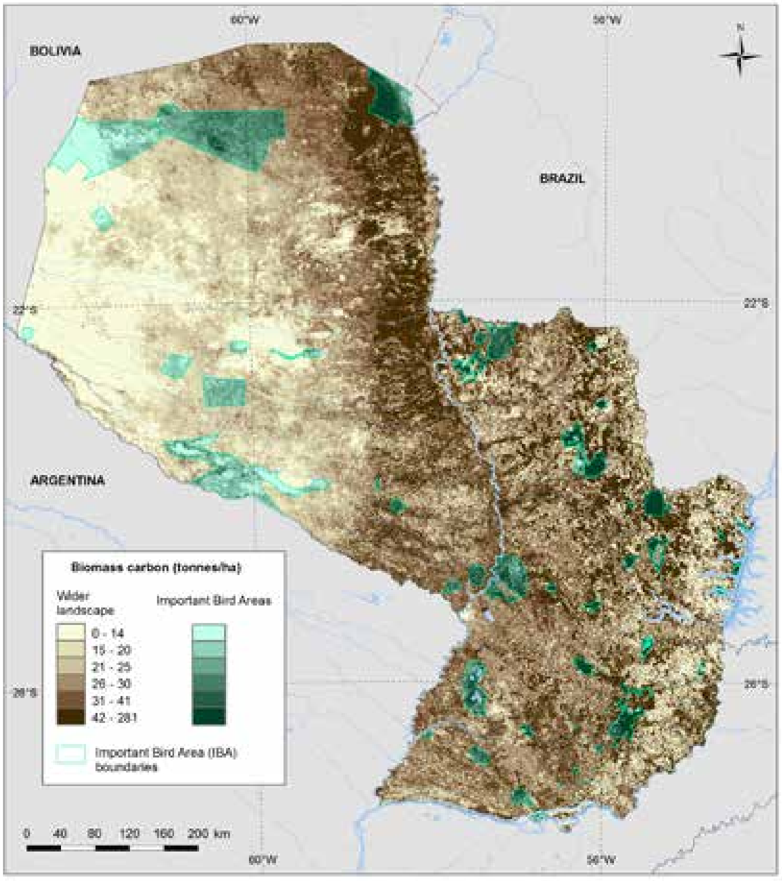
REDD+ actions in areas where the potential richness of threatened species and carbon reserves are high (dark red) could offer benefits for the conservation of biodiversity as well as for climate change mitigation. It may be particularly important to control and avoid indirect land-use change in areas with high potential richness of threatened species but low carbon stock (green).



Method and data sources:
Threatened forest species: Based on mammal, bird and reptile species that are found in forest habitats and are classified as 'Critically Endangered', 'Endangered', or 'Vulnerable' by the IUCN Red List of Threatened Species (2013) Version 2012.2 http://www.iucnredlist.org. Downloaded January 2014.
Biomass carbon: Saatchi, S. et al. (2011) "Benchmark map of forest carbon stocks in tropical regions across three continents", PNAS, 108. 24: 9899-904.

A 1 km^2 hexagon grid covering Paraguay was generated using Jenness Enterprises repeating shapes tool in ArcGIS 10.0. Hawths Analysis tools were used to generate species richness by calculating the number of species ranges intersecting with each hexagon. Hexagons were shaded by species number. Potential species richness was reclassed and split into 5 natural breaks classes. Biomass carbon was reclassed and split into 5 quantile classes. The two layers were then combined to produce a matrix of potential threatened forest species richness and biomass carbon.

Map 10: Important Bird and Biodiversity Areas in relation to biomass carbon



Method and data sources:
Biomass carbon: Saatchi, S. et al. (2011) "Benchmark map of forest carbon stocks in tropical regions across three continents", PNAS, 108: 24: 9899-904.
Important Bird Areas: Key Biodiversity Areas (KBAs) of the world including Important Bird Areas (IBAs) and Alliance for Zero Extinction sites (AZEs) compiled by BirdLife International and Conservation International, October 2012. For further information please contact mapping@birdlife.org.

Information about the location of IBAs and biomass carbon could be used to prioritize areas and approaches for the implementation of REDD+ that produce benefits and avoid risks for biodiversity in Paraguay.

Paraguay's national bird, the Bare-throated Bellbird (*Procnias nudicollis*), depends on the Atlantic forest for its survival. It is considered Vulnerable by IUCN. *Photo by Ben Tavener https://flic.kr/p/dfTNnr (CC BY-NC-ND 2.0).*

may therefore offer additional biodiversity benefits. Important Bird and Biodiversity Areas in Paraguay are shown in relation to biomass carbon stocks in Map 10.

4.3 Soil erosion control and hydrological services

Soil erosion control and hydrological services were identified in consultations with stakeholder groups as important benefits of retaining and restoring forests through REDD+ in Paraguay. Forests, especially those on slopes, can stabilize soil and help prevent soil erosion. Deforestation and forest degradation may diminish the capacity of land to store water, and cause greater surface runoff after heavy rains, with attendant erosion and sedimentation, increasing downstream flood risk and leading to water shortages at other times of the year. Soil particles carried by runoff can contribute to higher sediment loads in streams and rivers, leading to a build-up of silt, which can damage downstream infrastructure, such as hydroelectric and other dams. This has particular relevance for the functioning of the Itaipú Dam, the world's largest hydroelectric power facility, jointly owned by the governments of Paraguay and Brazil, which generates 72.5% of Paraguay's electricity supply (Itaipú Binacional 2014a). The importance of protecting natural forest close to the Itaipú reservoir is recognized nationally; there are seven protected areas adjacent to its banks in Paraguay, and the Itaipú Binational Corporation makes efforts to protect soil in its watershed management programmes (Itaipú Binacional 2014b).

This report uses a simple approach to highlight where forest may be particularly valuable in preventing soil erosion (Map 11; Annex II provides a more detailed methodology). An index was developed using the following criteria: slope; wettest month precipitation; and the presence of downstream features with the potential to be adversely affected by sedimentation (hydroelectric and other dams). A simple classification for each criterion (low, medium, high or presence/absence) was applied; the results were then combined and overlaid with forest cover data for Paraguay.

The role of forest in limiting erosion and sedimentation is most critical where high rainfall combines with steep slopes to increase erosion risk within catchments above dams and lakes (Map 12). Carefully designed and targeted REDD+ actions may help contribute to soil erosion control in these areas. Further analyses of areas that have lost forest, or that have degraded forest, in catchments where erosion risk is high may help to identify potential locations for forest restoration with additional benefits for the stabilization of soils.

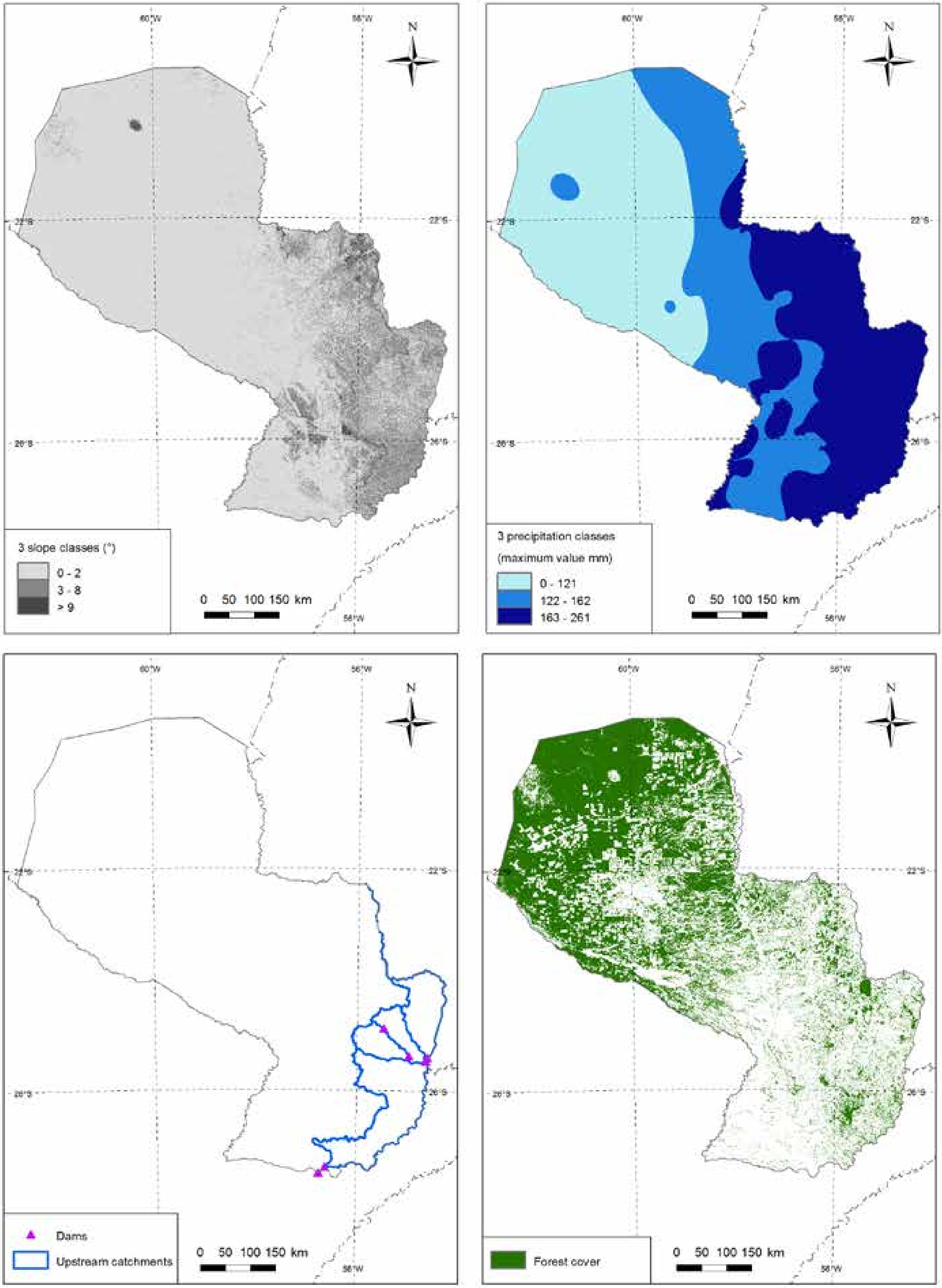
With few natural barriers, wind (including warm wind from the Amazon basin between October and March, and cold wind from the Andes between May and August) also contributes to the erosion of topsoil in Paraguay, especially in dry areas. Wind may develop speeds as high as 161 km/h, which may lead to significant changes in temperature within a short period of time (CIA 2014). Wind speed in excess of 6 metres/second over dry soil is thought to have the potential to cause erosion (Roose 1996). However, after a review of available data sets for Paraguay[3], it was not considered possible to include wind speed as a factor in the analysis of soil erosion, as spatially explicit data was not available at a resolution high enough to influence the results of the analysis.

[3] Wind velocity data for Paraguay is available at a resolution of 10 minutes (which is equivalent to 344 km^2 at the equator; New et al. 2002).

By exposing and/or compacting soil, deforestation and forest degradation on slopes may lead to erosion and sedimentation, diminish the capacity of the land to store water, and cause greater surface runoff after heavy rains. *©Julia Thorley.*

Map 11: Methodology: importance of forest for soil erosion control

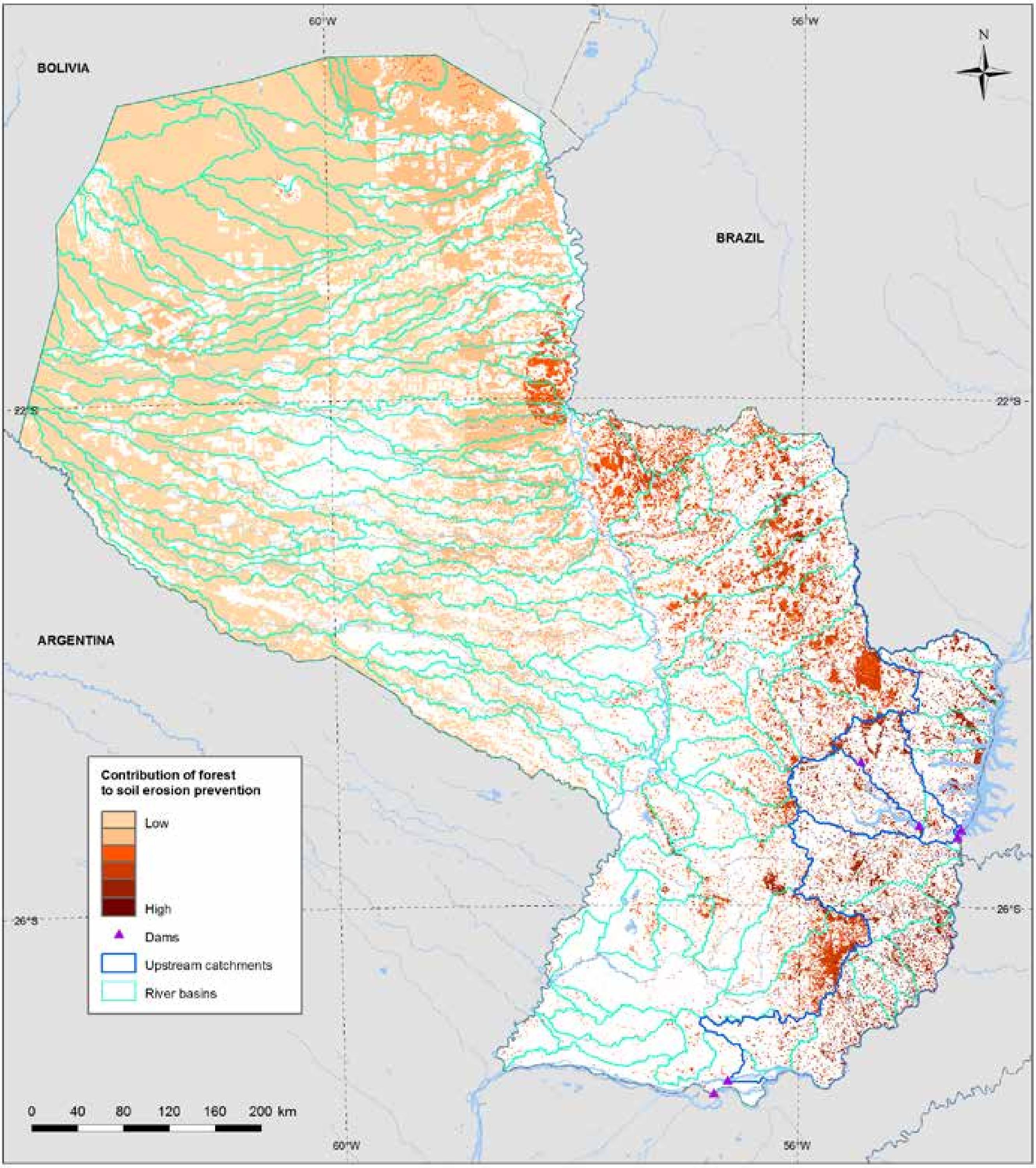
Areas with high slope and high precipitation have been identified as having the greatest potential soil erosion risk. Upstream catchments of dams are shown as areas of particular value for soil erosion control.



Method and data sources: See Map 12.

Map 12: Importance of forest for soil erosion control

Information about erosion-prone areas can be used to prioritize REDD+ actions to prevent soil loss and negative impacts of sedimentation in bodies of water, as well as to preserve the role of forests in the water cycle. The goal for forested areas would be to prevent deforestation; the goal for areas with degraded forest or without forest cover would be to restore forest.



Method and data sources:
Elevation: Lehner, B., Verdin, K., Jarvis, A. (2008): New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU, 89(10): 93-94. See: http://hydrosheds.cr.usgs.gov/
Precipitation: WorldClim http://www.worldclim.org/.
Dams: IABIN dams of Paraguay compiled by TNC combined with Lehner, B., R-Liermann, C., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P. et al.: High resolution mapping of the world's reservoirs and dams for sustainable river flow management. Frontiers in Ecology and the Environment. Source: GWSP Digital Water Atlas (2008). Map 81: GRanD Database (V1.0). Available online at http://atlas.gwsp.org.
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.

The relative importance of forest has been evaluated as a function of slope, rainfall and the presence of something downstream that could be adversely affected by soil erosion (dams). This method uses an overlay approach, where wettest month precipitation per cell (split into 3 classes using natural breaks classification) has been combined with data generated for slope (split into 3 classes using natural breaks classification), and upstream catchments of dams, to indicate areas where forest may be of particular importance for erosion control.

Deforestation may limit the capacity of soils to retain water, and may make parts of Paraguay more prone to flooding. *Photo by Juan Andrés Del Puerto González https://flic.kr/p/nDx3Dx (CC BY-NC-ND 2.0).*

4.4 Areas potentially important for more than one benefit

The previous sections have identified areas where REDD+ actions could potentially deliver individual specific benefits in addition to climate mitigation. However, all else being equal, the greatest priority for REDD+ might be to focus on areas where actions to reduce deforestation can provide more than one benefit. Drawing on the maps of biomass carbon (Map 6a), potential richness of threatened species found in forest habitats (Map 9), Important Bird and Biodiversity Areas (Map 10) and the importance of forest for limiting soil erosion (Map 12), spatial information on individual benefits can be overlaid to identify forest areas of potential importance for more than one benefit from REDD+ (Map 13a) (Annex III provides a more detailed methodology).

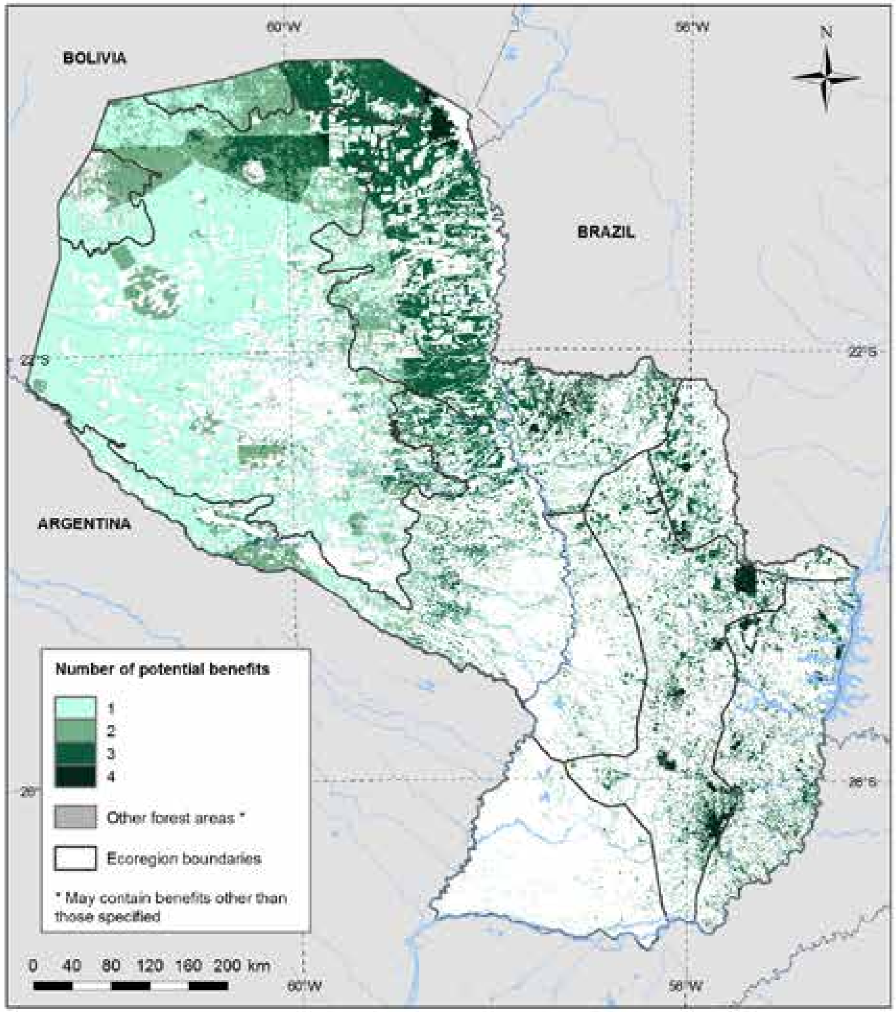
Areas of greater priority for REDD+ actions to reduce deforestation, even if there are challenges related to cost or feasibility, may be locations where both deforestation risk and potential for benefits are high (Map 13b). This map shows that the remaining forest in the Chaco Seco and Pantanal ecoregions are particularly valuable in terms of providing benefits, but are also at high risk of deforestation.

The combined benefits in an area will vary according to which, and how many, benefits are being considered. Maps 14a and b and 15a and b show alternative sets of benefits for the Chaco region, focused on biodiversity conservation. Map 14a combines priority sites (those with moderate to high value) for endemic species (plants, amphibians, mammals and birds), areas considered to be of value for diversity of habitat, fragile ecosystems, and biodiversity corridors of the Chaco (GEF 2003), with biomass carbon (taking the top three classes from the carbon map, which includes areas with >26 tC/ha). Map 14b highlights the biodiversity benefits that are at risk of future deforestation, using the data from Map 5.

Map 15a combines important sites (those with moderate to very high value) for flagship plant species, threatened plant species and plant diversity (GEF 2003), with biomass carbon (taking the top three classes from the carbon map, which includes areas with >26 tC/ha). Map 15b highlights the multiple benefits for plant diversity in the Chaco region that are at risk of future deforestation, using the data from Map 5.

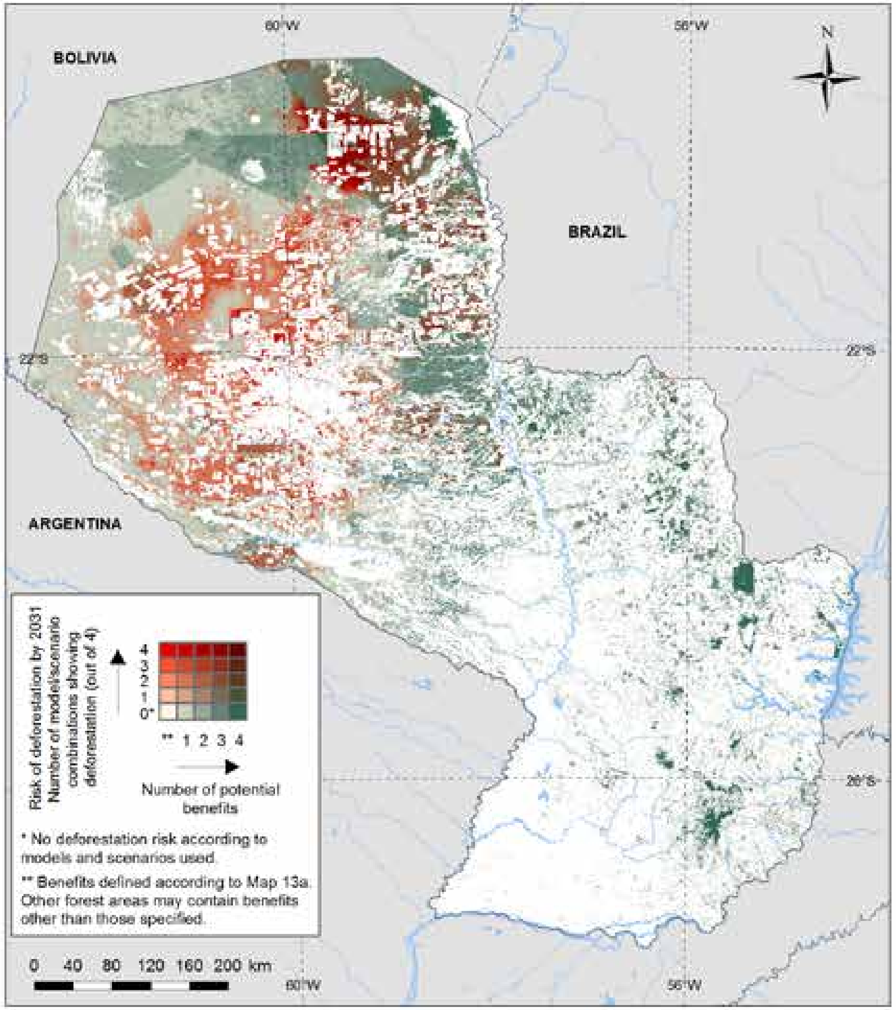
Map 13a: Multiple benefits: carbon, biodiversity and soil erosion control

Drawing on the maps of biomass carbon (Map 7a), potential richness of threatened forest species (Map 9), Important Bird and Biodiversity Areas (Map 10) and the importance of forest for limiting soil erosion (Map 12), it is possible to identify forest areas of importance for more than one benefit.



Map 13b: Multiple benefits at risk of future deforestation

Using information on projected deforestation risk by 2031 (Map 5), areas of forest important for various combinations of potential benefits (Map 13a) that are at risk can be highlighted. Areas that are of potential importance for multiple benefits, but that are also at high risk of future deforestation, are shown in dark red. These areas could be priority locations for REDD+ actions to reduce deforestation.



Methods and data sources:

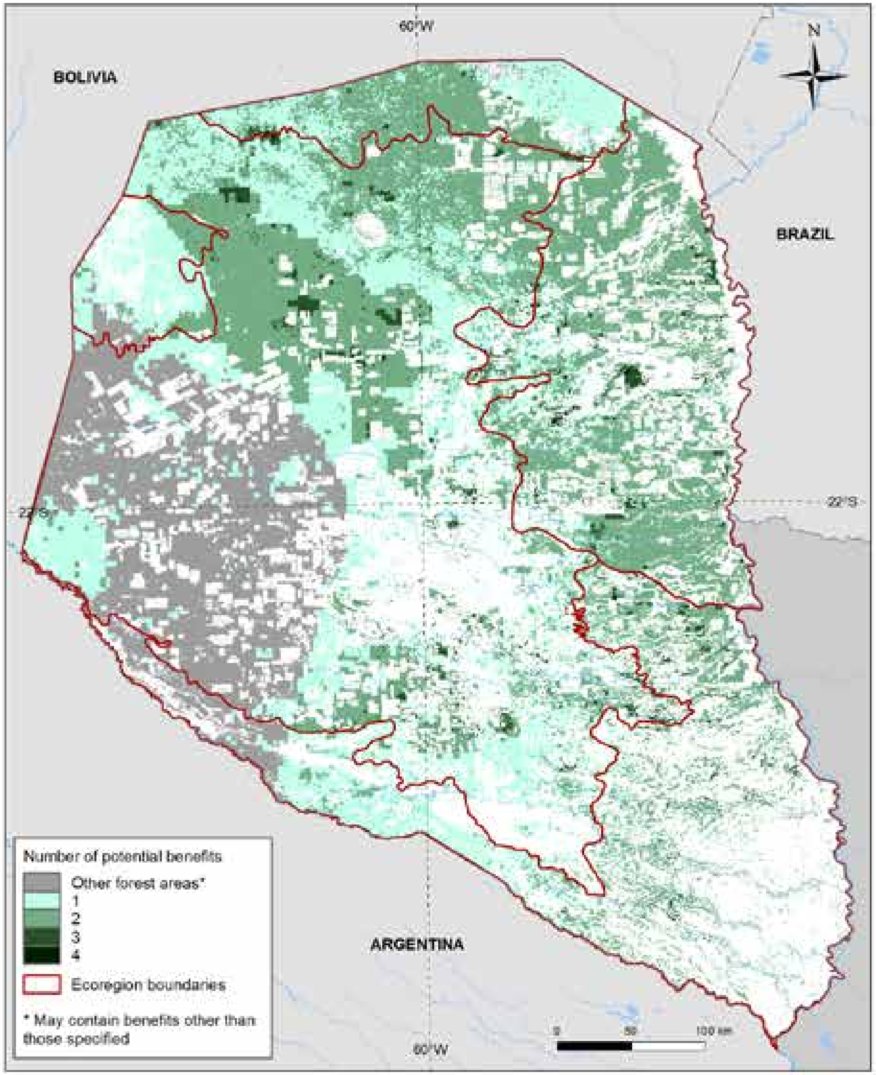
Map 13a: Biomass carbon: See Map 6a. The top three classes of carbon (> 26 tC/ha) were used to represent areas of greatest importance for carbon in this map. **Potential richness of threatened forest species:** See Map 9. Areas with > 5 species per 1km² hexagon were used to represent areas of greatest importance for threatened forest species. **Important Bird Areas:** Key Biodiversity Areas (KBAs) of the world including Important Bird Areas (IBAs) and Alliance for Zero Extinction sites (AZEs) compiled by BirdLife International and Conservation International, October 2012. **Soil erosion:** All except the lowest class from Map 12 have been used to identify areas of greatest importance here. **Forest cover:** PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+. **Ecoregions:** See Map 4.

Map 13b:

Combined benefits: See Map 13a for methods and inputs. **Projected deforestation:** CATIE (2014). Análisis de cambio de uso de la tierra (1990-2011) y formulación de escenarios de deforestación futura (2031) de los bosques del Paraguay. Turrialba, Costa Rica: CATIE. Deforestation probability is based on observed land-use change between 1990 and 2000, which was then validated for the 2000-2011 period (an off-sample approach). **Forest cover:** See above.
The risk of deforestation, according to agreement between model/scenario combinations, was combined with the number of potential benefits as specified above.

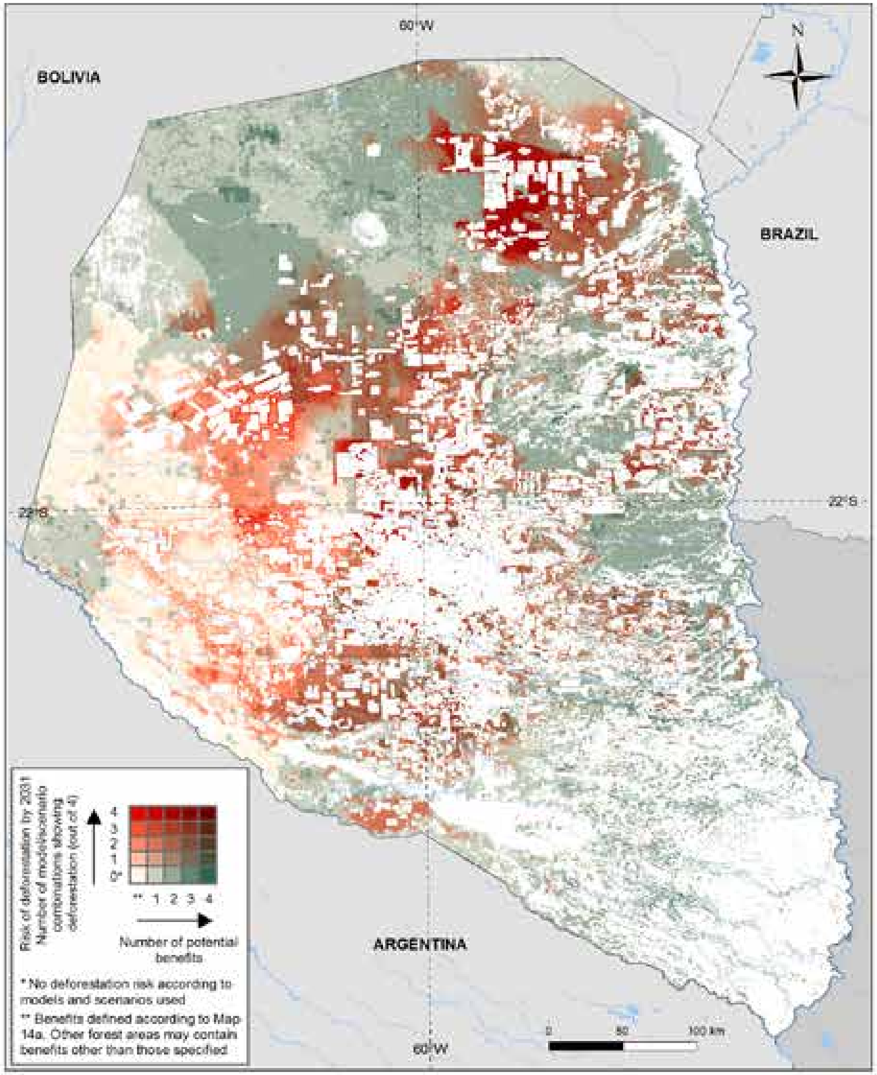
Map 14a: Multiple biodiversity benefits in the Chaco region

This map combines priority sites for endemic species (plants, amphibians, mammals and birds), areas considered to be of value for diversity of habitat, fragile ecosystems and biodiversity corridors of the Chaco (GEF 2003) with biomass carbon (taking the top three classes from the carbon map, which includes areas >26 tC/ha).



Map 14b: Multiple biodiversity benefits in the Chaco region at risk of future deforestation

Using information on projected deforestation risk by 2031 (Map 5), areas of forest important for biodiversity benefits in the Chaco (Map 14a) that are at risk can be highlighted. Areas that are of potential importance for multiple biodiversity benefits, but that are also at high risk of future deforestation, are shown in dark red.



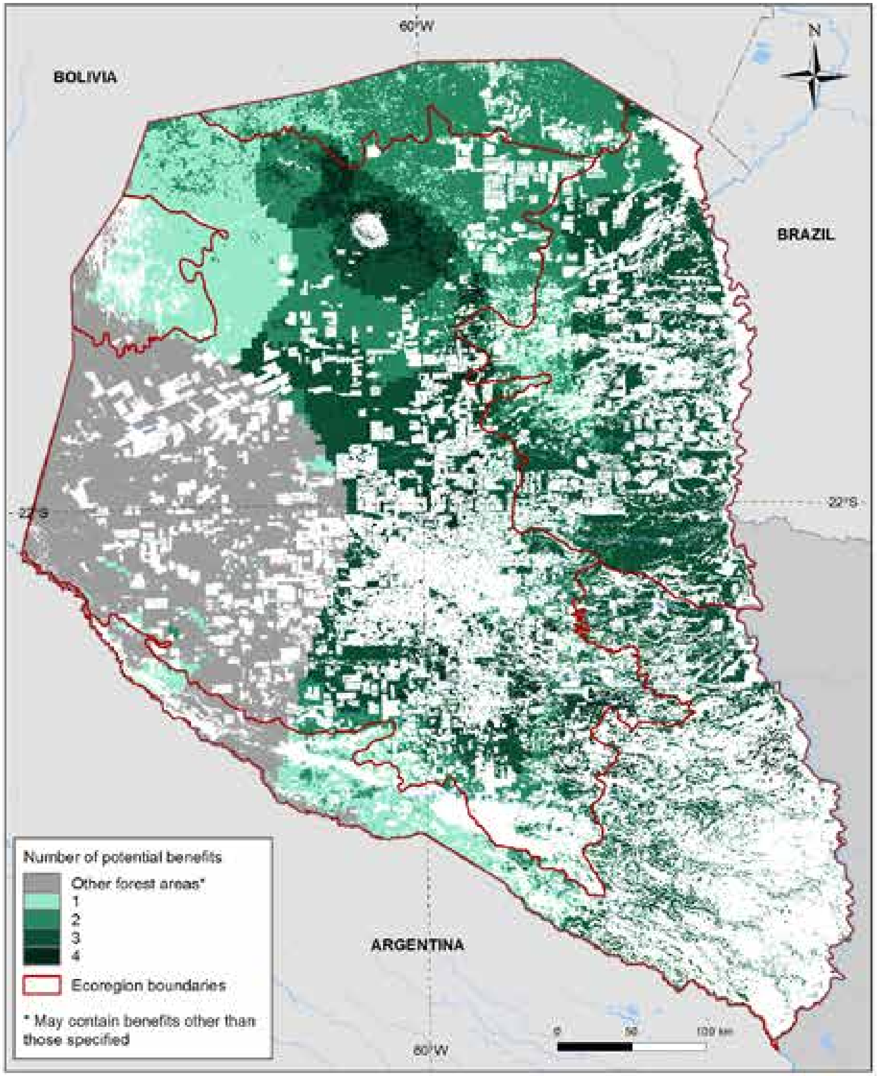
Method and data sources:

Map 14a: Biomass carbon: Saatchi, S et al. "Benchmark map of forest carbon stocks in tropical regions across three continents", PNAS, 108. 24 (2011): 9899-904.The top 3 classes of carbon (areas >26 tC/ha) were used to represent areas of greatest importance for carbon in this map.**Fragile ecosystems; Priority sites for endemic species; Habitat diversity; Biodiversity corridors:** Sites classed as Moderate to Very high importance have been included in this map to represent areas of greatest importance. Proyecto GEF 1010-00-14 Areas Prioritaras para la Conservacionen Cinco Ecorregiones de Sudamerica (2003) Secretaria del Ambiente / DGPCB / CDC Paraguay. Project partners: Equipo Técnico CDC, SEAM, Proyecto GEF PAR/98/G33, PRODECHACO, CIF/FIA/UNA, MHNP. 'Proyecto GEF 1010-00-14 'Areas Prioritaras para la Conservacionen Cinco Ecorregiones de Sudamerica. Base de Dates Biologicos de Conservacion BCD, Centre de Datos para la Conservacion, 2002. Distribucion de Especies, Tropico, 2002. **Forest cover:** PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+. **Ecoregions:**La Secretaria del Ambiente (SEAM) Paraguay, 2013. Data was reclassified and summed, then clipped to forest cover to show where areas of forest in the Chaco may be of importance for these benefits.

Map 14b: Combined benefits: See above. **Projected deforestation:** CATIE (2014). Análisis de cambio de uso de la tierra (1990-2011) y formulación de escenarios de deforestación futura (2031) de los bosques del Paraguay. Turrialba, Costa Rica: CATIE. Deforestation probability is based on observed land-use change between 1990 and 2000, which was then validated for the 2000-2011 period (an off-sample approach). The risk of deforestation, according to agreement between model/scenario combinations, was combined with the number of potential benefits as specified above.

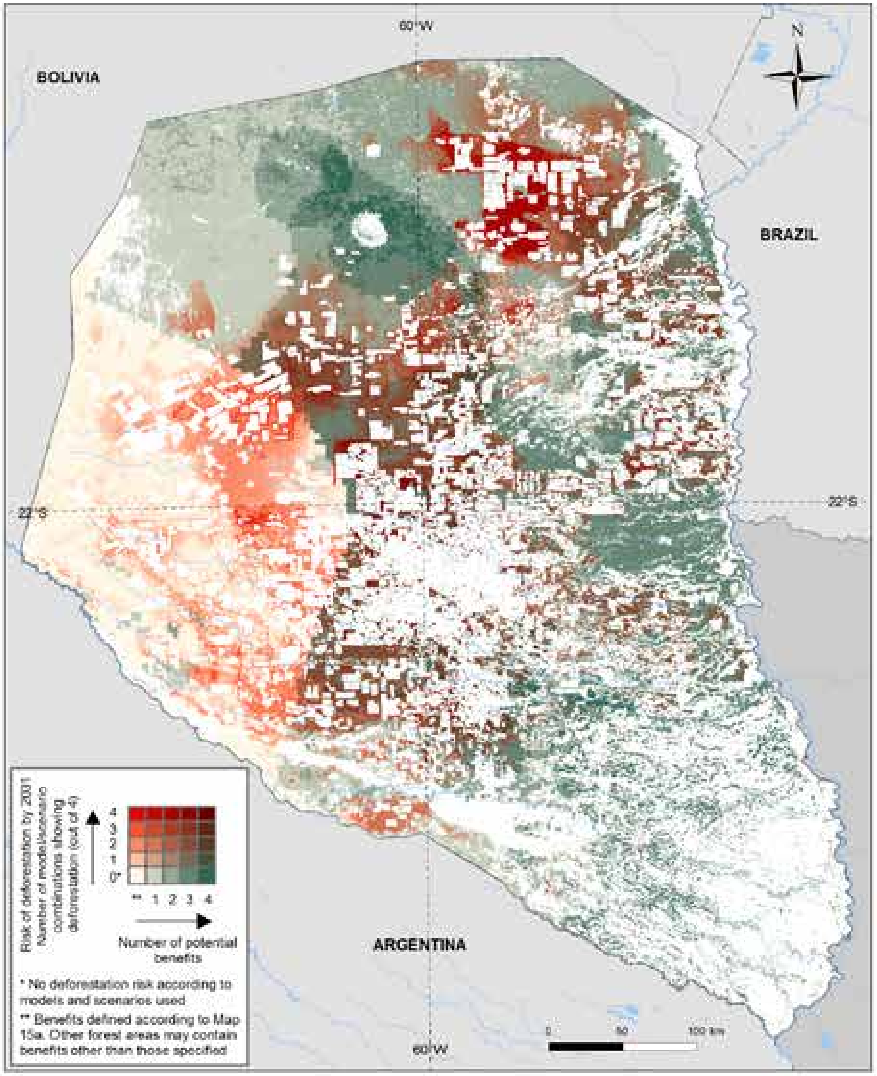
Map 15a: Multiple benefits for plant diversity in the Chaco region

This map combines important sites for flagship plant species, threatened plant species and plant diversity (GEF 2003), with biomass carbon (taking the top three classes from the carbon map, which includes areas >26 tC/ha).



Map 15b: Multiple benefits for plant diversity in the Chaco region at risk of future deforestation

Using information on projected deforestation risk by 2031 (Map 5), areas of forest important for plant diversity in the Chaco (Map 15a) that are at risk can be highlighted. Areas that are of potential importance for plant diversity, but that are also at high risk of future deforestation, are shown in dark red.



Map 15a: Biomass carbon: Saatchi, S et al. "Benchmark map of forest carbon stocks in tropical regions across three continents", PNAS, 108. 24 (2011): 9899-904 The top 3 classes of carbon (areas >26 tC/ha) were used to represent areas of greatest importance for carbon in this map **Priority areas for flagship plant species; Priority areas for endangered plants; Important sites for plant diversity:** Sites classed as Moderate to Very high importance have been included in this map to represent areas of greatest importance. Proyecto GEF 1010-00-14 Areas Prioritaras para la Conservacionen Cinco Ecorregiones de Sudamerica (2003) Secretaria del Ambiente / DGPCB / CDC Paraguay. Project partners: Equipo Técnico CDC, SEAM, Proyecto GEF PAR/98/G33, PRODECHACO, CIF/FIA/UNA, MHNP. "Proyecto GEF 1010-00-14 "Areas Prioritaras para la Conservacionen Cinco Ecorregiones de Sudamerica. Base de Dates Biologicos de Conservacion BCD; Centre de Datos para la Conservacion, 2002. Distribucion de Especies, Tropico, 2002. **Forest cover:** PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+. **Ecoregions:** La Secretaria del Ambiente (SEAM) Paraguay, 2013. Data was reclassified and summed, then clipped to forest cover to show where areas of forest in the Chaco may be of importance for these benefits.
Map 15b: Combined benefits: See above. **Projected deforestation:** CATIE (2014). Análisis de cambio de uso de la tierra (1990-2011) y formulación de escenarios de deforestación futura (2031) de los bosques del Paraguay. Turrialba, Costa Rica: CATIE. Deforestation probability is based on observed land-use change between 1990 and 2000, which was then validated for the 2000-2011 period (an off-sample approach).
The risk of deforestation, according to agreement between model/scenario combinations, was combined with the number of potential benefits as specified above.

Areas of greatest priority for REDD+ actions to reduce deforestation, even if there are challenges related to cost or feasibility, may be locations where both deforestation risk and potential for benefits are high. *Photo by Andrea Ferreira https://flic.kr/p/afjAgc (CC BY-NC-ND 2.0).*

The spatial layers used in these maps were developed through the "Catalyzing Conservation Action in Latin America" project, which was implemented by the United Nations Environment Programme, with funding from the Global Environment Fund, The Nature Conservancy, and six Latin American Conservation Data Centres between 2000-2003. The goal of the project was to analyze and identify priority sites with globally significant biodiversity, and also to explore management options for biodiversity conservation through a scientific and participatory process involving key stakeholders and decision makers (GEF 2003; Rodríguez 2005).

Priority areas for conservation were determined through a protected area gap analysis involving ecological, landscape and conservation criteria. Ecological criteria were based on diversity, endemism, threatened species, sensitivity and specialist species. Taxa included in the analysis were selected according to whether they had representative species in all types of vegetation in the region; the existence of habitat specialists; the presence of species with restricted distribution ranges; and whether it was possible to include all or the majority of the species within the taxa in the analysis. The landscape criteria used were degree of forest fragmentation (to indicate threat) and landscape diversity (to indicate areas with potential for high biodiversity). The integration of these components allowed the identification of priority conservation sites – generally areas with high biodiversity and endemism that are under threat, and that are not part of a national protected areas network (Rodríguez 2005).

5. Culture, livelihoods and sustainable forest use

There is a growing consensus that decisions on conservation and the sustainable use of forests are directly connected to basic needs and local livelihoods. REDD+ will significantly increase its chances of success if it becomes an income source for communities. Spatial analyses can help to identify locations where REDD+ actions could be designed to contribute to reducing poverty and inequality, and also where REDD+ may be able to support traditional livelihoods and cultures of indigenous peoples and forest-dependent communities.

While Paraguay is considered a country with medium levels of human development, one in three people currently live in poverty, and one in five in extreme poverty (DGEEC 2008; IFAD 2012). Inequality has been exacerbated by insecure land tenure and high concentrations of land ownership (90% of Paraguay is privately owned; within this, 82% of Paraguay's arable land is owned by 2% of the population; R-PIN 2008). While urban poverty has declined over the past few years, approximately half of Paraguay's rural population still live in poverty, with women and indigenous peoples disproportionately affected. Remote rural areas in Paraguay may suffer from low market access, weak infrastructure and few opportunities for agricultural production, which together create "poverty traps", from which it is difficult to escape (IFAD 2012; Lawlor et al. 2013). In areas of high forest cover and high poverty, there may also be a relatively high dependence on forests for livelihoods, especially in times of hardship; the rural poor are the most likely to be reliant on ecosystem services, and are therefore the most vulnerable to changes in those services (MEA 2005; Sunderlin et al. 2008).

REDD+ actions, designed with participation from local stakeholders, can benefit livelihoods by helping to clarify and strengthen land tenure rights, enhancing community capacity for forest management and collective action, and sustaining ecosystem services important for food security and adaptation to climate change (Lawlor et al. 2013). However, REDD+ actions could also cause livelihood risks for forest-dependent communities. It is necessary to consider potential risks in these areas, such as loss of livelihoods due to closures in timber and timber-related industries and reduced investment in agriculture.

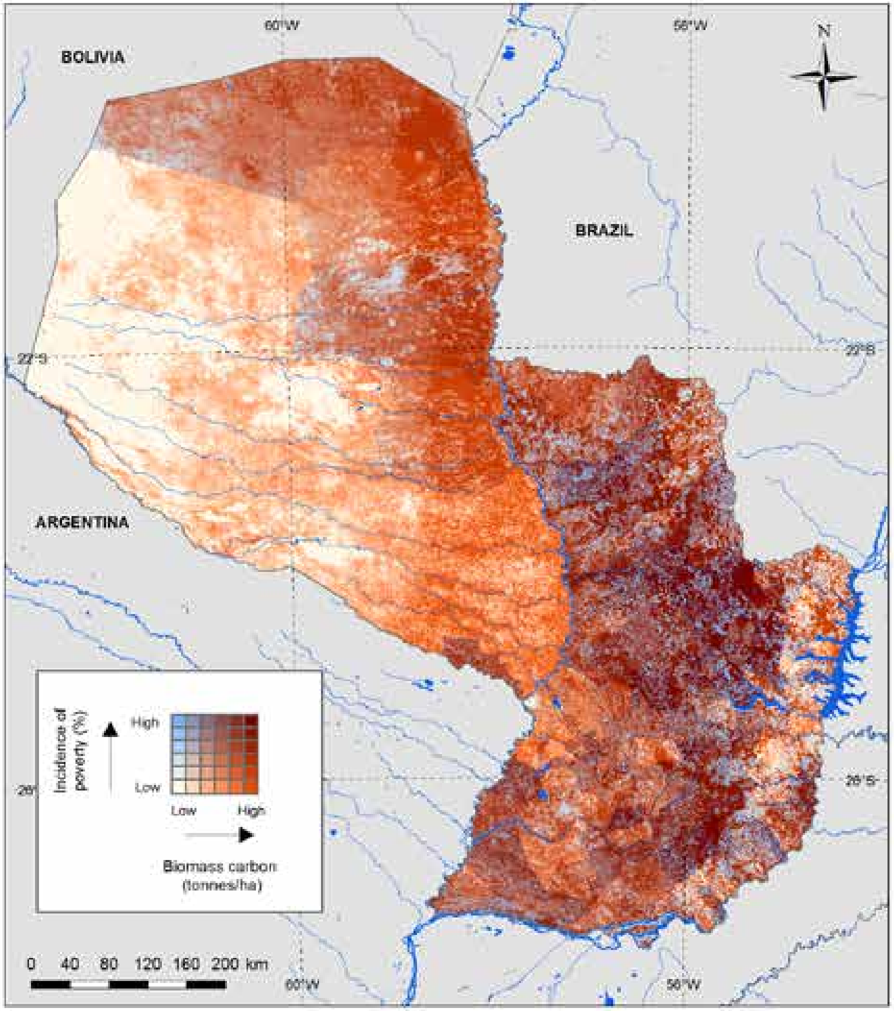
The sale of artisanal products such as decorated gourds contributes to the livelihood strategies of the Pai Tavyterá indigenous community.
Photo by Solar Map Project Paraguay https://flic.kr/p/drk8Sw (CC BY-NC-SA 2.0).

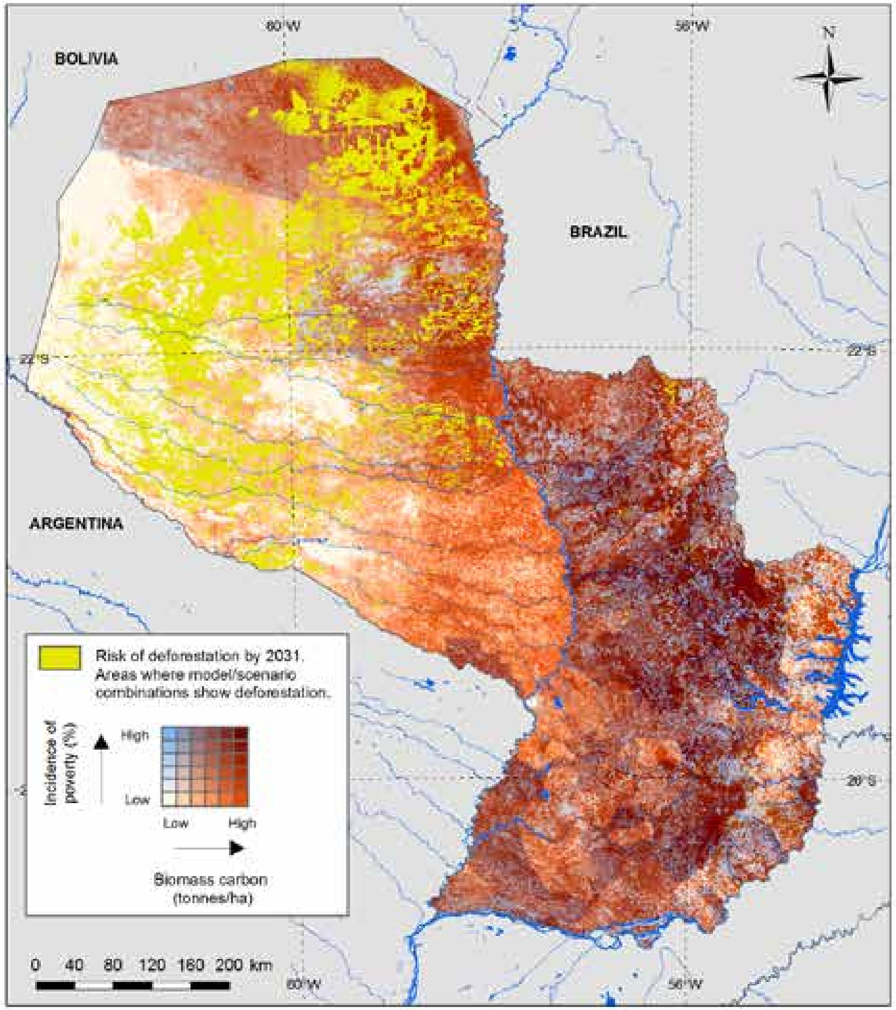
Map 16a: Incidence of poverty in relation to biomass carbon

REDD+ actions in areas of high poverty should be designed with particular care and attention to the needs of the poor, and the potential for both benefits and risks to local livelihoods. Dark brown on the map indicates areas high in carbon and high in poverty; blue shows areas low in carbon but high in poverty; and orange reflects areas high in carbon but low in poverty.

Map 16b: Incidence of poverty in relation to biomass carbon and deforestation risk

Here, areas with deforestation risk (in yellow, showing the results of all model/scenario combinations from Map 5), have been overlaid on the previous map, 16a. Together, these maps can identify areas where reducing deforestation may be a priority for addressing poverty through supporting livelihoods.





Method and data sources:
Map 16a: Biomass carbon: Saatchi, S. et al. (2011) "Benchmark map of forest carbon stocks in tropical regions across three continents", PNAS, 108, 24: 9899-904.
Poverty: Incidence of poverty (%) per municipality 2012. La Dirección General de Estadística, Encuestas y Censos (DGEEC).
Map 16b: Projected deforestation: CATIE (2014). Análisis de cambio de uso de la tierra (1990-2011) y formulación de escenarios de deforestación futura (2031) de los bosques del Paraguay. Turrialba, Costa Rica: CATIE. Deforestation probability is based on observed land-use change between 1990 and 2000, which was then validated for the 2000-2011 period (an off-sample approach).

Biomass carbon was divided into 6 quantile classes, and poverty data into 6 natural breaks classes. These were combined to produce a matrix of areas of high-low carbon and high-low poverty.

Map 16a shows the distribution of biomass carbon in relation to poverty in Paraguay. REDD+ efforts in areas of high poverty should be designed with particular care and attention to the needs of the poor. This map could be used to identify locations where it is particularly important to consider the impacts (both positive and negative) of REDD+ actions on livelihoods and poverty. Map 16b combines Map 16a with areas at risk of future deforestation (Map 5; CATIE 2014), to highlight areas where the retention of forests may be of critical importance for poor rural communities where food security and livelihoods depend to a great extent on forest resources. Both maps show the proportion of the population in poverty as a percentage of the total population within each municipality (Paraguay has 17 departments and 1 capital district, as well as 225 municipal governments).

5.1 Indigenous peoples and forests

The 2002 national indigenous census identified 20 groups of indigenous peoples, with 5 different language families, living mainly in 496 communities in Paraguay. Comprising approximately 2% of Paraguay's total population, with nearly equal numbers in the eastern and Chaco regions, indigenous peoples in Paraguay are about eight times more likely to live in poverty than the rest of the population, suffering high levels of unmet basic needs (UN 2009). An estimated 91,5% of Paraguay's nearly 110 000 indigenous peoples live in rural areas (DGEEC 2008), many of which have suffered or are at risk of deforestation and forest degradation (Altervida 2008). While indigenous peoples of the Chaco were traditionally able to adapt to periods of environmental stress or food shortages by moving into other areas, deforestation and the privatization of land have greatly limited their mobility (Global Forest Coalition 2014). REDD+ actions aimed at retaining forest or restoring forest cover in or near indigenous settlements may help to ensure food and livelihood security for indigenous peoples.

Information on the location of indigenous settlements in Paraguay, although partial, can be used to prioritize locations for the implementation of REDD+ actions that provide both livelihood benefits and continued access to forest resources for indigenous communities, and to ensure that indigenous peoples are consulted during the different phases of REDD+ planning and implementation. Based on data from the 2002 indigenous census (DGEEC 2002), which was validated in 2008, Map 17 shows indigenous settlements in Paraguay. As this information is based on surveys, and not on cadastral boundaries, it should not be used to reflect the legal borders of indigenous settlements; in addition, many indigenous settlements are located on land that does not yet have legal title, so are not shown here.

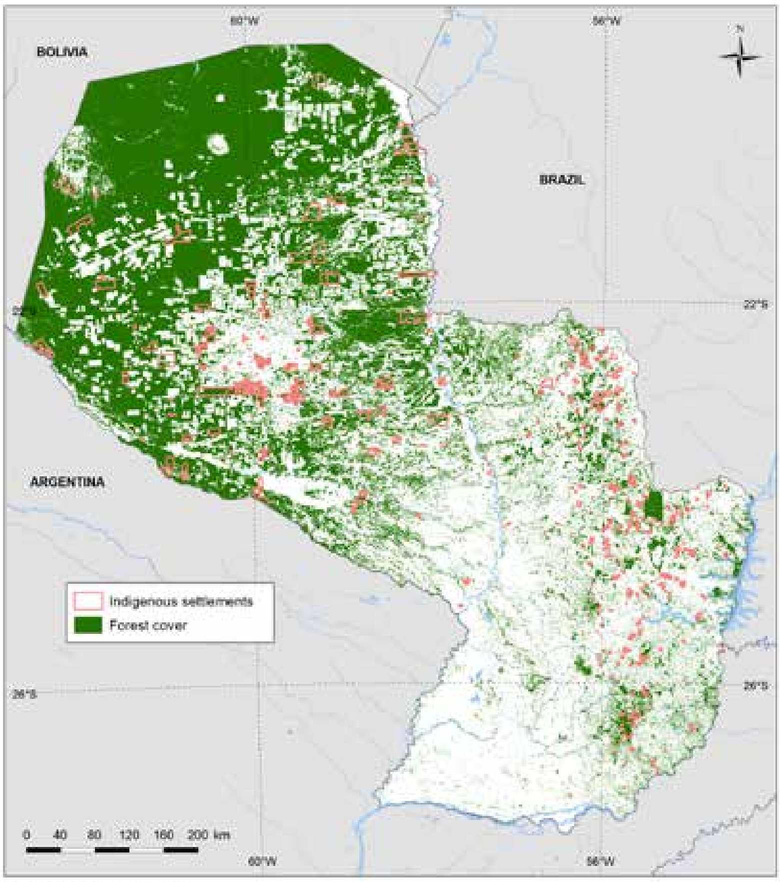
Although the national constitution is intended to guarantee that indigenous peoples have sufficient land to ensure they are able continue "their traditional way of life"[4], only 55% of Paraguay's indigenous communities have their own land, and the areas provided for indigenous settlements are usually insufficient for their intended purpose (IFAD 2012). There are also restrictions on what indigenous peoples can take from their land. Although much logging in indigenous settlements is selective, indigenous communities are often unable to access the legal documents needed to transport wood out of their communities, as required under the 1973 Forest Law. As a result, communities are left with the choice of selling wood below market prices, or bartering it (R-PIN 2008). Under Paraguayan wildlife law, indigenous peoples are only able to harvest wild flora and fauna using traditional methods, in order to meet their basic needs. This means that hunting is often done illegally, and brings in much lower prices than through legal sales (R-PIN 2008). Living in areas that are too small to sustain traditional livelihoods, with restrictive regulations on what can be taken from the land, indigenous peoples often face pressures to convert or lease out land for mechanized agriculture and logging (R-PIN 2008).

Remaining forest areas in Paraguay often are home to sites that are considered sacred to Paraguay's indigenous peoples; the beliefs of the Paĩ Tavyterã culture centre around particular sacred mountains and hills, while the Mbya revere a sacred site in each community, called the "Opy", which is used for daily prayers. As further spatial information becomes available on the location of sacred sites in Paraguay (the preservation of which was considered a high priority during stakeholder consultations), this could be used to further prioritize areas for the implementation of REDD+ actions that maintain forest linked with sacred sites and cultural values. The objectives would be to maintain forest in forested areas, and avoid afforestation in areas near sacred sites that have a more open landscape.

[4] Paraguay's 1981 Indigenous Law established each family's right to receive, as a minimum, 20 ha of land in the Eastern region or 100 ha in the Chaco.

The seeds of the achiote (*Bixa Orellana*) tree are used by some indigenous communities in Paraguay for natural make-up and in rituals. *Photo by Solar Map Project Paraguay https://flic.kr/p/drjXJc (CC BY-NC-SA 2.0).*

Map 17: Indigenous settlements and forest cover



Method and data sources:
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.
Indigenous settlements: DGEEC 2002.

Spatial information on the distribution of indigenous communities in Paraguay may help to target REDD+ actions that provide both livelihood benefits and continued access to forest resources for indigenous communities. It may also highlight areas where the interests of indigenous peoples are affected by decisions being made about REDD+, which could enable greater involvement of indigenous peoples in management of land.

5.2 Non-timber forest products

Non-timber forest products, which may include foods, medicines, fibres and fuel, form part of livelihood strategies for forest-dependent communities in Paraguay, and have both subsistence and commercial value. Approximately 95% of indigenous peoples in Paraguay depend on forest products for their food supply (R-PIN 2008). Forest foods often help to ensure food security for forest-dependent communities, increasing the nutritional quality of rural diets and supplementing other sources of food (FAO 1992). The collection of food from dry forests can also be very important when other sources of food fail (FAO 2014); the nutritional intake of people who live near dry forests is thought to be affected by the nutritional diversity of wild foods available (Blackie et al. 2014).

A number of indigenous communities in Paraguay selectively harvest wood to make artisanal products for sale in market cities, and have explored options for the sustainable harvesting of traditional forest resources such as yerba mate for commercial use. However, detailed information on the financial contributions of non-timber forest products to indigenous and other local livelihoods in Paraguay is not currently available.

Forests in Paraguay also provide traditional medicinal remedies; protecting the availability of medicinal plants was identified as a priority benefit of REDD+ during national stakeholder consultations in Paraguay. Medicinal plants are often used as alternatives to conventional medicine, particularly in rural communities, but are also used more widely throughout Paraguay for daily healthcare needs. A large portion of Paraguay's population takes medicinal plants with their daily tea or tereré (e.g. Burrito (*Aloysia polystachya*) or Cola de Caballo (*Equisetum giganteum*)) (MAG 2009; Acosta 2007).

In addition to subsistence use, a proportion of medicinal plants are extracted for commercial ends by poorer households (MAG 2009). As the production and cultivation of medicinal and aromatic plants in Paraguay is still an under-developed industry, demand is often met through wild harvest, putting some medicinal plants in danger of extinction (MAG 2009). The expansion of cultivation, which could alleviate demand on natural forests and

Samu'u (*Ceiba chodatii*), a tree characteristic of the Chaco region, is used by some indigenous groups to make canoes, crafts, ropes and dye. *Photo by Andrea Ferreira https://flic.kr/p/fHz3SC (CC BY-NC-ND 2.0).*

The sustainable production of yerba mate (*Ilex paraguariensis*) may offer livelihood opportunities for forest-dependent communities. *Photo by Llosuna http://commons.wikimedia.org/wiki/Ilex_paraguariensis#mediaviewer/File:Yerba_Mate.jpg (CC-BY-SA 3.0).*

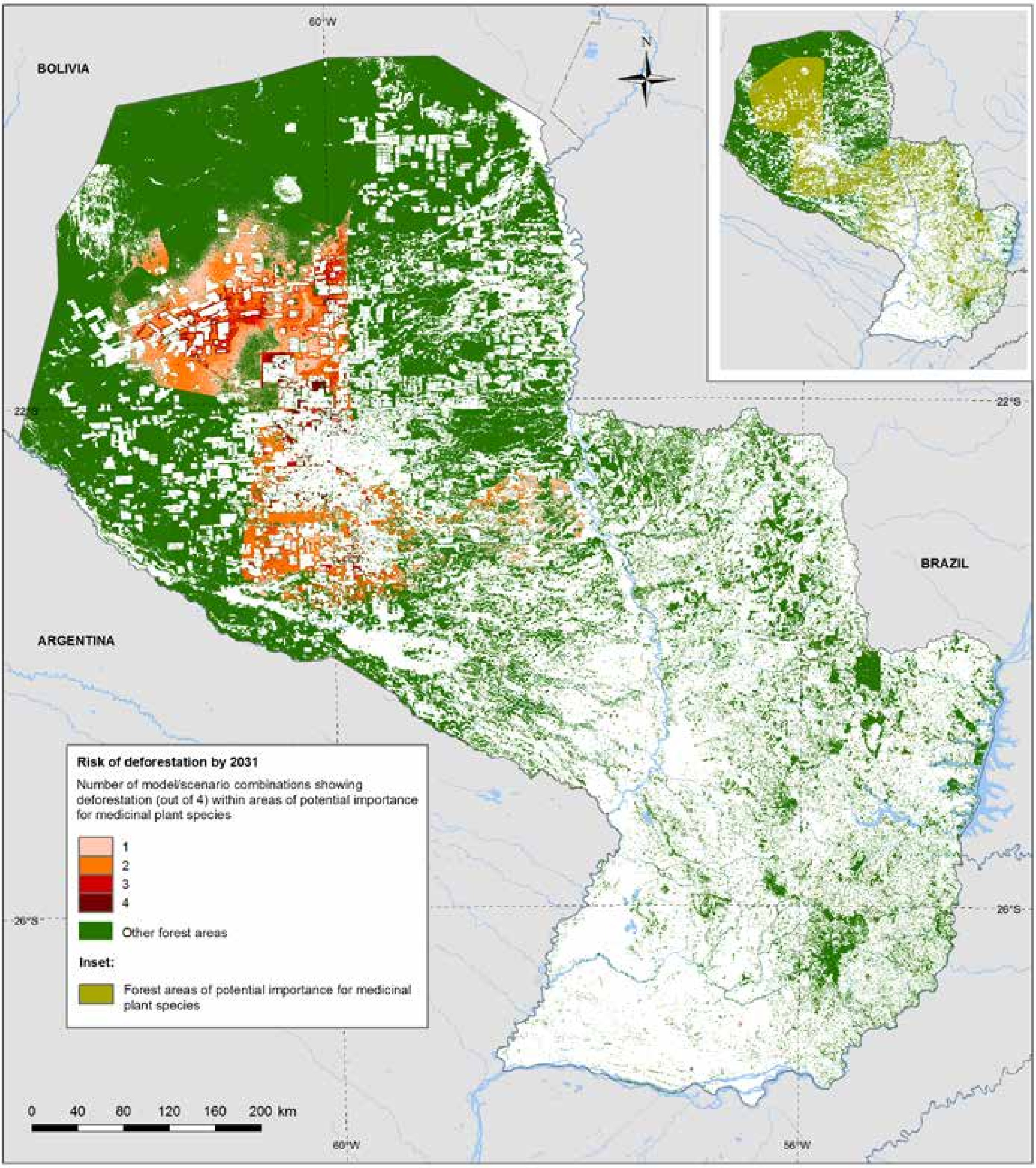
contribute to alternative livelihoods strategies for local communities, is hampered by lack of training and technical assistance (USAID 2010). An inventory of nationally useful or marketable plant species for food, medicine, construction and other uses may help to address issues related to unsustainable extraction (Mereles 2007).

Using historical specimen locality records from the Missouri Botanical Garden Database (MOBOT), Map 18 shows the potential distribution of 9 medicinal plant species found in forests, that are also listed as being of commercial importance in the markets of Asunción and Gran Asunción (Basualdo et al. 2004), located in areas with deforestation risk (Map 5; CATIE 2014) (Annex IV provides additional methodological detail). This information could be used to prioritize areas and approaches for REDD+ implementation that maintain or increase the availability of medicinal plants in areas at risk of deforestation, both for local use and commercialization (including in developing new pharmaceutical products), with a particular focus on sustainable extraction.

Natural resin from the trunk of the *Protium heptaphyllum* tree is traditionally used for the treatment of inflammatory conditions and to speed the healing of wounds. *Photo by João Medeiros https://flic.kr/p/8fv6Rg (CC BY 2.0).*

Map 18: Medicinal plants at risk of future deforestation

This map shows the potential distribution of nine medicinal plant species found in forests, that are also listed as being of commercial importance in the markets of Asunción and Gran Asunción (Basualdo et al. 2004), located in areas at risk of future deforestation (Map 5; CATIE 2014). The lightest shading indicates that that only one of the model and scenario combinations used projects deforestation, while the darkest shading, most of which is located in the Chaco Seco, indicates that all four possible model and scenario combinations project deforestation. This information could be used to prioritize REDD+ actions that maintain or increase the availability of medicinal plants, both for subsistence and commercial use.



Method and data sources:
Projected deforestation: CATIE (2014). Análisis de cambio de uso de la tierra (1990-2011) y formulación de escenarios de deforestación futura (2031) de los bosques del Paraguay. Turrialba, Costa Rica: CATIE. Deforestation probability is based on observed land-use change between 1990 and 2000, which was then validated for the 2000-2011 period (an off-sample approach).
Medicinal plant species: Based on locality records from the Missouri Botanical Garden Database (MOBOT, http://www.tropicos.org/) the potential distribution of 9 forest medicinal plant species that are also listed as being of commercial importance in the markets of Asunción and Gran Asunción was mapped. Locality records within 1.45 decimal degrees were aggregated and the resulting polygon smoothed. This was then clipped to current forest cover, to show where areas that may support these species could exist. Species are: *1. Aspidosperma quebracho-blanco; 2. Croton urucurana; 3. Caesalpinia paraguariensis; 4. Erythrina crista-galli; 5. Peltophorum dubium; 6. Prosopis ruscifolia; 7. Protium heptaphyllum; 8. Sapium haematospermum; 9. Tabebuia impetiginosa.*
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.

6. Forest restoration opportunities

As discussed in previous sections, in addition to losing nearly one-quarter of its forest cover between 1990 and 2011 (PNC ONU-REDD+ 2011; R-PP 2014), large areas of forest in Paraguay have been degraded through agricultural expansion, biomass extraction, unsustainable logging and fires. REDD+ actions to enhance forest carbon stocks through forest restoration were considered high priorities by national stakeholders during 2011, 2013 and 2014 UN-REDD workshops in Paraguay. Restoration is also a national policy objective: Paraguay's Five-Year Climate Change Plan 2008-2012 included a goal to support the natural regeneration of forests in 10% of Paraguay's land area (SEAM 2008). In addition to REDD+, other international processes have also focused attention on restoration opportunities. The Convention on Biological Diversity's Aichi Biodiversity Target 15 states that "By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks have been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification." The Bonn Challenge set the goal of restoring 150 million hectares of degraded and deforested lands by 2020.

Forest landscape restoration, a long-term process of regaining ecological integrity and enhancing human well-being in degraded and deforested landscapes (IUCN 2014), not only contributes to climate change mitigation goals by sequestering carbon with restored forest and other trees, but may also support livelihoods and biodiversity through the supply of potable water; the reduction of soil erosion; support for wildlife habitats; and the provision of (timber and non-timber) forest products (GPFLR 2011). Restoration and afforestation may involve either 'passive' (natural regeneration of secondary forests with minimal human input) or 'active' (which involves planting trees or seeding to expand forest cover on non-forest, deforested or degraded land) approaches (Kapos et al. 2012). The impact of restoration or afforestation techniques on both carbon and biodiversity will vary according to site conditions, local ecology and overall REDD+ objectives (Kapos et al. 2012).

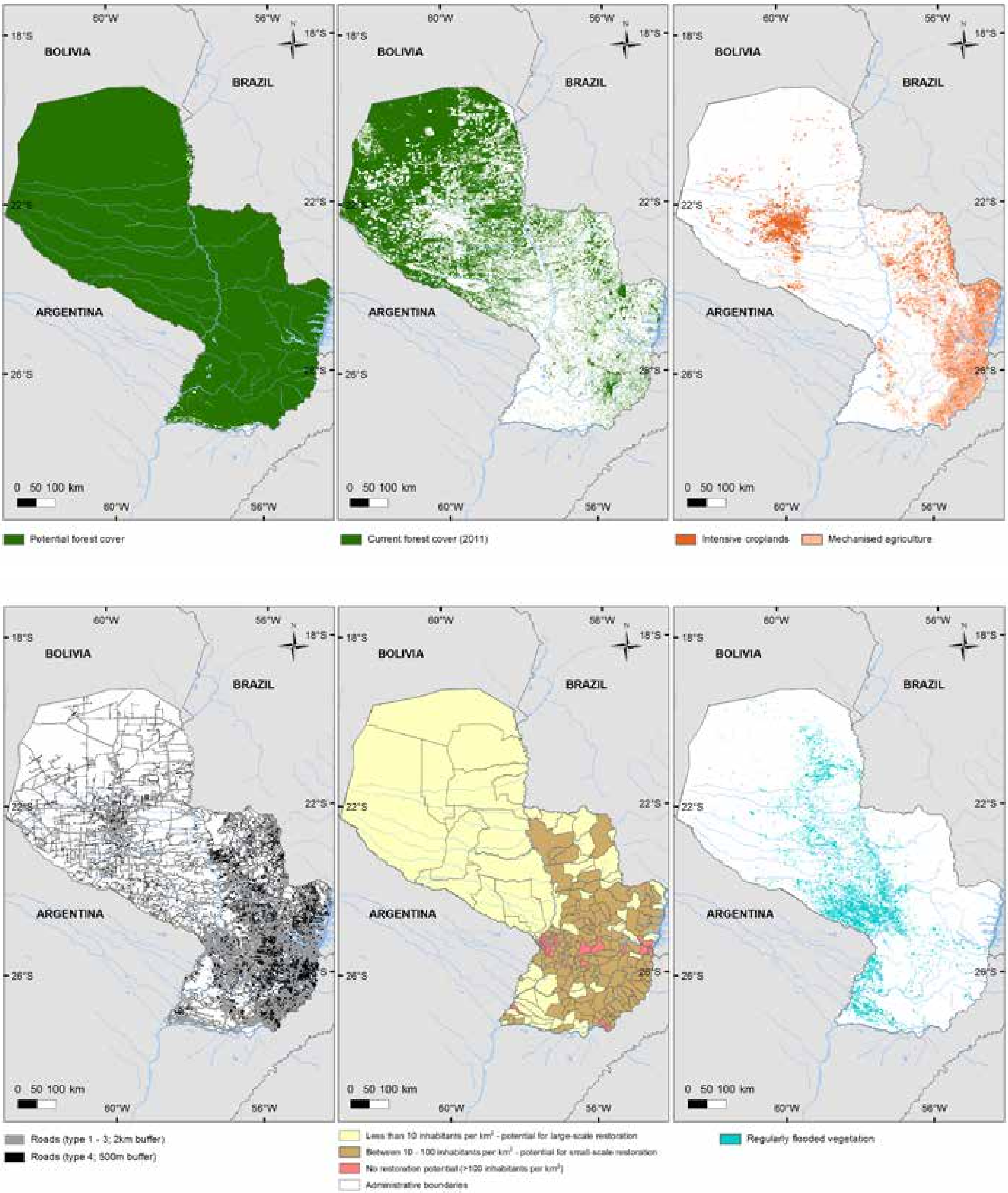
REDD+ actions in Paraguay which provide opportunities to turn deforested and degraded land into carbon sinks could therefore help to achieve national objectives, and may offer opportunities to secure environmental benefits and improve livelihoods. However, these actions also have potential risks. Reforestation or forest plantation projects may offer perverse incentives to designate forested areas as degraded as a precursor to clearing and planting the land, causing loss of primary forest and biodiversity in the process (Barr and Sayer 2012). There is also a risk that for restoration purposes governments may assert control over forest landscapes currently managed by local communities with traditional tenure systems. Clarification of land tenure, as well as respect for the Cancun safeguards, will help ensure that REDD+ financing is restricted to projects that do not lead to the loss of natural forest cover, and may contribute to the structuring of restoration initiatives in ways that support local livelihoods, with participation from local and indigenous communities, and with adequate benefits-sharing mechanisms (Barr and Sayer 2012).

There are a number of approaches available to identify and prioritize areas that are suitable for forest restoration. Planning methods that use national datasets to the greatest extent possible, and include national consultation on the development of criteria and thresholds to identify areas appropriate for restoration, will produce the most nationally useful and relevant results. IUCN's Restoration Opportunities Assessment Methodology (ROAM) offers a methodology to identify and map restoration opportunities, and to help determine which degraded landscapes offer the most value to society when restored. The World Resources Institute (WRI) has developed a methodology that takes account of human pressures to assess where opportunities remain to restore forest. Here, we identify restoration potential by comparing a global map of original forest extent (WRI 2011) to current forest cover in Paraguay (PNC ONU-REDD+ Paraguay 2011), taking account of areas where restoration is less likely to be suitable or successful, based on the following factors:

- **Land use:** Areas with intensive agriculture (Pittman et al. 2010) and mechanized agriculture (from a PNC ONU-REDD+ derived map of 2011 land use in Paraguay) have been excluded. While croplands and pasture are not likely to offer extensive restoration opportunities, the strategic planting of trees in these areas could enhance agricultural productivity and other ecosystem functions (WRI 2011). Agroforestry, the planting of trees in agricultural landscapes, may provide ecosystem benefits, such as improved soil fertility, conservation of soil moisture and increased food production (GPFLR 2011), as well as potential benefits for biodiversity, as living fences and dispersed trees may provide important habitats or biological corridors to different groups of animals (Harvey et al. 2008), while sustaining rural livelihoods.

Map 19: Methodology: potential forest restoration opportunities

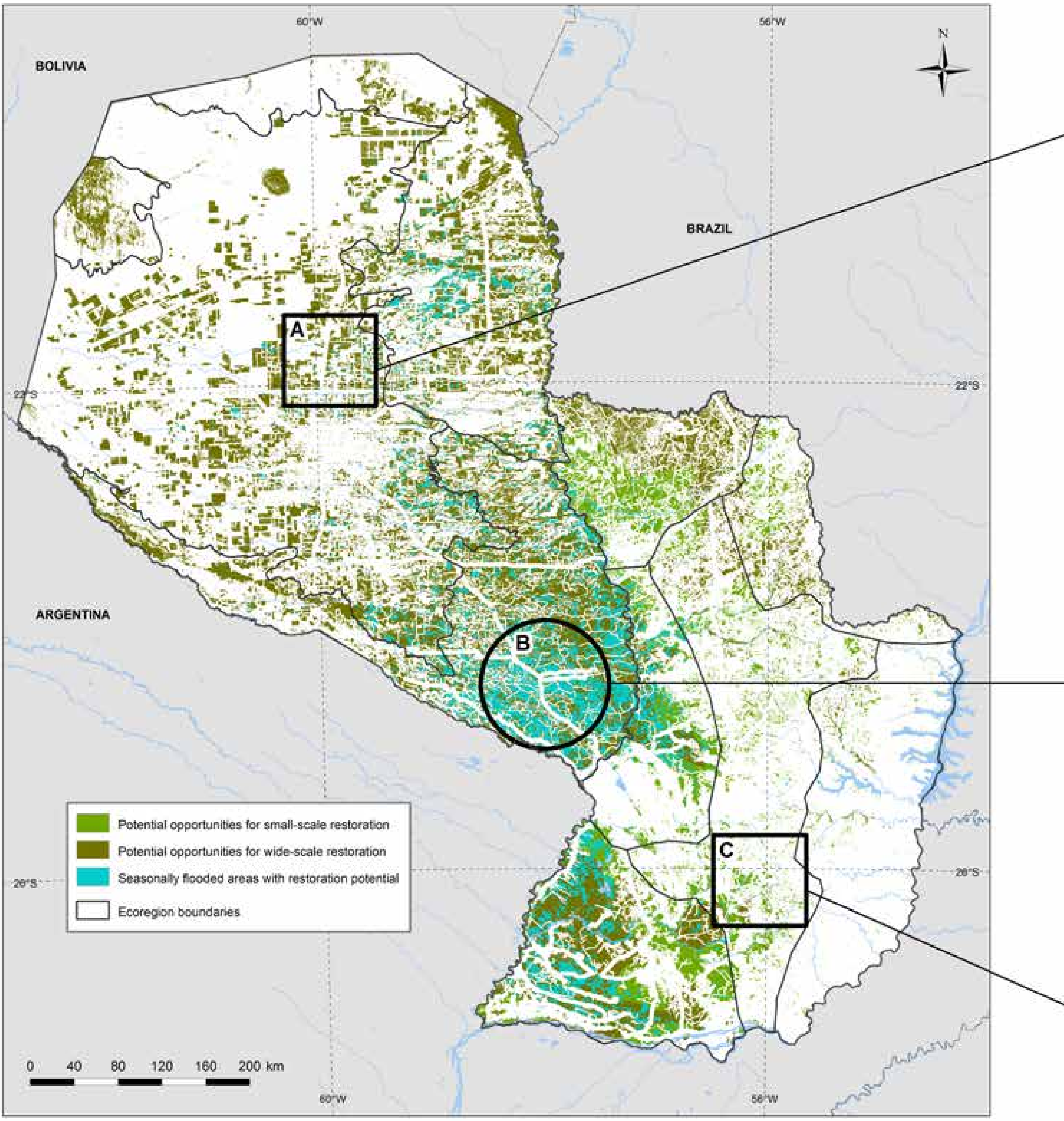
These input layers have been used to develop the map of potential forest restoration opportunities in Paraguay.



Method and data sources: Potential forest cover: Potapov, P., Laestadius, L., and Minnemeyer., S. (2011) Global map of forest cover and condition. World Resources Institute: Washington, DC. Available online: www.wri.org/forest-restoration-atlas. **Current forest cover (2011):** PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+. **Intensive croplands:** Pittman, K., Hansen, M.C., Becker-Reshef, I., Potapov, P., Justice, C.O. (2010) Estimating Global Cropland Extent with Multi-year MODIS Data. Remote Sensing. 2010, 2, (7), 1844-1863; doi:10.3390/rs2071844. http://www.mdpi.com/2072-4292/2/7/1844. **Mechanised agriculture:** Paraguay land-use map 2011. Agencias Cooperantes: Programa Nacional Conjunto ONU-REDD. **Roads:** Dirección General de Estadísticas Encuestas y Censos (DGEEC) 2012. Areas within 2 km of a type 1-3 road, and within 500 m of a type 4 road were not considered to have restoration potential. **Population:** Dirección General de Estadísticas Encuestas y Censos (DGEEC) Paraguay. Cartografía Censal Censo Población y Vivienda 2013. Areas with between 10 - 100 inhabitants per km² were considered to have potential opportunities for smallscale restoration. Areas with less than 10 inhabitants per km² were considered to have potential opportunities for large-scale restoration. Areas with greater than 100 inhabitants per km² were not considered to have potential for restoration. **Regularly flooded shrub and herbaceous cover:** GLC 2000. Global Land Cover 2000 Project. The analysis also takes account of areas that are prone to seasonal flooding. While there is restoration potential in these areas, inundation and water stress may be limiting factors for forest growth.

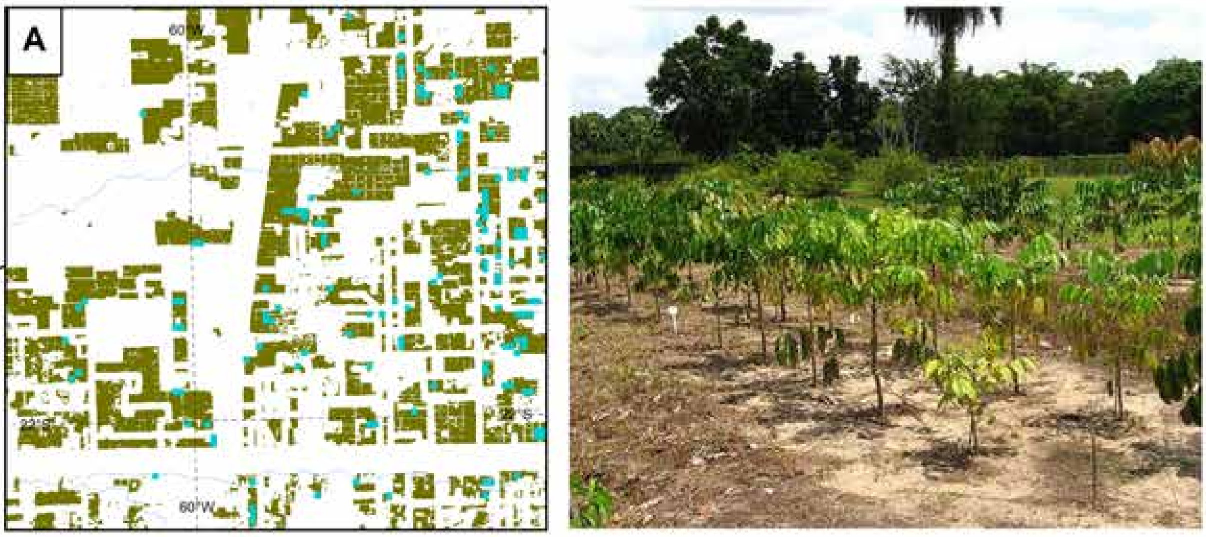
Map 20: Potential forest restoration opportunities

This map shows potential restoration opportunities in Paraguay, highlighting areas that may be suitable for wide- or small-scale restoration, and as well as seasonally flooded areas with restoration potential. It is important to note that the original vegetation of some of the areas considered potentially suitable for restoration may not have been forested, or may have been forest mixed with other ecosystems. Therefore, while there may be restoration potential in these areas, the objective may not necessarily be to restore closed forest, but rather to restore mosaic or open canopy ecosystems.

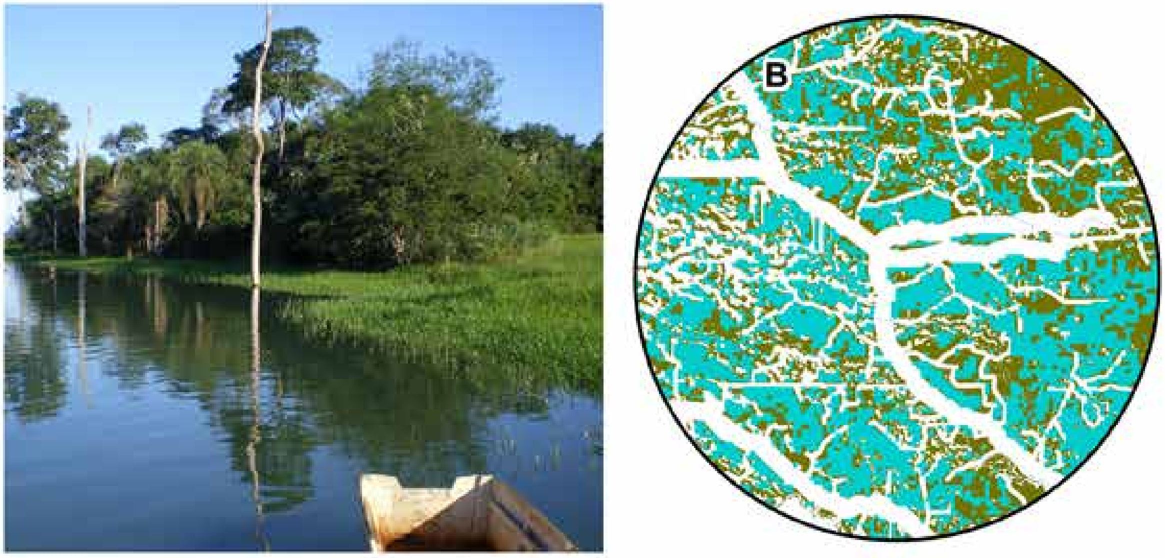


Method and data sources: For methodology and input layers please see Map 19.
Ecoregions: La Secretaría del Ambiente (SEAM) Paraguay, 2013.

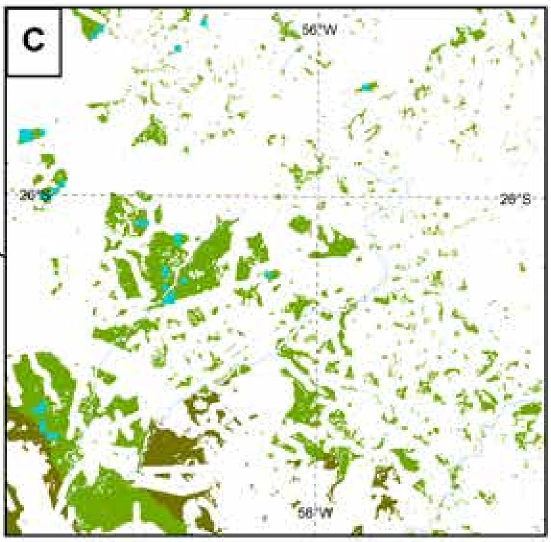
a. Photo by Mauro Guanandi http://commons.wikimedia.org/wiki/File:Bacurizal.jpg (CC-BY-SA 3.0).
b. Photo by Hugo Diaz Lavigne http://es.wikipedia.org/wiki/Ecorregiones_de_Paraguay#mediaviewer/Archivo:LIMOY_4.png (CC-BY-SA 3.0).
c. Photo by Peer V http://commons.wikimedia.org/wiki/Gran_Chaco#mediaviewer/File:ParaguayChaco_acaballo.jpg (CC-BY-SA 3.0).



(A) Wide-scale restoration opportunities may be present on land that is not densely populated (with less than 10 inhabitants per km²), where there are likely to be fewer demands on specific areas of land.



(B) While seasonal flooding may limit potential for forest growth, opportunities for restoration could be explored in these areas.



(C) While areas with higher population density (between 10-100 inhabitants per km²) and areas with croplands and pasture may not offer extensive restoration opportunities, small-scale or mosaic restoration may be possible, and could enhance agricultural productivity and other ecosystem functions (WRI 2011).

- **Human pressures:** Population thresholds have been used to distinguish between different types of restoration opportunities that may be available in Paraguay, as well as where restoration is unlikely to be feasible due to population pressures. Areas with a population density of 10 or less people per km² are considered as offering potential opportunities for wide-scale ecosystem restoration, as there are likely to be fewer demands on specific pieces of land. Areas with between 10-100 inhabitants per km² may offer opportunities for smaller scale, mosaic restoration of ecosystems, as well as benefits related to enhanced carbon stocks and biodiversity. However, these areas may present more difficulties for restoration in terms of land tenure and competing uses of land. While areas with more than 100 inhabitants per km² were not considered suitable for restoration, the planting of trees in densely populated rural areas may contribute to the healthy functioning of ecosystems.

- **Proximity to roads:** Areas with easy access to roads are more likely to be suitable for production and settlement, and less likely to be available for restoration. A 2 km buffer was applied to major roads (types 1, 2 and 3), and a 500 m buffer was applied to smaller roads (type 4) (DGEEC 2012), to remove these areas from consideration. While proximity to roads may impede forest recovery (Lugo 2002; Pfaff et al. 2007; Crk et al. 2009), it may also facilitate the access necessary to implement active forest restoration efforts.

This analysis also distinguishes areas that are prone to seasonal flooding, where potential opportunities for forest restoration, for environmental and/or economic goals, could be investigated and validated, depending on conditions and circumstances on the ground. While there may be restoration potential in these areas, inundation during the rainy season and water-stress during the dry season are limiting factors for forest growth (McClain 2002). Map 20 shows areas that may offer potential opportunities for forest restoration in Paraguay (Map 19 shows the input layers for this map).

It is important to note that the global map of original forest cover for Paraguay (WRI 2011) likely shows an overestimate of areas that could be returned to forest. The original vegetation of some of the areas considered potentially suitable for restoration may not have been forested, or may have been forest mixed with other ecosystems. Therefore, while there may be restoration potential in these areas, the objective may not necessarily be to restore closed forest, but rather to restore mosaic or open canopy ecosystems. Further investigation of the original natural vegetation of the area and consultation with national experts and stakeholders, as well as validation on the ground, are necessary to plan concrete restoration actions (development of a national map of original vegetation would also help to refine this analysis).

The incorporation of local knowledge and restoration practices, particularly those with proven success in certain regions, may have a fundamental role in developing more effective methods to restore biodiversity and ecosystem functions of forests. These approaches are also more likely to be compatible with sustainable local livelihoods (Chazdon 2014).

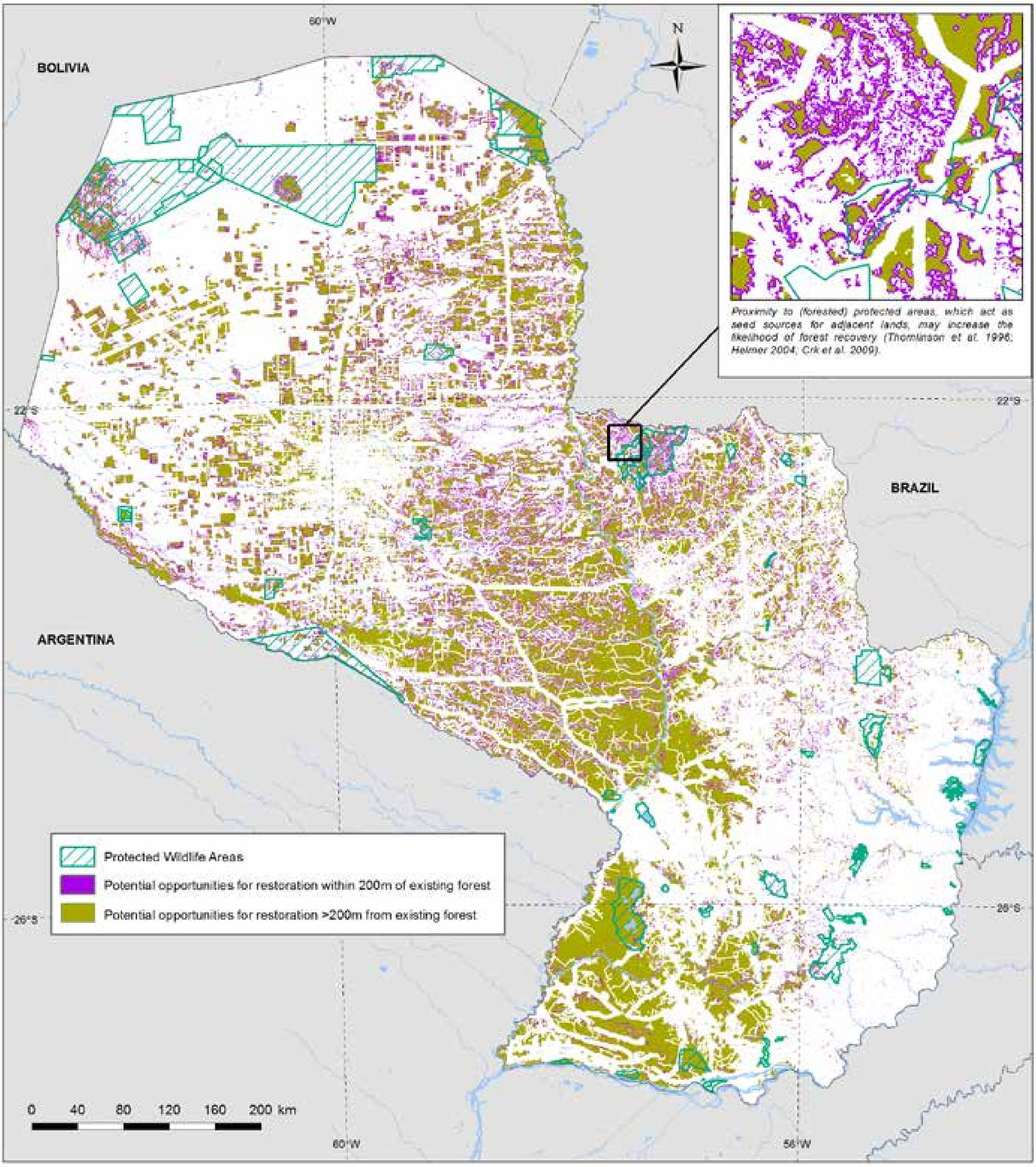
Consideration of conditions that contribute to the likelihood of successful restoration may also help to identify suitable areas. Areas far from seed sources or which have been heavily disturbed for extended periods of time are far less likely to recover naturally than other areas. Indeed, distance from existing forest and from protected areas has been found to be relevant when considering where restoration efforts are most likely to succeed. A study of forest restoration in Puerto Rico (Crk et al. 2009) found that the percentage of forest within a 100 m radius of a given point had a positive effect on forest recovery, indicating the role of existing forest in promoting forest recovery. Proximity to (forested) protected areas, which act as seed sources for adjacent lands, may also increase the likelihood of forest recovery (Thomlinson et al. 1996; Helmer 2004; Crk et al. 2009). Map 21 shows forest restoration opportunities in relation to existing forest and protected areas, possibly indicating where forest restoration efforts could be most successful.

In addition to considering where restoration is more likely to be successful, REDD+ actions aimed at restoring forests in areas that provide additional social or environmental benefits, may make the best use of limited resources. Additional benefits that could be provided by restoration in Paraguay were identified and prioritized through a process of national consultation, and mapped collaboratively during the 2014 joint working session with SEAM, INFONA and UNA. The benefits identified were potential of restored forest to support livelihoods (using poverty data from Map 16a), to conserve and enhance biodiversity (using information on threatened richness of species found in forest habitats, as in Map 9), and to provide soil erosion control (Map 12). As Map 22a shows, restoration in parts of the Pantanal, Aquidabán and Ñeembucú ecoregions may also provide benefits for livelihoods, biodiversity and soil erosion control (Annex V provides further methodological detail).

Map 22b shows biodiversity benefits of areas with

Map 21: Potential forest restoration opportunities and proximity to existing forest and protected areas

Proximity to existing forest and protected areas has been found to have a positive effect on forest recovery, possibly indicating where restoration efforts could be most successful. Protected areas (Map 8) are indicated with green hashed lines, while areas with potential restoration opportunities (Map 20) located within 200 m of existing forest are shown in purple.

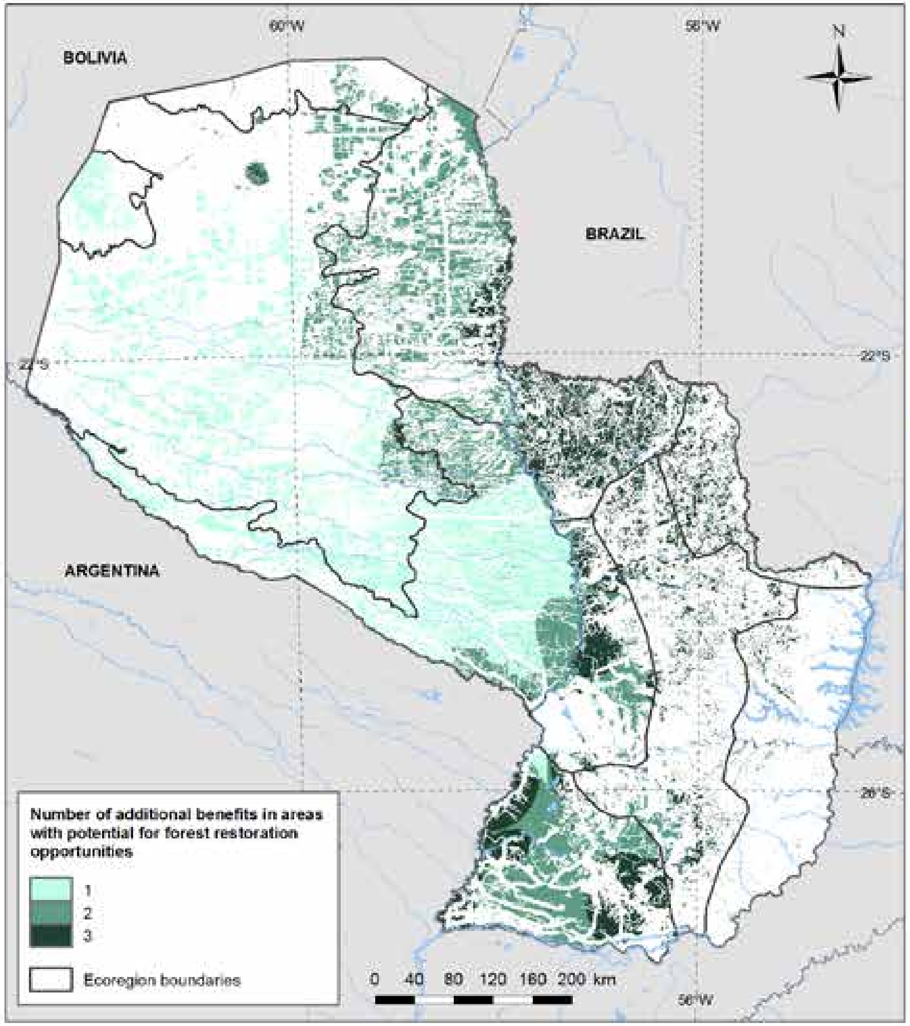


Method and data sources:
Forest restoration potential: See Map 20.
Forest cover: PNC ONU-REDD+ Paraguay (2011). Mapa de bosque/no bosque. Inventario Forestal Nacional. Asunción, Paraguay: PNC ONU-REDD+.
Protected Wildlife Areas: Dirección General de Protección y Conservación de la Biodiversidad de la Secretaría del Ambiente (SEAM) 2011

A 200m buffer was applied to existing forest cover. Areas of potential restoration opportunities falling within this zone have been highlighted on the map.

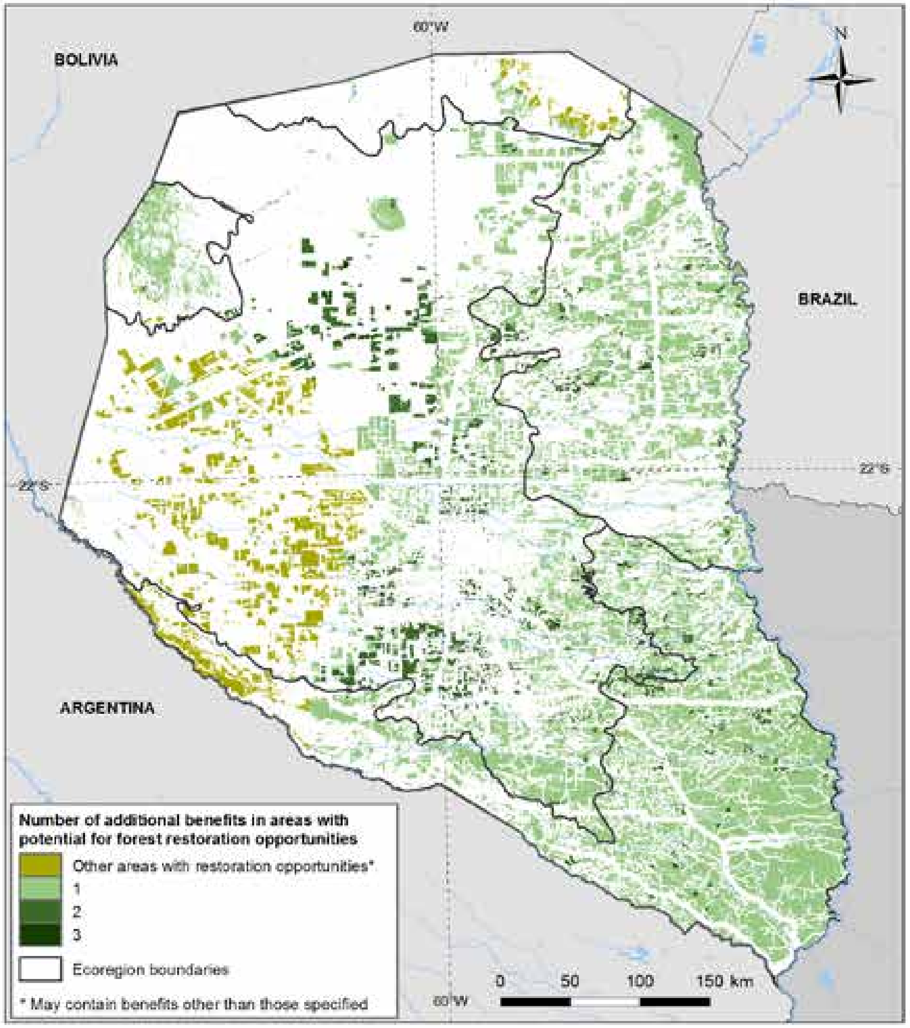
Map 22a: Multiple benefits in areas with potential forest restoration opportunities

Using Map 20 as a basis, this map shows areas with potential to provide additional benefits through the restoration of forest cover. The benefits considered are the potential of restored forest to support livelihoods; to conserve and enhance biodiversity; and to control soil erosion. Darker shading indicates areas important for a higher number of these benefits.



Map 22b: Multiple biodiversity benefits in areas with potential forest restoration opportunities in the Chaco region

This map shows areas with potential to provide additional biodiversity benefits in the Chaco region through the restoration of forest cover. It combines priority sites for endemic species (plants, amphibians, mammals and birds); areas considered to be of value for diversity of the habitat; fragile ecosystems; and biodiversity corridors of the Chaco (GEF 2003). Darker shading indicates areas important for a higher number of these benefits.



Method and data sources:

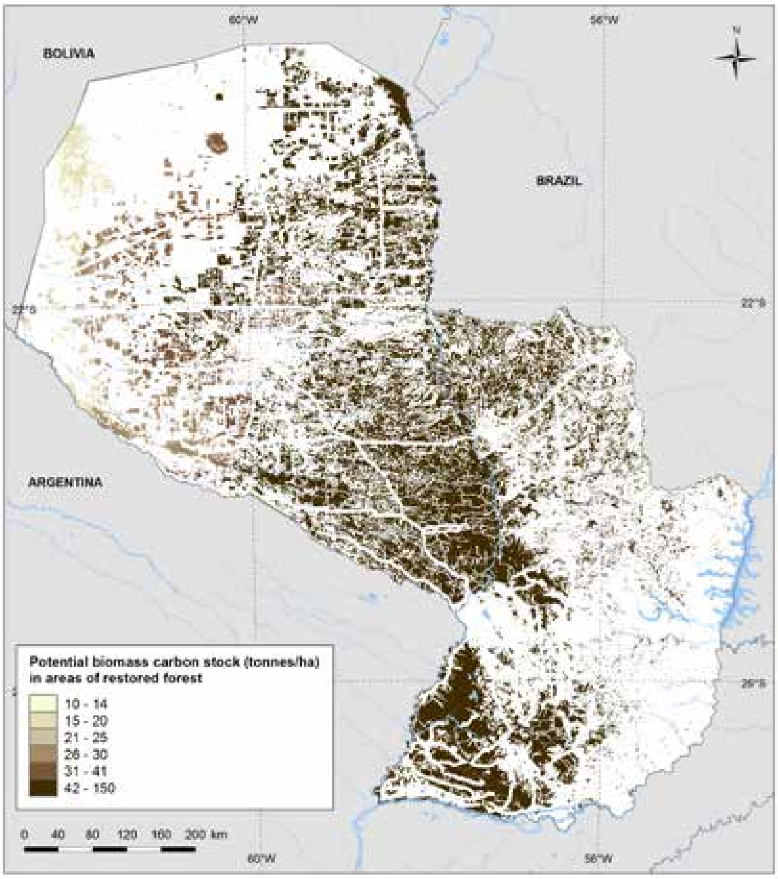
Map 22a: Forest restoration potential: See Map 20. **Poverty:** Areas with >15% of the population living in poverty have been included in this map. Incidence of poverty (%) per municipality 2012. La Dirección General de Estadística, Encuestas y Censos (DGEEC). **Threatened forest species:** See Map 9. All areas of potential importance for threatened forest species (between 4 and 18 species) have been included in this map. **Soil erosion:** See Map 12. The top four classes from Map 12 have been used to identify areas of greatest importance here. **Ecoregions:** See Map 4.
The above benefits were reclassified and summed to show areas where there is high potential to provide additional benefits through the restoration of forest cover (maximum 3 benefits). Other benefits aside from those specified may also be present.

Map 22b: Forest restoration potential: See Map 20. **Fragile ecosystems; Priority sites for endemic species; Habitat diversity; Biodiversity corridors:** See Map 14A. Sites classed as Moderate to Very high importance for these parameters have been included in this map to represent areas of greatest importance. **Ecoregions:** See Map 4.
The above benefits were reclassified and summed to show areas where there is high potential to provide additional benefits through the restoration of forest cover. Nb. That although 4 benefits have been summed, there are no areas where all 4 coincide in this map, therefore the top score for an area is 3.

potential forest restoration opportunities in the Chaco region. Using Map 20 as a basis, this map combines priority sites (those categorized as moderate to very high) for endemic species (plants, amphibians, mammals and birds); areas considered to be of value for diversity of the habitat; fragile ecosystems; and biodiversity corridors of the Chaco (GEF 2003). Several areas in the Chaco Seco are highlighted as offering restoration opportunities, as well as multiple benefits for biodiversity.

Forest restoration can result in increased carbon stocks, the potential for which will vary according to biophysical conditions and type and scale of restoration implemented. A process-based model has been used to predict carbon flows between leaves, stems, roots and soil pools to assess potential carbon stocks held in undisturbed vegetation with around 70% accuracy when assessed at global scales (Smith et al. 2013). Combining data on potential terrestrial biomass carbon derived from this model for Paraguay with information on forest restoration opportunities (Map 20), Map 23 shows potential biomass carbon stocks in areas of restored forest (subject to the approaches used).

Map 23: Potential biomass carbon stock in areas with potential forest restoration opportunities



Method and data sources:
Terrestrial carbon potential:
Smith, M, D.W. Purves, M.C. Vanderwel, V. Lyutsarev and S. Emmott. The climate dependence of the terrestrial carbon cycle, including parameter and structural uncertainties, Biogeosciences, vol. 10 (2013). Copyright Computational Science Laboratory of Microsoft Research 2014.
http://research.microsoft.com/en-us/um/cambridge/groups/science/tools/msrtcm/default.htm

Data on terrestrial carbon potential of vegetation has been clipped to areas of potential opportunities for restoration, as presented in Map 20, to show where forest restoration may provide the greatest carbon benefits.

Combining data on potential terrestrial biomass carbon, derived from a model that has been used to assess potential carbon stocks held in undisturbed vegetation (Smith et al. 2013), with information on forest restoration opportunities (Map 20), this map shows potential biomass carbon stocks in areas of restored forest (subject to the approaches used).

7. Conclusions and outlook

This report shows how spatial analyses can help support land-use planning for REDD+ in Paraguay. The maps presented here are a way of making information available to planners and decision-makers on locations where REDD+ actions may have the potential to achieve additional social and environmental benefits, as well as where REDD+ actions need to take account of potential risks. These may be important inputs for a national REDD+ strategy, as well as for the development of approaches to ensure that REDD+ plans take account of the Cancun safeguards. The benefits examined in this report reflect priorities identified by national stakeholders in Paraguay, and include the role of forests in storing carbon, supporting biodiversity, protecting soil and providing cultural, social and livelihood benefits for indigenous and forest-dependent communities.

Forest restoration has the potential to enhance forest carbon stocks, which will vary according to the type and scale of restoration implemented. *© Shutterstock.*

Areas with potential to deliver multiple social and environmental benefits from REDD+ actions, both nationally as well as for the Chaco region specifically, as well as those under pressure from deforestation, are identified.

As more and better data become available, the spatial analyses presented here should be updated and extended accordingly to provide better support for planning, including at sub-national scales. Maps addressing similar questions could be developed for ecoregion-scale planning and decision-making, depending on the availability of appropriate data. Further spatial information on sacred sites and forest-related employment opportunities, for example, would help to extend the analysis of forest values. Information on the extent and location of forest degradation, in addition to the effects of degradation on ecosystem services, could help decision makers to develop policies and implement plans related to forest management, restoration of degraded forests and payment for environmental services mechanisms (FAO 2011). Spatial information on forest designation, existing community-based forest management measures and timber yields could also help assess the potential for other REDD+ activities, such as the sustainable management of forests.

In addition to social and environmental benefits and risks, an important criterion in REDD+ planning in Paraguay will be the relative costs of different actions. Information on the implementation costs of REDD+ actions, in combination with spatial information on the distribution of benefits and risks, can help decision-makers to more thoroughly assess where to locate REDD+ actions (World Bank 2011). Related work on opportunity costs in Paraguay (Ruíz Díaz 2014) has sought to provide the information necessary for an overview of land value in Paraguay in order to help consider potential gains from REDD+ actions in relation to the costs of REDD+. The development of decision-support tools that combine spatial analyses identifying areas important for multiple benefits with cost assessments of REDD+ can help planners to design REDD+ actions in Paraguay in a cost-effective way that ensures multiple social and environmental benefits, while avoiding potential risks.

Annexes

Annex I

MODIS Active Fire Product: Fire Information for Resource Management System (FIRMS) detects fires in one km pixels that are burning at the time of overpass under relatively cloud-free conditions. It uses a contextual algorithm in which thresholds are applied to observed middle infrared and thermal infrared brightness temperature. False detections are rejected by examining the brightness temperature relative to neighbouring pixels. Fire Radiative Power provides information on the measured radiant heat output of detected fires, depicting the pixel-integrated fire radiative power in MW (MegaWatts).

Annex II

To evaluate the importance of forest for limiting soil erosion, an overlay approach is used, combining data on precipitation (wettest month precipitation per cell) with data generated for slope and upstream catchments of dams. This is then combined with forest cover data. This process involves the generation of single layers with three classes (low, medium and high) for wettest month per cell precipitation (0-121 mm; 122–162 mm; and 163-261 mm; natural breaks classification) and for slope steepness (0–2°; 3–8°; and >9°; natural breaks classification). A binary layer is generated for the presence or absence of a dam catchment. These single layers are then combined additively. As there are 3 classes for slope (1–3), 3 classes for mean precipitation (1–3) and 2 for the presence or absence of a dam catchment (0–1), the resulting output has a maximum value of 7, and a minimum value of 2, and therefore 6 classes. These classes represent a low to high potential importance of forests for limiting soil erosion, with highest values representing higher erosion impact in the absence or degradation of forests. No weighting is used in this approach; the relative importance of high precipitation is the same as that for steep slopes.

Annex III

It is possible to identify areas important for various combinations of benefits, where darker shading indicates the presence of a greater number of the benefits being considered. The following benefits were combined to create this map:

- **Biomass carbon:** The top three classes of biomass carbon (≥26 tonnes/ha) were combined.

- **Potential richness of threatened forest species:** Areas with ≥5 species ranges occurring within forest habitats, based on mammal, bird and reptile species classified as Critically Endangered, Endangered, and Vulnerable by the IUCN Red List of Threatened Species (2013), were used to represent areas with highest potential richness of threatened species.

- **Important Bird and Biodiversity Areas:** Important Bird and Biodiversity Areas (IBAs) in Paraguay (Map 10) are included here.

- **Soil erosion control:** The relative importance of forest has been evaluated as a function of slope, rainfall and the presence of something important downstream that could be adversely affected by soil erosion (hydroelectric and other dams). All except the lowest class from Map 12 have been used to represent areas of greatest importance here.

These elements were added together to produce a combined raster that was then clipped to forest, to indicate forest areas of potential importance for these benefits (maximum four benefits).

Annex IV

The potential distribution of nine medicinal plant species found in forests that are also listed as being of commercial importance in the markets of Asunción and Gran Asunción (Basualdo et al. 2004), was mapped using specimen locality records from the Missouri Botanical Garden Database (MOBOT). Point locality records of specimens found within 1.45 decimal degrees of each other were aggregated; a polygon of the locality records was created and then smoothed. This was clipped to forest at risk of future deforestation (Map 5), to show areas that may support the following species, which are risk of deforestation:

1. *Aspidosperma quebracho-blanco*
2. *Croton urucurana*
3. *Caesalpinia paraguariensis*
4. *Erythrina crista-galli*
5. *Peltophorum dubium*
6. *Prosopis ruscifolia*
7. *Protium heptaphyllum*
8. *Sapium haematospermum*
9. *Tabebuia impetiginosa*

Annex V

Using Map 20 as a basis, this map shows areas with potential to support the following additional benefits through the restoration of forest cover:

- The potential of restored forest to support livelihoods (using poverty data from Map 16a). Areas with >15% incidence of the population living in poverty have been included.

- The potential of restored forest to conserve and enhance biodiversity (using information on potential richness of threatened species found in forest habitats, as in Map 9). All areas of potential importance for threatened forest species (based on mammal, bird and reptile species classified as threat status Critically Endangered, Endangered, and Vulnerable and as occurring within forest habitats by the IUCN Red List of Threatened Species (2013) Version 2012.2) have been included.

- The potential of restored forest to provide soil erosion control (as shown in Map 12). The top four classes from Map 12 have been used.

The above benefits were reclassified and summed to show areas with potential to provide additional benefits through the restoration of forest cover (maximum three benefits). Other benefits aside from those specified may also be present.

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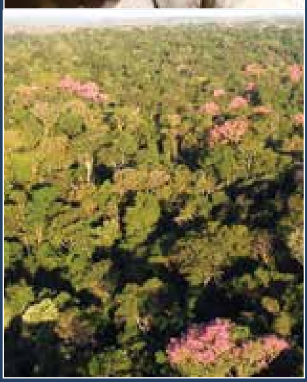

REDD+ can contribute to achieving more policy goals than climate mitigation alone. In Paraguay, REDD+ has the potential to deliver multiple benefits, which will depend on the location and type of REDD+ action implemented. The maps presented in this report are a way of making available to planners information on locations where the potential for multiple social and environmental benefits may make reducing deforestation and forest degradation and restoring forests priorities for REDD+ action, as well as where REDD+ actions need to take account of potential risks.

This report illustrates how spatial analyses can support the REDD+ planning process in Paraguay, showing how the suitability of areas for different REDD+ actions and the characteristics associated with possible benefits and risks differ according to location.

The benefits examined in this report reflect priorities identified by national stakeholders in Paraguay, and include the role of forests in storing carbon; controlling soil erosion; and supporting biodiversity and livelihoods.

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