THE FUTURE OF MADRE DE DIOS

Smithsonian's Working Landscape Simulator for Sustainable Development

HADRIEN VANTHOMME, ANA MARÍA SÁNCHEZ-CUERVO,
PAOLA GÁRATE, ADRIANA BRAVO, AND FRANCISCO DALLMEIER

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A Smithsonian Contribution to Knowledge

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Madre de Dios in Peru is one of the most biodiverse regions on Earth, and it is a central piece for connecting protected areas within the Vilcabamba–Amboró Conservation Corridor. As revealed with satellite imagery, the exceptional landscape of Madre de Dios is threatened by unplanned development along the Interoceanic Highway, which bisects the region from north to south. Land-use changes in the last 25 years have reduced landscape connectivity and degraded the ecosystem services on which Madre de Dios's inhabitants rely.

The Smithsonian Center for Conservation and Sustainability developed a new tool to help Madre de Dios's stakeholders define a common vision for the future of their region: the Smithsonian Working Landscape Simulator. *The Future of Madre de Dios* presents the framework and implementation of this participatory, holistic, and quantitative tool. The study contemplates four scenarios of future changes for the region: current trends, expansion of alluvial gold mining, land planning, and landscape conservation. The land-cover changes expected under each scenario until 2040 are modelled, and the resulting landscapes are evaluated for 15 indicators of success, covering economic prosperity, human well-being, and environmental integrity. This book illustrates the results from these analyses and presents recommendations that will contribute to the promotion of sustainable development in Madre de Dios.

“The most difficult thing is the decision to act,
the rest is merely tenacity.”
– *Amelia Earhart* –

“The pessimist complains about the wind;
the optimist expects it to change;
the realist adjusts the sails”
– *William Arthur Ward* –

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FOREWORD

Pedro Gamboa

Chief of Peru's Servicio Nacional de Áreas Naturales Protegidas por el Estado (SERNANP) [National Service of Natural Areas Protected by the State]

Madre de Dios, recognized as "the capital of biodiversity," has five protected natural areas in its territory: The National Parks of Manu, Alto Purús and Bahuaja Sonene, the Amarakaeri Communal Reserve, and the Tambopata National Reserve. In 3,800,000 ha or 45% of the territory of Madre de Dios, they conserve representative samples of its great biodiversity and cultural legacy.

The conservation of these natural spaces allows us to effectively integrate the management of other natural protected areas that make up the Vilcabamba–Amboró Conservation Corridor. They are about 30 million hectares that for a moment make us think that the territorial borders between Peru and Bolivia are imaginary, and that the cultural brotherhood—which dates from the pre-Inca era—has found in this Corridor a space of peaceful and harmonious coexistence for the sustainable development of the peoples and the conservation of each of these sacred natural spaces.

The natural protected areas are a National Heritage; their conservation is a priority, which will only be achieved thanks to the joint and articulated work between the different levels of government (national, regional and local), the private sector, the civil society, and the native communities. For that reason, the fight against illegal mining, deforestation, and other activities that affect them should not stop. Madre de Dios should not only be proud that these spaces are free of these scourges but should continue to fight so that these illicit activities disappear completely from all their territory.

The natural protected areas of Madre de Dios and Peru contribute to the development of the population, who take advantage in a sustainable manner of natural resources such as the Brazil nut, the *aguaje*, the cocoa, and the landscape resources through nature tourism, among others. This is an example of how conservation and sustainable development are a reality that benefits thousands of people and the true legacy for future generations.

FOREWORD

Krishna R. Urs

U.S. Ambassador to Peru

As Ambassador of the United States to Peru, I have had the great fortune to travel to many different regions of this wonderful country. The Peruvian Amazon is both beautiful and unique, and Madre de Dios an enormous reason for that.

In this book, the authors have sought to predict the "uncertain and complex" future of the Madre de Dios region of Peru through a tool that attempts to foresee the extent to which human activities and policies currently being implemented will impact the region. This will contribute to conservation efforts, inform policymakers to route their steps in the right direction, and support global environmental advocacy by enabling us to learn from this analytical tool.

The Future of Madre De Dios: Smithsonian's Working Landscape Simulator for Sustainable Development continues the Smithsonian Institution tradition of showcasing concern for the Amazon basin, a region of over 6.3 million square kilometers—over a third of South America—that constitutes the lungs of the planet. The United States Embassy in Peru shares the Smithsonian's concern and is committed to supporting Peru's efforts to combat the illicit activities that result in a variety of environmental crimes, including in Madre de Dios. The innovative tool presented by the Smithsonian in this book will help define a collective path toward sustainable economic prosperity, social well-being, and environmental integrity that could be a model to be deployed elsewhere in Peru and the world.

FOREWORD

Thomas E. Lovejoy

Senior Fellow, United Nations Foundation; and Professor of Environmental Science and Policy, George Mason University

The very name Madre de Dios carries a mystical air: a faraway place west of the Andes, with forests brimming with life, rivers originating in the Andes and heading ultimately to the Atlantic, and, beyond the settlements, indigenous peoples deeply knowledgeable about and dependent on their natural environment. Long buffered by the mountain barrier, this is no longer the case, as highways, illegal gold-mining, and other activities gouge their imprint on this biological Shangri-La.

Smithsonian scientists under the leadership of Francisco Dallmeier have been engaged in exploring and chronicling the biological riches of the region. Yet they have come to realize—as in the words of Smithsonian Secretary S. Dillon Ripley—that every biologist with a conscience should spend some time on conservation.

That is what this volume is about: (1) looking up from microscopes, specimen jars and collecting nets to examine what is happening—and more important what could happen—to the biological patrimony of this extraordinary region; and (2) suggesting modification to the trajectories of deforestation and other environmental impacts. The consequence is a very thoughtful vision of an alternate future for Madre de Dios and its natural wonders and riches.

This volume presents a bold new vision for the future of Madre de Dios. It simultaneously respects the natural wonders while spotlighting ways in which the mixed and non-indigenous settlements can achieve a sustainable trajectory. This is a new, conceptually bold yet simultaneously thoughtful vision. It is not a blindered narrow straitjacket of missed development opportunities—almost all of those "opportunities" are myopic and represent a Siren's call to a false prosperity.

In contrast, the outlines of the vision described here ensure that Nature in all its astounding variety will always be a part of the region, and that its inhabitants will thrive because their aspirations are imbedded in nature.

PREFACE

Smithsonian research in Madre de Dios began in the 1980s with more than ten years of expeditions in Manu National Park. The research expeditions inventoried, monitored, and documented the rich biodiversity of the park. Dozens of national and international biologists and students contributed to the baseline knowledge of Manu and to the management and conservation in the region.

Since then, the Smithsonian Institution conducted numerous other projects in Peru, such as the biodiversity inventory for the Camisea region in the 1990s and others in the last twenty years. The Smithsonian led multidisciplinary teams of biologists and provided innovative recommendations to minimize the impacts of infrastructure and energy development in the country. These projects pioneered the offshore–inland model with a no-roads development framework, the placing of infrastructure outside critical and natural habitats, the development of canopy bridges along linear infrastructures, and the rainforest restoration approaches. For twenty years, Smithsonian has worked to integrate conservation needs with development priorities to sustain biodiversity.

So when we were invited in 2014 by Hunt Oil Exploration and Production Company of Peru to conduct biodiversity research in the Amarakaeri Communal Reserve of Madre de Dios, it felt like coming back home. Things had changed a lot though, and the region was very different from what we had encountered all those years before. With Hunt Oil, we felt we needed to go beyond biodiversity management, and try to understand the changes in a more integrated manner. The team then developed a participatory scenario-planning assessment of Madre de Dios to evaluate the consequences of contrasting stakeholders' visions of the development of the department based on qualitative and quantitative data. This analysis provides a holistic view of Madre de Dios's future that can contribute to maintaining the functionality of the Vilcabamba–Amboró conservation corridor at a larger scale. We believe this approach offers decision makers a forward-looking conservation and sustainable-development vision that should be replicated in other regions of the country and beyond.

Francisco Dallmeier and **Hadrien Vanthomme**
Director *Research Ecologist*
Center for Conservation and Sustainability
Smithsonian National Zoo and Conservation Biology Institute

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Hadrien Vanthomme is a conservation biologist and tropical forest ecologist. He has conducted research in Africa and Latin America on how the management of natural resources and large-scale infrastructure impact tropical biodiversity and ecosystems, supporting multi-sectorial innovative best practices to achieve sustainable development.

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Ana María Sánchez-Cuervo is a conservation biologist. Her research involves the use of geographical information systems, spatially explicit models, spatial analysis, and multivariate statistics to understand patterns, causes, and consequences of global environmental change.

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Adriana Bravo is a tropical biologist interested in ecology, conservation, and education. She has more than 15 years of experience working in ecology and conservation projects in Neotropical forests. Adriana was the director of the Wandari Biodiversity Program for the Smithsonian Conservation Biology Institute in Lima, Peru.

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Francisco Dallmeier directs the Center for Conservation and Sustainability of the Smithsonian Conservation Biology Institute and the National Zoo. The center's mission is to apply the expertise of the Smithsonian to integrate conservation needs with sustainable development priorities.

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The Smithsonian Conservation Biology Institute and its Center for Conservation and Sustainability (CCS) generates scientific information and develops modelling tools and best practices to inform sustainable development actions. In line with the United Nations' 2030 agenda for sustainable development, CCS has worked with the private sector since 1996 to develop conservation and development best practices to conserve biodiversity and ecosystem services that benefit people and wildlife. The CCS research team has more than 30 years of experience working in Madre de Dios, as well as other Amazon, Andean, and coastal regions of Peru, and is well informed of the regional conservation and development challenges. The CCS approach to sustainable working landscapes in Madre de Dios offers a comprehensive view of potential scenarios for the region and empowers stakeholders to make informed decisions on critical conservation and development issues.

Ecosystem Services LLC is a forestry, renewable energy, and natural resources company specialized in the generation of internationally marketable environmental services. Guided by the principles of ethical investment, social justice, gender equality, environmental conservation, and sustainable development, Ecosystem Services LLC's mission is to conserve the planet's biodiversity through the generation of financial returns for investors and the provision of development opportunities for people. To achieve this, Ecosystem Services LLC is developing and marketing ecosystem services with emphasis on carbon dioxide offsets and forest conservation to achieve sustainable development, with a main focus in Latin America.

Centro de Investigación Científica Amazónica (CINCIA) generates scientific knowledge and integrates this knowledge to craft environmental management initiatives to promote sustainable development and, where needed, reforestation and pollution mitigation. CINCIA's vast expertise in forestry, propagating native trees, restoring nutrients to depleted soils, and understanding the damage caused by mercury dumping is used to devise solutions for reforestation of one of the most biodiverse places on Earth while mitigating the damage to land, soils, water, and fish life from increasing deforestation and mercury poisoning. CINCIA scientists work to build trust with government leaders, miners, and farmers toward more efficient land use and less environmental damage.

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We appreciate the participation of public and private institutions that collaborated and supported this investigation. Many thanks to all of them, especially to the National Service of Protected Areas (SERNANP) and the Regional Government of Madre de Dios (GOREMAD). Our deepest thanks to all the people who gave their time to review the early versions of this document, giving us extraordinary comments and helpful recommendations. Special thanks to Letícia Santos de Lima, who contributed greatly to the modelling process and the spatial analysis. Funding for this research has been provided by Hunt Oil Exploration and Production Company of Peru.

ABBREVIATIONS AND ACRONYMS

ACCA/ACA: Asociación para la Conservación de la Cuenca Amazónica / Amazon Conservation Association

BBOP: Business and Biodiversity Offsets Program

CCS: Center for Conservation and Sustainability (SCBI)

CEPLAN: Centro Nacional de Planeamiento Estratégico del Perú

CINCIA: Centro de Investigación Científica Amazónica

DIGOT: Dirección General de Ordenamiento Territorial del MINAM

DIGRVU: Dirección General de Políticas y Regulación en Vivienda y Urbanismo del MVCS

DIGSPACR: Dirección General de Saneamiento de la Propiedad Agraria y Catastro Rural del MINAGRI

DIGTT: Dirección General de Transporte Terrestre del MTC

DIRAGRI: Dirección Regional de Agricultura de los GORE

DIREMIN: Dirección Regional de Energía, Minas, e Hidrocarburos de los GORE

DIRFF: Dirección Regional Forestal y de Fauna de los GORE

DIRTC: Dirección Regional de Transporte y Comunicaciones de los GORE

DIRVCS: Dirección Regional de Vivienda, Construcción, y Saneamiento de los GORE

DIT: Diagnostico Integrado del Territorio; Integrated Diagnostic of the Territory

DNCPE: Dirección Nacional de Coordinación y Planeamiento Estratégico del CEPLAN

EE: Estudios Especializados; Specialized Studies

EPA: Environmental Protection Agency (U.S.)

ESIA: Environmental and Social Impact Assessment

GBIF: Global Biodiversity Information Facility

GDP: Gross Domestic Product

GEOIDEP: Portal de la Infraestructura de Datos Espaciales del Perú del IDEP

GORE: Gobiernos Regionales

GOREMAD: Gobierno Regional de Madre de Dios

GRPPAT: Gerencia Regional de Planeamiento Participativo y Acondicionamiento Territorial de los GORE

HDI: Human Development Index

IBGE: Instituto Brasileiro de Geografia e Estatística

IDB: Inter-American Development Bank

IDEP: Infraestructura de Datos Espaciales del Perú

IIRSA: Iniciativa para la Integración de la Infraestructura Regional Suramericana de la BID

INE: Instituto Nacional de Estadistica de Bolivia

INEI: Instituto Nacional de Estadística e Informática del Perú

INGEMMET: Instituto Geológico Minero y Metalúrgico del MINEM

IPCC: Intergovernmental Panel on Climate Change

IUCN: International Union for Conservation of Nature

MAAP: Monitoring of the Andean Amazon Project of ACCA

MINAGRI: Ministerio de Agricultura y Riego del Perú

MINAM: Ministerio del Ambiente del Perú

MINCETUR: Ministerio de Comercio Exterior y Turismo del Perú

MINEM: Ministerio de Energía y Minas del Perú

MTC: Ministerio de Transportes y Comunicaciones del Perú

MVCS: Ministerio Vivienda, Construcción y Saneamiento del Perú

NGO: Nongovernmental Organization

NTFP: Non-Timber Forest Product

PNUD: Programa de las Naciones Unidas para el Desarrollo

POT: Plan de Ordenamiento Territorial; Territorial Management Plan

PRODES: Programa ProDescentralización de USAID

PROFONANPE: Peruvian Trust Fund for National Parks and Protected Areas

REDD+: Reducing Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries of the UNFCCC

SCBI: Smithsonian Conservation Biology Institute

SDOT: Secretaria de Demarcación y Organización Territorial del VMINGT

SENAMHI: Servicio Nacional de Meteorología e Hidrología

SERFOR: Servicio Nacional Forestal y de Fauna Silvestre del MINAGRI

SERNANP: Servicio Nacional de Áreas Naturales Protegidas por el Estado de Perú

SPDA: Sociedad Peruana de Derecho Ambiental

UNESCO: United Nations Educational, Scientific and Cultural Organization

UNFCCC: United Nations Framework Convention on Climate Change

USAID: United States' Agency for International Development

VMINGT: Viceministerio de Gobernanza Territorial del Perú

WHO: World Health Organization

WWF: World Wildlife Fund

ZEE: Zonificación Ecológica y Económica; Ecological and Economical Zoning

GLOSSARY OF ESSENTIAL TERMS

Biodiversity: the variety within and among living organisms, communities, and biotic processes, whether naturally occurring or modified by humans. Biodiversity can be measured in terms of genetic diversity, the identity and number of different types of species, communities, and biotic processes, and the amount and structure of each. It can be observed and measured at any spatial scale ranging from microsites to the entire biosphere (DeLong 1996).

Cadastre: official record of the owners of land and of the amount and value of the land they own.

Development: the process of economic and social transformation that is based on complex cultural and environmental factors and their interactions (Jacobs and Asokan 1999).

Ecosystem services: the benefits (products and services) that people, including organizations and businesses, derive from ecosystems (Reid et al. 2005). They include provisioning services such as food, water, and timber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services that contribute to the supply of the other services such as soil formation, photosynthesis, and nutrient cycling (Reid et al. 2005). The provision of ecosystem services relies on properly functioning ecosystems (Hooper et al. 2005) and justifies the implementation of conservation actions.

Ecosystem service assessment: an approach in planning intended to support the development of policies and instruments that integrate social, economic, and ecological perspectives (Seppelt et al. 2011). Proper identification and prioritization of ecosystem services at local and regional scales with stakeholders facilitate decisions related to management and protection (Landsberg et al. 2013). Despite its challenges (Reed 2008, Young et al. 2013), proper stakeholder engagement leads to numerous benefits like decreasing the likelihood of marginalization, empowering stakeholders through knowledge development, increasing perception of a fair decision-making process, and providing social learning opportunities (Luyet et al. 2012, Durham et al. 2014).

Forest fragmentation: the process in which human activities break up large, contiguous forest tracts into smaller patches. Fragmentation disrupts the population dynamics of forest species, reducing biodiversity, and affecting ecosystem functioning and services (Saunders et al. 1991, Foley et al. 2007).

Green infrastructure: the interconnected network of natural and semi-natural areas that conserves natural ecosystem values, functions, and services, sustaining social and economic health (Benedict and McMahon 2012). Examples include rivers, forests, marshes, protected areas.

Gray infrastructure: relatively permanent and foundational capital investment of a territory that underlies and makes possible all its economic activity. It includes administrative, energy, telecommunications, transportation, utilities, waste removal, processing, lodging, education, health, and research facilities.

Scenarios: plausible, challenging, and relevant stories about how the future might unfold, which can be told in both words and numbers (Raskin et al. 2005). Stories in words refer to the qualitative narratives, while stories in numbers refer to the quantitative evaluation of scenarios using key indicators of success, such as ecosystem services or socioeconomic indicators. The quantitative evaluation of scenarios is done with mathematical models describing the relationships between key drivers of change (i.e., any natural or human-induced factor that directly or indirectly causes a change) and indicators of success.

Scenario planning: a structured way to think about the future to facilitate decision making (Chermack 2004). Scenario planning consists in exploring a handful of plausible future states of a territory called scenarios. These states are inferred from present and recent past conditions and extrapolated to the future. By exploring scenarios, stakeholders can define a preferred future state and the optimal trajectory to transition from the present to the preferred state. Scenario planning was developed simultaneously by Herman Kahn to formulate strategies for the U.S. Military (Kahn and Wiener 1967) and by Gaston Berger to help formulate public policy (Berger 1966).

Stakeholder: in the context of this study, an individual, group, or organization that can affect or is affected by the management of a territory (inspired from Freeman 2010). The 13 categories of stakeholders considered in this study include: national government, regional government, indigenous communities, farmers, non-timber forest product extractors, loggers, formal and informal miners, hydrocarbons companies, hydropower managers, tourism companies, conservation nongovernmental organizations, universities and research institutions, and civil society.

Sustainability: the quality of being able to continue for a long time while causing little or no damage to the environment (Bell and Morse 2013).

Sustainable development: a human development that meets the needs of the present without compromising the ability of future generations to meet their needs (Brundtland 1987). The concept recognizes that human development is not separate from the supporting ecosystems in which it takes place. Going further than this ambiguous and historical definition, the term in used here as a negotiated development path that fairly balances present and future economic, well-being, and environmental interests (inspired by Kates et al. 2005).

Territory: an area of land under the jurisdiction of a governing entity.

Working landscapes: productive territories where ecosystems are managed sustainably (Cannavò 2007). Working landscapes include gray infrastructure (e.g., roads, cities, power lines) that provide economic services, and green infrastructure (e.g., rivers, forests, marshes, protected areas) that provide ecosystem services and support biodiversity. When gray and green infrastructures are appropriately and jointly managed, the landscape can achieve sustainable development.

EXECUTIVE SUMMARY

Context

The Amazonian region of Madre de Dios in southern Peru, in the foothills of the tropical Andes, is the heart of one of the most biodiverse regions of the world. Hosting some of Earth's most renowned protected areas, the region sits at a critical location within the Vilcabamba–Amboró conservation corridor, which connects 30 million hectares from Peru to Bolivia. Despite this global significance, the exceptional ecosystems of Madre de Dios are rapidly being changed, like most of the neighboring Amazonian regions.

An analysis of satellite imagery between 1993 and 2017 reveals that landscape changes began with forest conversion starting in the 1980s with the political promotion of agriculture. The region had unreliable roads at the time, and most of the economy was based upon the exploitation of forest products such as tropical wood, Brazil nut, and latex. Deforestation for alluvial gold mining started in 1996–1998 and accelerated with the pavement of the Interoceanic Highway in 2010. In the meantime, agriculture and urban areas expanded, also contributing to deforestation.

Today, Madre de Dios maintains a relatively high human development index, a low deforestation rate, and low population density but falls far behind its neighbors in terms of economic development. One of the most important drivers of change for the region has been the completion of the Interoceanic Highway, which triggered the accelerated conversion of forest to agriculture, mining, and urban lands. Currently, national economic growth, immigration, and the rise of international gold prices are other important drivers of deforestation and ecosystem degradation.

These have contributed to loss of biodiversity, release of carbon in the atmosphere, accelerated erosion of soils, and loss of the capacity of vegetation and wetlands to retain pollutants. Athough forest still covered 97.6% of the region in 2017, the concentration of deforestation along the Interoceanic Highway and the development of highly polluting gold mining activities along rivers and at the head of watersheds raise concerns that landscape connectivity of the Vilcabamba–Amboró conservation corridor might become disrupted, and that the ecosystem services on which Madre de Dios inhabitants rely might collapse.

The accelerating landscape changes in Madre de Dios call for a rapid and decisive response of the regional and national governments of Peru.

Fortunately, the region is well placed to embark on a sustainable development path for several reasons, including the ambitious reforms of territorial management policies at the government level, Madre de Dios's relatively good environmental and social performance compared to its neighboring regions, its small population, its impressive network of protected areas, and a territorial planning process on the way.

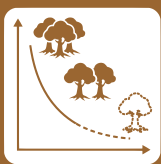
Four Scenarios Using the Smithsonian Working Landscape Simulator

The Smithsonian Center for Conservation and Sustainability (CCS) engaged in an innovative project to promote sustainable development through the provision of strategic information and analysis. The CCS developed a modelling tool to help Madre de Dios's stakeholders define a common vision for the future of their region: the Smithsonian Working Landscape Simulator.

Smithsonian's Working Landscape Simulator is a structured, seven-step framework for assessing and facilitating territorial management. This tool combines ecosystem service assessment, scenario planning, and the working landscape concept into a new approach.

The CCS team developed four quantitative scenarios with Madre de Dios stakeholders, describing what would happen in the region in four alternative

The Four Scenarios Evaluated

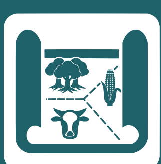


Current Trends Scenario

This scenario maintains present-day political, economic, and social tendencies. Informal and illegal extractive activities drive the economy without active regional management. Madre de Dios experiences an increase in economic development led by gold mining and agriculture, at the cost of increased deforestation, degradation of ecosystem services, mercury pollution, public health issues, and social conflicts.

Expansion of Alluvial Gold Mining Scenario

Informal and illegal gold mining expands due to poor land management, weak law enforcement, increased immigration, and high international gold prices. Economic productivity is high in the mining and agriculture sectors, associated with a reduction of logging and Brazil nut productivity, alarming degradation of the environment, and reduction of human well-being.



Land Planning Scenario

The land management plan for the region's sustainable development is enforced after 2020. All economic activities are formalized and carried out within the zoning of the plan, successfully slowing down the expansion of mining. These actions result in good economic performance of the other sectors and improved ecosystem services and human well-being.

Landscape Conservation Scenario

A new land management plan focused on biodiversity and landscape conservation is enforced after 2020. Protected areas are considered sanctuaries, deforestation is strongly limited, and degraded lands are restored. These actions result in limited economic growth in the agriculture and mining sectors, good human well-being performance, and optimal environmental performance.

human development futures. The stakeholders consulted included the national government, regional government, indigenous communities, farmers, non-timber forest product extractors, loggers, formal and informal miners, hydrocarbons companies, hydropower managers, tourism companies, conservation nongovernmental organizations, universities and research institutions, and civil society. The team then modelled land-cover changes in the region for each of the scenarios up to 2040. The CCS then evaluated a series of 15 indicators quantifying scenario success in three dimensions of sustainability: economic prosperity, human well-being, and environmental integrity.

Key Results and Recommendations

This study is the first to model the future consequences of human development on a range of ecosystem services and socioeconomic indicators at the landscape level in the Peruvian Amazon. The Smithsonian's approach for Madre de Dios offers contrasting visions of the future based on unbiased qualitative and quantitative data, and a variety of balanced stakeholder viewpoints, to offer a holistic view of the region's future.

No one scenario brings the highest performance in all indicators, and all represent a different trade-off among economic development, human well-being, and environmental preservation. These dimensions of sustainability are interdependent, and a decision about one dimension affects the success of the others. The scenario analysis shows active territorial management of the region's landscape provides higher performance than unmanaged development. This calls for a holistic and integrated management approach to land zoning, considering economic, well-being, and environmental processes.

The workshops with stakeholders realized in this study and the results of the modelling process tell us the new vision for Madre de Dios should be guided by the following universal principles: sustainability, equity, cultural respect, holistic view, transparency, and probity. Achieving sustainable development in the region requires a reform of the structure and responsibilities for territorial planning within the national, regional, and district governments to better integrate sectorial efforts of territorial planning. A revision of the legal framework related to territorial planning is also needed to facilitate the implementation of the regional sustainable development vision and to remove perverse regulations that promote environmental damages.

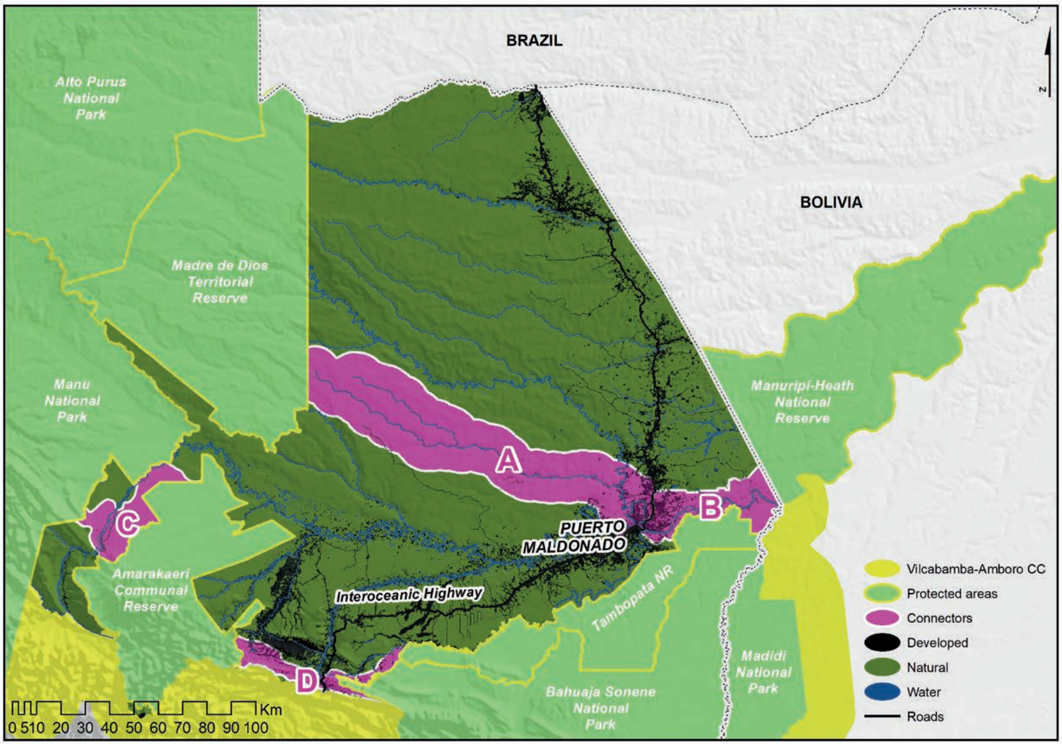
An important recommendation expressed during the stakeholders' consultations was to complete and implement a territorial management plan in the region. For this, the regional government should first unify development goals across stakeholders' aspirations and in accordance with national priorities. It is also necessary to complete the fine scale (less than 1:100,000) land-use zoning of the region and establish a unique cadastre to identify and resolve land-use overlaps. Until this is achieved, the region should temporarily suspend and update the processes for granting new concessions of any kind, to avoid creating more overlaps. Finally, the approbation of a territorial plan would also require proper control and monitoring, to ensure activities are developing legally in the region.

Sustainable efforts should be equally encouraged in the civil society and the private sector. The diffusion of good practices across sectors was considered a priority by local stakeholders, such as the restoration and reforestation of lands degraded by economic activities. These good practices could be compiled and disseminated through sectorial roundtables, or by providing support to small-scale economic operators. Some products like wood, Brazil nut, and those derived from native biodiversity and sustainable use need to be integrated in more effective production chains, and several sectors could benefit from innovative technologies.

A First Step toward Sustainable Development

The future of Madre de Dios is uncertain and complex to predict, so territorial planning should include built-in adaptive management mechanisms, with plans about urban development, social services, and adaptation to climate change that are revised periodically. Another proven way to be more resilient to changes is to invest in research and training in the region, so that innovative local solutions to new challenges can be found rapidly. Finally, all these efforts should be participative and require active outreach and communication to make information related to territorial planning freely and easily accessible.

While these actions are being taken, we suggest testing the practical implementation of sustainable development—including the completion of ecological and economic fine-scale zoning, curation of a regional cadastre, testing of new technologies for mining and agriculture, restoration of degraded and abandoned lands, biological monitoring, and promotion of ecotourism, agroforestry, certified logging, fish farming, and Brazil nut extraction—in priority areas in the region including protected areas and four priority connectors. These experiments could help test innovative sustainable solutions and preserve important places and ecosystem services threatened by unplanned development.



The CCS team identified four connectors that need immediate action (see map above): Pariamanu (A), lower Madre de Dios (B), upper Madre de Dios (C), and South Huepetuhe (D).

MADRE DE DIOS AT A TIPPING POINT

The Exceptional Biodiversity of Madre de Dios

The Amazon rainforest covers 6 million km^2 and is estimated to host 390 billion trees and about 16,000 tree species (Ter Steege et al. 2013). It is one of the most biodiverse areas of the planet for many taxa, including plants, insects, amphibians, birds, fishes, and mammals (Stotz 1996, Ter Steege et al. 2003, Young et al. 2004, Ceballos et al. 2005, Erwin et al. 2005, Pimm and Jenkins 2005, Ceballos and Ehrlich 2006). It covers most parts of the Amazon watershed (7 million km^2), with its Brazilian portion (70%) corresponding to the lowest parts of the watershed, and the headwaters located in the Andes of Peru (13%), Colombia (10%), Bolivia (5%), and Ecuador (2%).

Biodiversity in the Amazon roughly increases from east to west, with the highest levels being found in the Amazon headwaters (Bass et al. 2010). For this reason, the Andes Mountains and adjacent lowlands of Venezuela, Colombia, Ecuador, Peru, Bolivia, and the northern tropical portions within Argentina and Chile have been designated as a biodiversity hotspot. The Tropical Andes hotspot is considered the "global epicenter of biodiversity" (Myers et al. 2000); it contains about one-sixth of all plant life in the world, including 30,000 species of vascular plants; is home to the greatest variety of amphibians, birds, and mammals; and it takes second place among the world's hotspots for reptile diversity, all in just 1% of the earth's terrestrial surface (NatureServe and EcoDecisión 2015).

The Vilcabamba–Amboró conservation corridor (Figure 1) within the Tropical Andes hotspot has been recognized as the highest priority area to preserve the exceptional biodiversity of the region (CEPF and World Bank

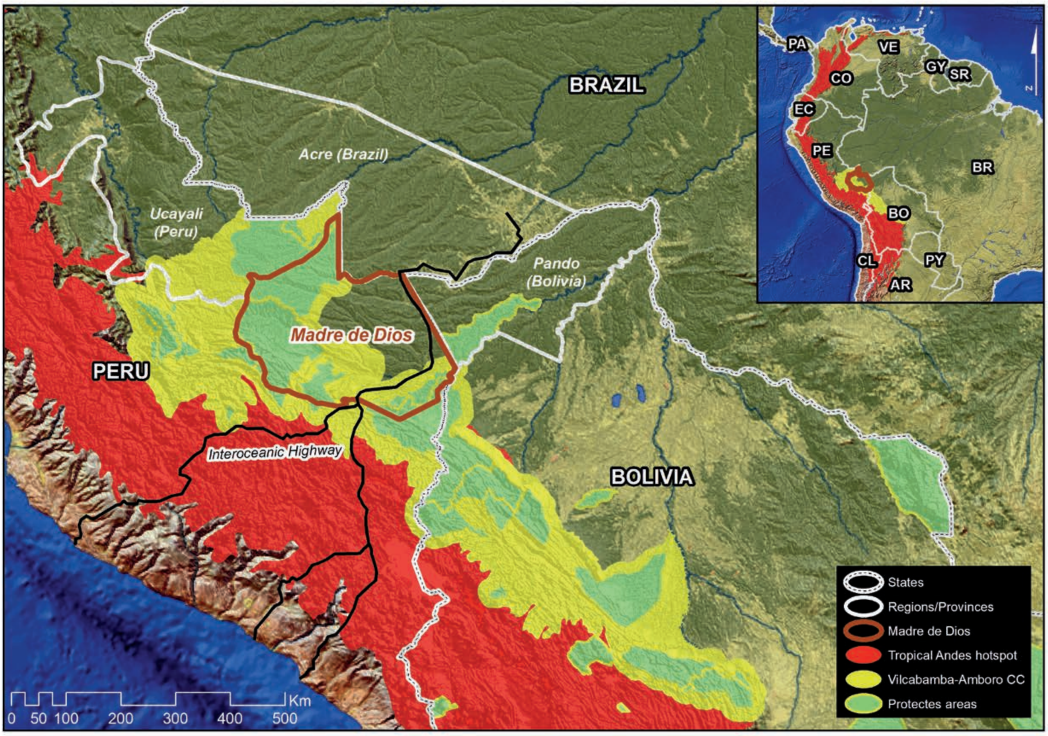


Figure 1. Madre de Dios region within the Vilcabamba–Amboró conservation corridor and the Tropical Andes hotspot. AR: Argentina; BO: Bolivia; BR: Brazil; CL: Chile; CO: Colombia; EC: Ecuador; GY: Guyana; PA: Panama; PE: Peru; PY: Paraguay; SR: Suriname; VE: Venezuela.

2005). This corridor connects 30 million ha of highly diverse ecosystems stretching from the Otishi National Park in the Vilcabamba mountain range in Peru to the Amboró National Park in Bolivia. The region of Madre de Dios in Peru hosts Manu National Park, one of the most emblematic protected areas of the Vilcabamba–Amboró conservation corridor, declared World Heritage site by UNESCO for its exceptional biodiversity, as well as the Tambopata National Reserve and Bahuaja-Sonene National Park.

The region of Madre de Dios is strategic in preserving the biodiversity of the Vilcabamba–Amboró conservation corridor. Within the Tropical Andes hotspot, it has been designated Peru's "capital of biodiversity" by law (Ley N°26311). Nearly half of the region's territory is designated as national parks, national reserves, communal reserves, or private conservation areas, with some in existence since the 1970s. Madre de Dios ecosystems are typical of the Amazon: *terra firme* forests, seasonally flooded forests, lowland humid forests, and pre-montane and montane forests up to 3967 m. The variety of ecosystems is a major source of the extraordinary biodiversity found in the region (Figure 2), with 6809 plant, 1212 bird, 272 fish, 256 mammal, 183 amphibian, and 143 reptile species (GBIF 2018). Tambopata, Bahuaja Sonene, and Alto Purus protected areas have a high level of endemism with at least 9 amphibian, 21 bird, 17 plant, 8 mammal, and 2 reptile species found only in those protected areas (GOREMAD 2015).

Madre de Dios in the Changing Amazon

Before the 1960s, Amazonian forests remained relatively intact, mainly due to their limited accessibility (Kirby et al. 2006). This changed in the 1960s and 1970s with the construction in Brazil of several paved roads and the creation of incentives to colonize the Amazon region, mainly to establish cattle ranches. First, the Polonoroeste project, a $1.6 billion road building and agriculture scheme in Mato Grosso and Rondonia, was executed in the 1980s, with funds from the World Bank (Wade 2011). Later, the Inter-American Development Bank (IDB) approved a loan to pave the B-364 highway from Porto Velho in Rondonia to Rio Branco in Acre, Brazil. This facilitated access, and the incentives for development triggered a massive immigration to the forests and large-scale unplanned deforestation that moved progressively from east to west following road development (Kirby et al. 2006). Numerous social conflicts among cattle ranchers, rubber trappers, and indigenous communities sparked across the region, drawing the attention of the international community. Public outcry led to the creation of a conservation plan for the Amazon and the establishment of the first protected areas in the late 1970s (Peres and Terborgh 1995).

At the same time, the Amazon landscape of Madre Dios in Peru started to change with the construction of a road connecting Puerto Maldonado, the capital of Madre de Dios, with the Andes. This road was expanded in the late 1970s to connect Puerto Maldonado to Acre (Naughton-Treves 2004). In the 1980s and early 1990s, the Peruvian government promoted agricultural expansion in the Amazon, encouraging the migration of people from the highlands to the forest. The new liberal and austere economic model promoted by the government and the economic crisis in the mid-1990s put an end to this national policy and resulted in a significant reduction of agriculture production in the region, and accelerated the shift of the economy toward alluvial gold mining.

Since 1990, Madre de Dios has had a unique trajectory compared to its Amazonian neighbors of Ucayali in Peru, Acre in Brazil, and Pando in Bolivia (Figure 1). The population density of Madre de Dios increased at a much slower rate than that of the other regions since the 1990s, resulting in the current lowest population density among neighbors (Figure 3A). The four regions started with an annual gross domestic product (GDP; Box 1) lower than $300 million each in 1990 (Figure 3B). In the following years, Acre has experienced an exponential economic boom, whereas the Peruvian regions have just started to experience economic growth, and Pando in Bolivia has been stagnating at less than $500

Figure 2. A sample of Madre de Dios biodiversity. Top row, from left: *Phyllomedusa vaillantii*, *Passiflora coccinea*, *Panthera onca*, *Caiman crocodilus*. Row 2: *Piaractus brachypomus*, *Heliconius melpomene*, *Florisuga mellivora*, *Tillandsia* sp. Row 3: *Tapirus terrestris*, *Mitu tuberosum*, *Bradypus variegatus*, *Pitangus sulphuratus*. Bottom row: *Podocnemis unifilis*, *Hypsiboas fasciatus*, *Hymenochaete* sp., *Erotylus incomparabilis*.







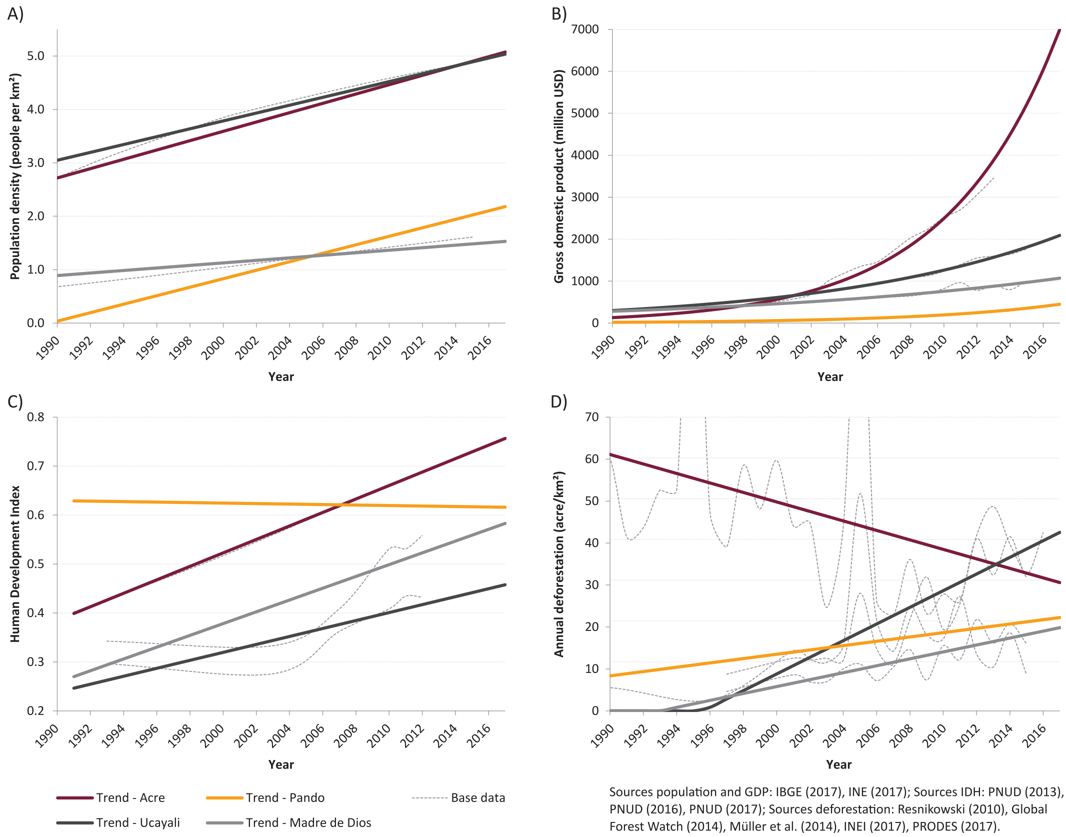



Figure 3. Social, economic, and environmental indicators of Madre de Dios and neighboring regions.

million GDP. Nationally, Madre de Dios's GDP remains behind all other Peruvian regions (INEI 2017). Currently, the Human Development Index (HDI; Box 1) is the highest in Acre, followed by Pando and Madre de Dios, and lowest in Ucayali (Figure 3C). Deforestation resulting from the economic development of these regions has been erratic (Figure 3D), but the trends show it began in Peru in the mid-1990s and has been much less intense in Madre de Dios than in Ucayali. In contrast, deforestation was high in the 1990s in Acre and Pando and has been decreasing in Acre since 1990, supported by strong anti-deforestation policies. Deforestation has increased steadily in Pando during this period. In summary, Madre de Dios maintains a relatively high human development index, a low deforestation rate and low population density, but falls far behind its neighbors in terms of economic development (Figure 3).

Madre de Dios's lagging economic development encouraged the national and local Peruvian governments to promote economic development in the region. Construction of the Interoceanic Highway connecting ports on the Atlantic coast of Brazil to those on the Pacific coast of Peru, occurring between 2007 and 2010, was a centerpiece of development efforts (Redwood 2012). The road profoundly modified the landscape of the region (Delgado 2008, Southworth et al. 2011), accelerating the transition of the regional economy from forest-based extractive industries to agriculture, cattle production, alluvial gold mining, and tourism, all promoting immigration and population growth (Figure 4). Based on 1993 and 2007 population censuses at the settlement levels (INEI 1994, 2008) and official projections of population changes (INEI 2010b), we modelled likely settlement-level population changes in Madre de Dios and extrapolated that between 140,000 and 160,000 people lived in Madre de Dios in 2017. Based on the demographic rate of increase of Amazonian native communities between 1993 and 2007, we estimated in 2017 that 4100 persons were living in one of the 14 native cultures found in the region, mostly Amarakaeri (27%), Matsiguenga (19%), Ese'ejja (15%), and Piro (13%) (INEI 2010a). Historically, the region received many immigrants from the neighboring Andean regions of Cusco, Puno, Arequipa, and Apurimac (INEI 2011), and from the neighboring countries of Brazil and Bolivia, attracted by the exploitation of forest products such as wood and Brazil nut, and by alluvial gold mining. In 1998, the Ministry of Energy and Mines estimated that 10,000 people worked directly in the gold sector in Madre de Dios, and between 20,000 and 30,000 people make a living indirectly from gold mining (GOREMAD 2006). Between 2012 and 2014, annual production of alluvial gold was estimated to be between 8 and 10 metric tons and to have contributed 15%–30% of the region's GDP (GOREMAD 2017). Historically, most immigrants have settled in the town of Puerto Maldonado, particularly between 2002 and 2007 (INEI 2011) to engage in small-scale alluvial mining, agriculture, or cattle production. Currently, national economic growth, immigration, and the rise of international gold prices are important drivers of deforestation and ecosystem degradation (Southworth et al. 2011, Swenson et al. 2011, Chávez Michaelsen et al. 2013). Peru's agricultural sector is changing slowly (World Bank 2017), with a decline in its contribution to the country's economy and in the share of agricultural workers

Box 1. Economic and Social Indices Used to Compare Regions

Gross domestic product (GDP) is a monetary measure of the market value of all final goods and services produced in a period. Nominal GDP estimates are commonly used to determine the economic performance of a region, and to make international comparisons.

Human Development Index (HDI) is a composite statistic of life expectancy, education, and per capita income indicators, which are used to rank countries in terms of human development. A country scores higher HDI when the lifespan is longer, the education level is greater, and the GDP per capita is higher.




Figure 4. Madre de Dios's main economic activities. Top row: mining (left) and agriculture (right). Row 2: tourism (left) and raising cattle (right). Row 3: logging (left) and harvesting Brazil nuts (right). Bottom: harvesting latex (*Shiringa*, far left) and gathering traditional forest and river products.











in total employment since the 1990s, characteristic of an "urbanizing" economy. Concomitantly, the volume and value of Peruvian agricultural production has grown steadily at an rate of 3.3% per year, and the absolute number of agricultural workers has grown, in particular in the Peruvian Amazon (47% in the 1994–2012 period). This resulted in the conversion of 1.64 million hectares to agriculture lands nationwide. In the Peruvian Amazon, annual small-scale agriculture was progressively replaced with permanent crops (coffee, cocoa, palm oil) and pastures. Nowadays, most of the agricultural production in the Peruvian amazon is dedicated to national and international markets. The Amazonas and San Martin regions concentrate most of the agricultural activities of the Peruvian Amazon and tend to become saturated, forcing farmers to find new lands in other Amazonian regions of Peru.

The regional development and associated forest cover changes are likely to continue and accelerate in the future, with major infrastructure projects (highways, railroads, gas lines, hydroelectric projects, power lines, and river channelization) being planned in South America (Laurance et al. 2001, Timmons 2013). The construction of new infrastructure will have direct consequences on Madre de Dios's development. For example, the program for the Integration of Regional Infrastructure of South America (IIRSA) had a portfolio of active projects in 2017 representing an investment of $150 billion for the construction of infrastructure in the Amazon (IIRSA 2017). There are 151 proposals for hydroelectric dams in Colombia, Ecuador, Peru, and Bolivia (Finer and Jenkins 2012, Little 2014), 77 of which are located in the Peruvian Amazon and have a total estimated investment of $55.6 billion (PROTEGER 2017). Concessions for hydrocarbon exploration now cover 84% of the Peruvian Amazon (Little 2014) and investment commitments reached $7.2 billion in the 2015–2017 period (Tamayo et al. 2015). But the drop in international prices of hydrocarbons since 2014 has reduced these investments considerably, falling to $56 million for exploration and $296 million for exploitation in 2016, a 65% decrease compared to 2014. In 2018, the Peruvian government was expecting an increase in hydrocarbon investments of 5% compared to 2016 (Ernst & Young 2017), suggesting a new cycle of investments in the sector. With a hydrocarbon potential of 10 billion barrels of oil throughout its territory, oil and gas production in Peru will certainly continue and expand in the future. Mining concessions cover 21% of the total area of the Amazon Basin, mostly in Brazil and Peru (Little 2014). The construction of the Interoceanic Highway has opened Madre de Dios to changes, attracting migrants who engage in alluvial mining and agriculture, but also investors looking to develop infrastructure and exploit hydrocarbon resources and minerals. All these changes will likely accelerate the transformation of Madre de Dios in the coming decades.

Madre de Dios's Changing Landscape (1993–2017)

Changes in the landscape of Madre de Dios started in the 1960s and continued at a slow rate until the 1990s. The satellite analysis of landscape changes in the region (see page 29) clearly shows the rapid transformation of Madre de Dios between 1993 and 2017:

In 1993 (Figure 5), the road that now has become the Interoceanic Highway was unpaved and impassable during the rainy season. Amazonian forests covered more than 99% of the region's territory, except around Puerto Maldonado and Iberia, where agriculture (461 km^2, 0.6% of the region) was developed along the road as a result of the proactive policies of the 1980s. Agriculture in the region was typically migratory. First, farmer cut a surface of forest to establish corn, rice, or papaya. After a few years, the nutrient-poor Amazonian soil lost its fertility and the land was planted with grass to raise cattle (GOREMAD 2008). This cycle promotes deforestation, favors erosion, and releases contaminants such as nitrates and phosphates into surface waters. Forests of Madre de Dios were exploited through timbering of tropical hardwoods, as well as for the Brazil nut (*Castaña*), and latex (*Shiringa*) non-timber forest products. Alluvial gold mining was limited at the time encompassing 40 km^2, and concentrated along the Huepetuhe, Puquiri, Malinowski, and Inambari Rivers and their tributaries.

In 2003 (Figure 6), the condition of the Interoceanic Highway remained the same, but a secondary network of roads was starting to develop, branching from the main axis and totaling an estimated 408 km in length. Surface area of agriculture land had nearly doubled since 1993, with 432 km^2 of new agricultural land encroaching on the forest. In the same period, mining more than quadrupled in area, reaching a total of 174 km^2. Most of the expansion occurred in the mining sector of Huepetuhe, deforesting approximately 80 km^2, mostly between 1996 and 1998, and along the Puquiri and Inambari Rivers (Google Earth Engine Team 2015). Urban areas more than doubled in surface, mainly in Puerto Maldonado, but also in Iberia and smaller towns along the Interoceanic Highway, due to the flux of migrants coming mostly from neighboring Andean regions.

By 2013 (Figure 7), the last section of the road linking Puerto Maldonado with the Andean highlands had been paved, completing the transcontinental Interoceanic Highway and making the region accessible in all seasons. In the period between 2003 and 2013, the international price of gold went from less than $400 per ounce to above $1800, prompting the expansion of mining areas (Asner 2013). Between 2007 and 2013, the mining areas of Guacamayo-La Pampa (approximately 90 km^2) and Delta 1 along the Puquiri River (approximately 151 km^2) were opened, while Huepetuhe continued to grow (reaching approximately 121 km^2). The Inambari and

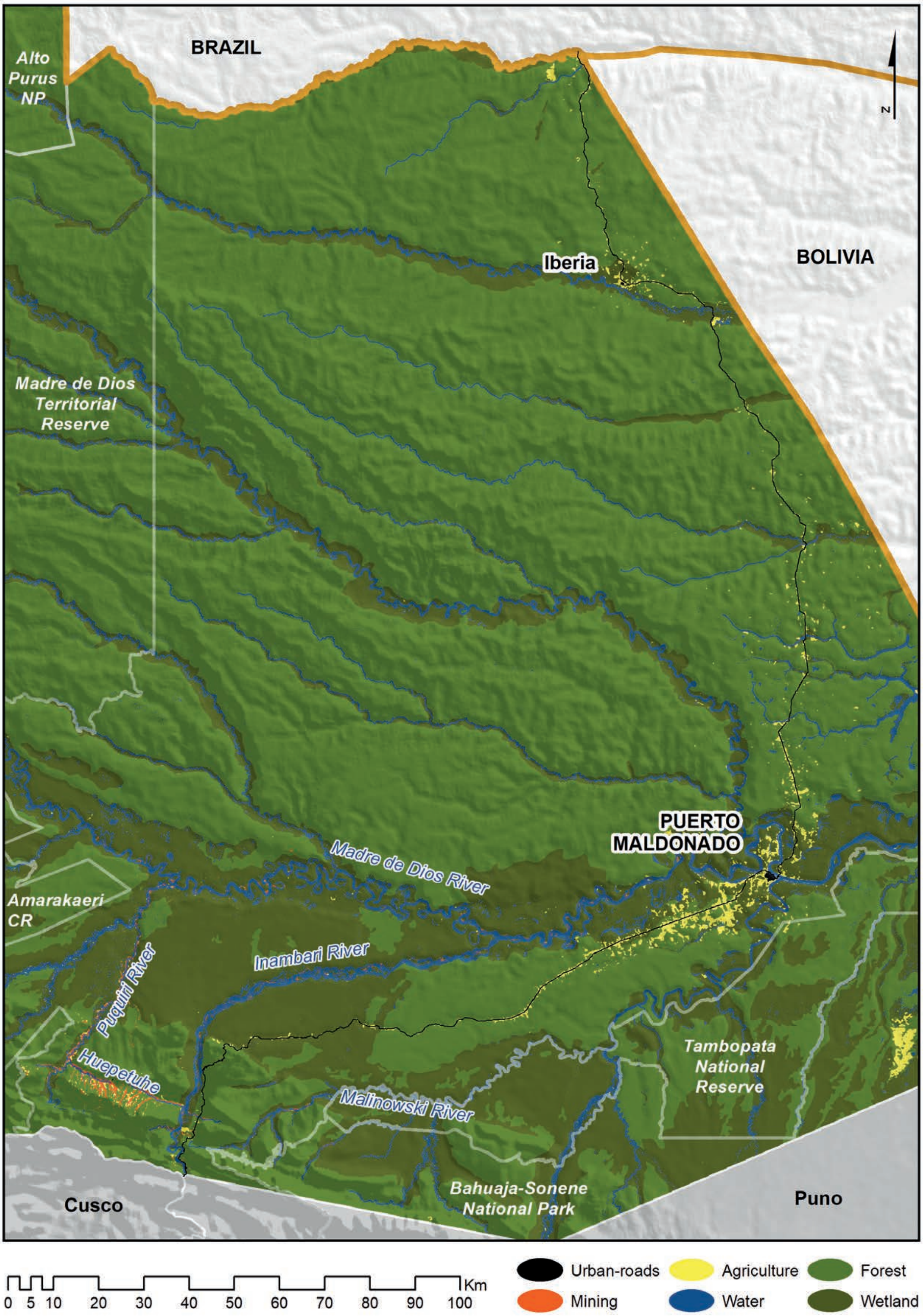


Figure 5. Madre de Dios landscape in 1993.

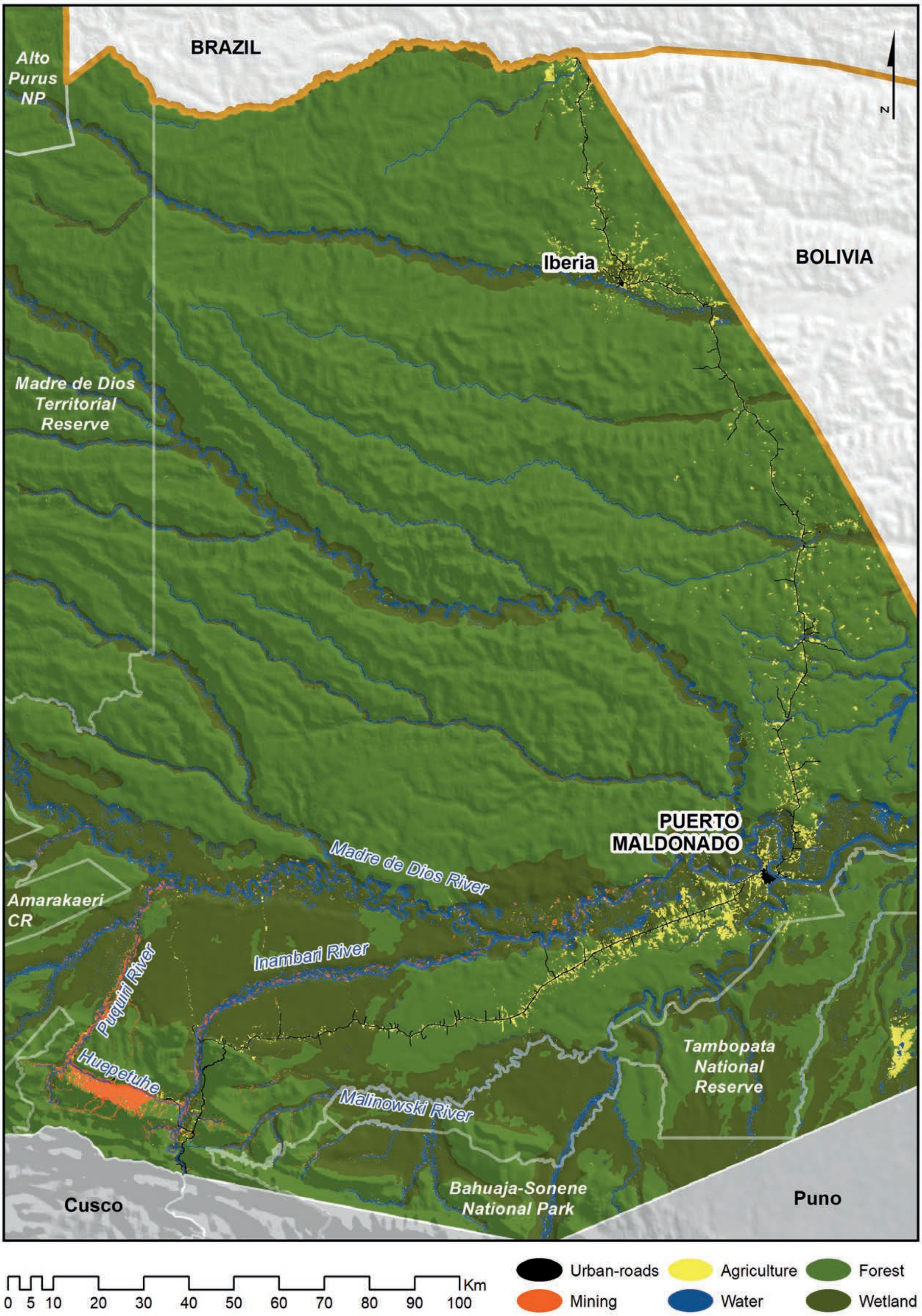


Figure 6. Madre de Dios landscape in 2003.

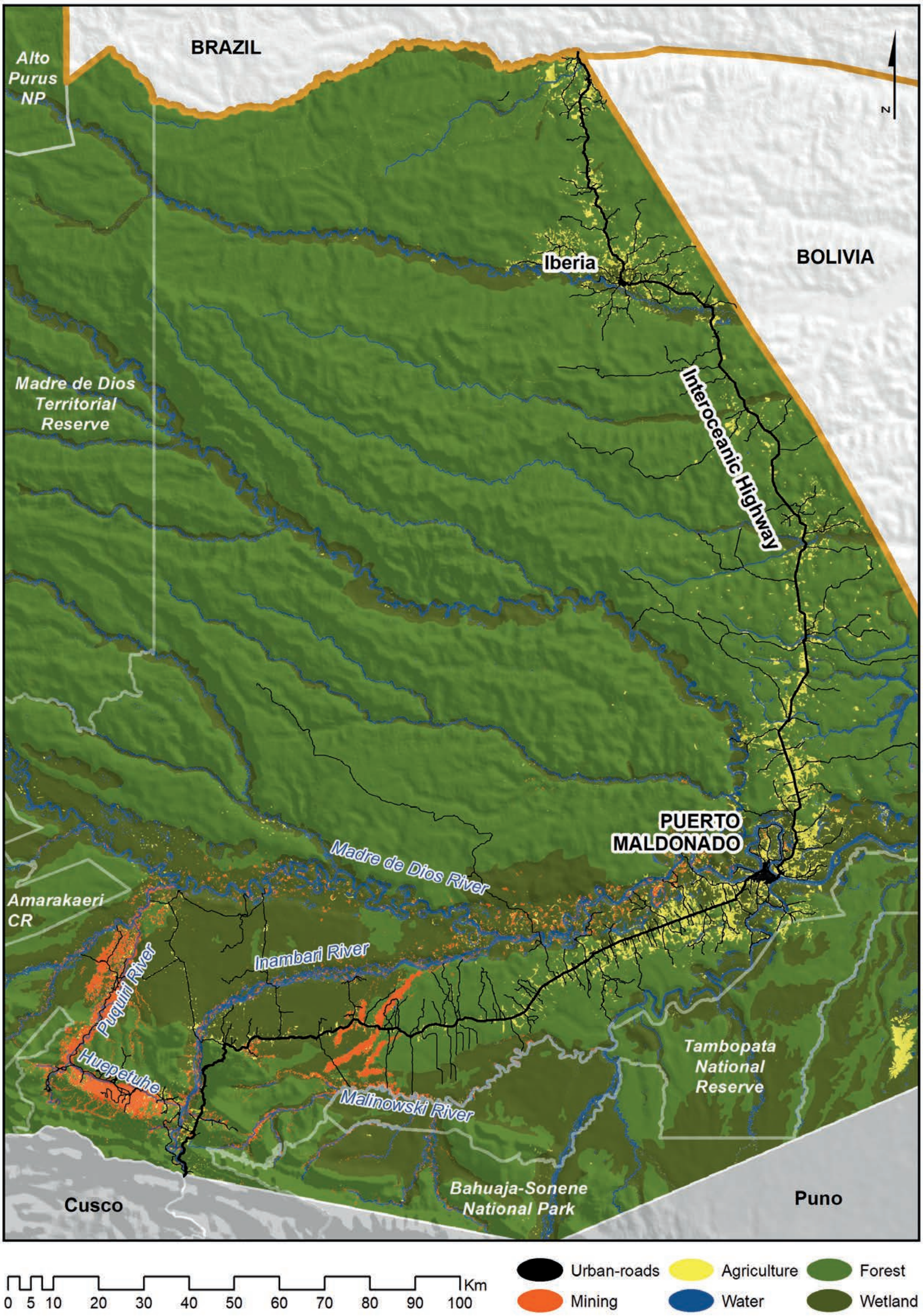


Figure 7. Madre de Dios landscape in 2013.

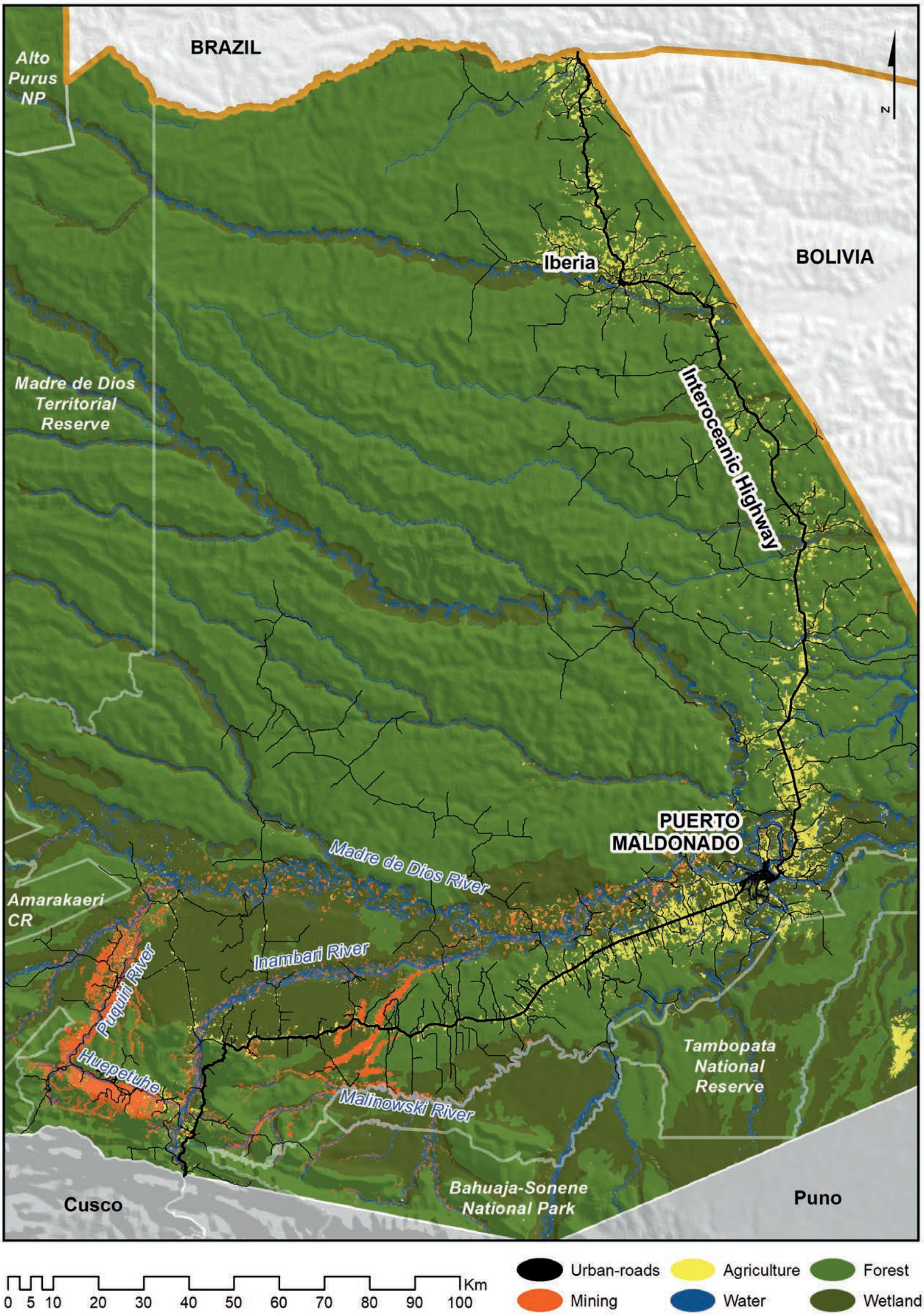


Figure 8. Madre de Dios landscape projected to 2017.

Malinowski rivers, along with their tributaries, were invaded by diffuse and small-scale deforestation for alluvial mining (Google Earth Engine Team 2015). Agriculture and urban areas continued to expand, reaching 1440 km^2 and 31 km^2, respectively. The gold rush, easier road access, burgeoning urbanization, and continued agricultural expansion accelerated the construction of secondary roads, with their length multiplied by seven compared to 2003, reaching 2889 km. The facilitated access provided by this extensive network of secondary roads allowed exploitation of resources up to 10 km away from them (Queiroz and Gautam 1992), including hunting and illegal logging that, in particular, have important consequences on the quality and functions of the ecosystems around roads.

We generated a map of Madre de Dios in 2017 (Figure 8), based on the rate of changes observed between the 1993, 2003, and 2013 maps. From this map, we estimate the forest still covers 97.6% of Madre de Dios. Agriculture now covers 1585 km^2 (nearly 2%) of the region, and mining 512 km^2 (0.6%). Other studies based on satellite imagery found higher gold mining surface, representing 682 km^2 (0.8% of the region's surface; Asner and Tupayachi 2017) and 958 km^2 (1.1%; Caballero et al. 2018). Secondary roads continue their rapid expansion (total 4380 km), connecting new agriculture and mining areas to the Interoceanic Highway. Today the region's landscape is a mosaic of agriculture, cattle ranching, urbanized zones, and alluvial gold mining lands around the Interoceanic Highway, with Brazil nut and selective timber extraction developing in the vast forests beyond the development front (Giudice et al. 2012, Nunes et al. 2012, Asner 2013). Most of these activities are performed illegally or in the informal sector, creating many conflicts between landowners (communities or concessionaires) and "invaders."

Deforestation for crop and cattle production, and alluvial gold mining in the last 25 years in Madre de Dios (Figure 9) has had multiple environmental consequences on Peru's capital of biodiversity (Box 2).

Deforestation contributed to the loss of biodiversity by destroying the habitats species need to survive, but also affected ecosystem services on which human society relies: the release of carbon in the atmosphere reinforced global warming, the loss of vegetation cover accelerated erosion of soils and reduced its fertility, and vegetation and wetlands disappearance hindered the capacity of the land to retain pollutants washed away from development areas (Fearnside 2005, GOREMAD 2006, Cárdenas Panduro 2010, Asner et al. 2013). All these changes are concentrated along the periphery of the Interoceanic Highway but also extend to protected areas like the Tambopata National Reserve. The strip of deforested lands along the Interoceanic Highway bisects Madre de Dios and can become an impassable barrier to animals migrating between the protected areas of the Vilcabamba–Amboró

Box 2. Consequences of Illegal and Informal Alluvial Gold Mining

Gold from primary rocky deposits in the Andes is broken down by weathering and erosion, and washed away by rivers. It is deposited in sediments accumulated over millennia in the Amazonian basin, over which grows the Amazonian rainforest. Alluvial gold mining requires washing the superficial sediments with water from powerful pumps and extracting gold flakes from the finer sediments by amalgamating it with mercury. The activity causes irreversible damage to ecosystems by promoting deforestation, erosion, and contamination of air and water with mercury and other toxins such as hydrocarbons (Mosquera et al. 2009). Large mining camps also cause a local increase of hunting and defaunation of the surrounding forests (SPDA 2014b).

Beyond environmental consequences, alluvial mining also comes at high human and societal cost. The mercury released in mining areas is a dangerous poison that accumulates in the food chain, particularly in fishes consumed by local people (Ashe 2012, Diringer et al. 2015). Most fish species in Madre de Dios have mercury levels in their tissues that are above WHO and EPA recommendations (Mosquera et al. 2009). Legal and illegal artisanal gold mining is often done in extremely poor health and safety conditions, and has ties to organized crime (Mosquera et al. 2009). Mining camps lack basic services such as running water, electricity, or access to health and education, and are usually plagued with violence, prostitution, and drug trafficking (SPDA 2014b).

After years of efforts to formalize the alluvial gold mining sector, most operators have not completed the procedure and still occupy lands that are disputed by other users (Mosquera et al. 2009). These "informal" gold miners are declared to the authorities, operate outside protected areas, and do not use heavy machinery operating on barges directly in water bodies. In theory, the state is steering informal miners toward formalization and adherence to all environmental norms. Failure by these minors to adhere to the criteria is illegal and subject to prosecution (SPDA 2014a), although pursuits are rare.

conservation corridor, threatening the connectivity of the entire landscape. Like an asphalt curtain, the deforestation front divides Peru's capital of biodiversity, aggravating the consequences of landscape fragmentation on the Vilcabamba–Amboró conservation corridor. Before fragmentation in Madre de Dios reaches levels observed in the Atlantic forest of Brazil (Box 3), the government of Peru needs to integrate aspects of landscape connectivity—the capacity of a landscape to facilitate the biodiversity flow among resource patches—in their management plans for the future sustainable development of Madre de Dios (Dourojeanni et al. 2009, Entenmann 2012).

Managing the Landscapes of Madre de Dios

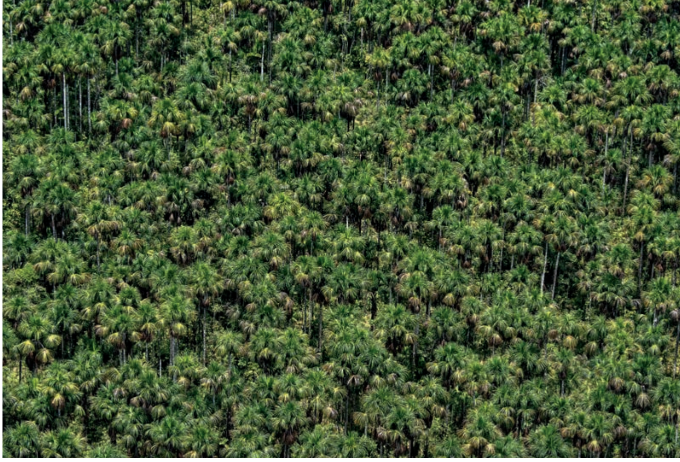
Madre de Dios has made significant progress in planning its territorial management, but not in implementing those plans. It has developed an ecological and economic macro-zoning of its territory (GOREMAD 2009) and a regional land




Figure 9. Elements of Madre de Dios's landscapes. Top row: rainforest highlands (left) and wetlands (right). Row 2: lowlands (left three) and Pampa de Heath (far right). Row 3: meadows (left) and cultivated fields (right). Bottom: alluvial gold mining fields and towns (left three) and urban areas (far right).



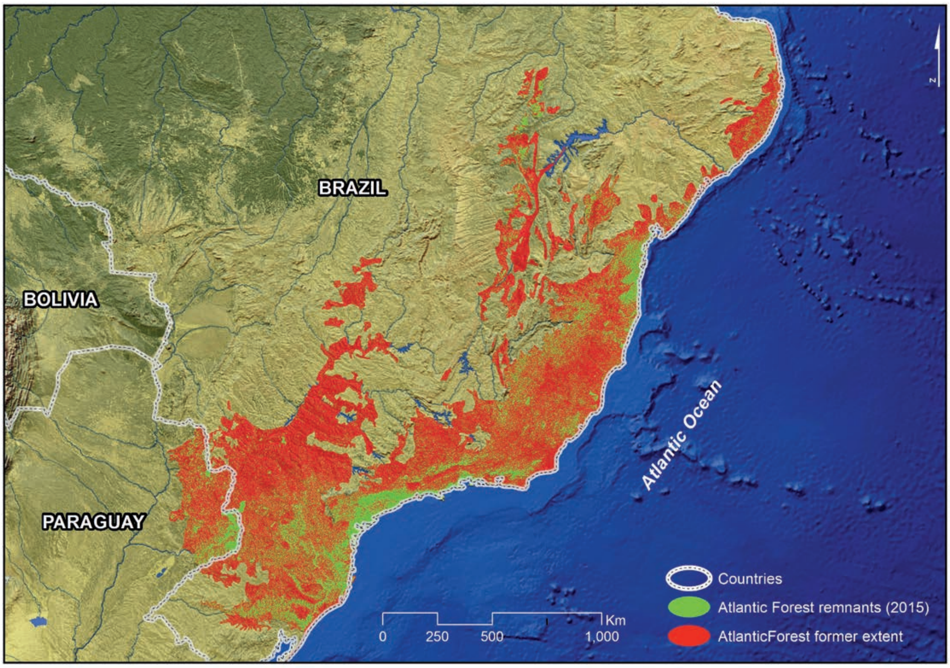








Box 3. Deforestation and Fragmentation of the Atlantic Forest of Brazil



Atlantic Forest former extant from Olson et al. (2001); 2015 Atlantic Forest remnants from Hansen et al. (2013).

Many human activities break up large, contiguous forest tracts into smaller patches, a process called forest fragmentation. Fragmentation disrupts the population dynamics of forest species, reducing biodiversity and affecting ecosystem functioning and ecosystem services (see page 37) (Saunders et al. 1991, Foley et al. 2007). Extensive areas of human-dominated landscape isolate patches of forest and can reduce or impede animal movements between forest fragments, reducing ecosystem resilience to land-cover and climate changes (Malhi et al. 2008). The Atlantic Forest of Brazil has lost 93% of its original surface area to agricultural expansion, ranching, logging, conversion to tree plantations, and road building (Pina-Costa et al. 2014), which has resulted in the loss of 48% of species (Brooks et al. 2002). Of the remaining species of plants, birds, mammals, reptiles and amphibians, 530 are in danger of extinction (Ribeiro et al. 2009). In the deforested areas, significant alterations of ecosystem services such as carbon storage, water provision and purification, or local climate regulation have occurred (Ribeiro et al. 2011, Izquierdo and Clark 2012). Banks-Leite et al. (2014) estimated the median yearly gross profit of agricultural lands in the Atlantic Forest at $467 per hectare per year, and that at least 424,000 ha (0.3% of original cover) needs to be restored to return the Atlantic Forest to 30% of its former extant. They suggest establishing payments for ecosystem services to farmers for protecting the forest, and compensating land owners with $133 per hectare per year. If this doesn't compensate for all the individual losses, it reduces the agricultural GDP of the affected municipalities by only 0.61%. The national cost of this plan was estimated at $200 million per year to restore the Brazilian Atlantic forest to 30% of its historical extent (Banks-Leite et al. 2014).

management plan extending through 2030 (GOREMAD 2014c), but these plans have not been validated or implemented. Consequently, the region continues to develop without planning, resulting in considerable overlap in land-use concessions that causes economic loss, social conflicts, and poverty as well as severe ecosystem degradation (GOREMAD 2014c).

The rapid landscape changes in Madre de Dios call for a rapid and decisive response of the regional and national governments of Peru. Lack of decisive actions will increase the ecological and social costs of this unplanned development toward unsustainability in a large portion of the landscape. Rapid landscape transformation will undeniably result in the decline of biodiversity in the most preserved protected landscapes in the Amazon Basin (Soares-Filho et al. 2006, Hansen et al. 2013), necessarily leading to the deterioration of ecosystem services and human well-being in the region.

A Vision for Madre de Dios

Madre de Dios has strong assets to embark on the path to conservation and sustainable development: the ambitious reforms of territorial management policies at the national level, Madre de Dios's relatively good environmental and social performance compared to its neighboring regions, a small population, an impressive network of protected areas, and a territorial planning process on the way. An inspiring vision for the region's development could rally the dispersed forces at play and channel them toward common sustainable development goals.

The Smithsonian Center for Conservation and Sustainability (CCS) engaged in a project to promote sustainable infrastructure planning through the provision of strategic information and analysis. The CCS developed a modelling tool to help Madre de Dios's decision makers and other stakeholders define a common vision for the future of their region: the Smithsonian Working Landscape Simulator. This tool goes beyond the raging debate of how much forest land should be conserved to preserve the most important ecosystem services a landscape is offering by taking a more realistic multidimensional approach. The evaluation of success of a conservation scheme is subjective, because ecosystems are complex and provide a vast array of services that are affected differently by development, and because local stakeholders do not equally bear the costs of the interventions and of the loss of services. What is considered a success by some stakeholders may be a catastrophe for others. The Smithsonian Working Landscape Simulator embraces this complexity and provides the key information needed to stimulate a healthy negotiation among local stakeholders, in pursuit of the best compromise possible.

2

THE WORKING LANDSCAPE SIMULATOR: AN INNOVATIVE APPROACH

A Tool for Decision Makers

The Smithsonian's Working Landscape Simulator is a carefully structured, seven-step framework for assessing and facilitating territorial management. The tool combines ecosystem service assessment, scenario planning, and the working landscape framework into a new approach. Below are the essential components and framework of the model.

Ecosystem services are the benefits (products and services) that people, including organizations and businesses, derive from ecosystems (Reid et al. 2005). They include *provisioning* services such as food, water, and timber; *regulating* services that affect climate, floods, disease, waste, and water quality; *cultural* services that provide recreational, aesthetic, and spiritual benefits; and *supporting* services, which contribute to the supply of the other services such as soil formation, photosynthesis, and nutrient cycling (Reid et al. 2005). The provision of ecosystem services relies on properly functioning ecosystems (Hooper et al. 2005) and justifies the implementation of conservation actions. An ecosystem service approach in planning is intended to support the development of policies and instruments that integrate social, economic, and ecological perspectives (Seppelt et al. 2011). Proper identification and prioritization of ecosystem services at local and regional scales with stakeholders facilitate decisions related to their management and protection (Landsberg et al. 2013). Despite its challenges (Reed 2008, Young et al. 2013), proper stakeholder engagement leads to numerous benefits, including decreasing the likelihood of marginalization, empowering stakeholders through knowledge development, increasing perception of a fair decision-making process, and providing social learning opportunities (Luyet et al. 2012, Durham et al. 2014).

Scenario planning (Figure 10) is a structured way to think about the future to facilitate decision making (Chermack 2004). It was developed simultaneously by both Herman Kahn, to formulate strategies for the U.S. Military (Kahn and Wiener 1967), and Gaston Berger, to help formulate public policy (Berger 1966). Scenarios are "plausible, challenging, and relevant stories about how the future might unfold, which can be told in both words and numbers" (Raskin et al. 2005). Stories in words refer to the qualitative narratives, while stories in numbers refer to the quantitative evaluation of scenarios using key indicators of success such as ecosystem services or socioeconomic indicators. The quantitative evaluation of scenarios is conducted

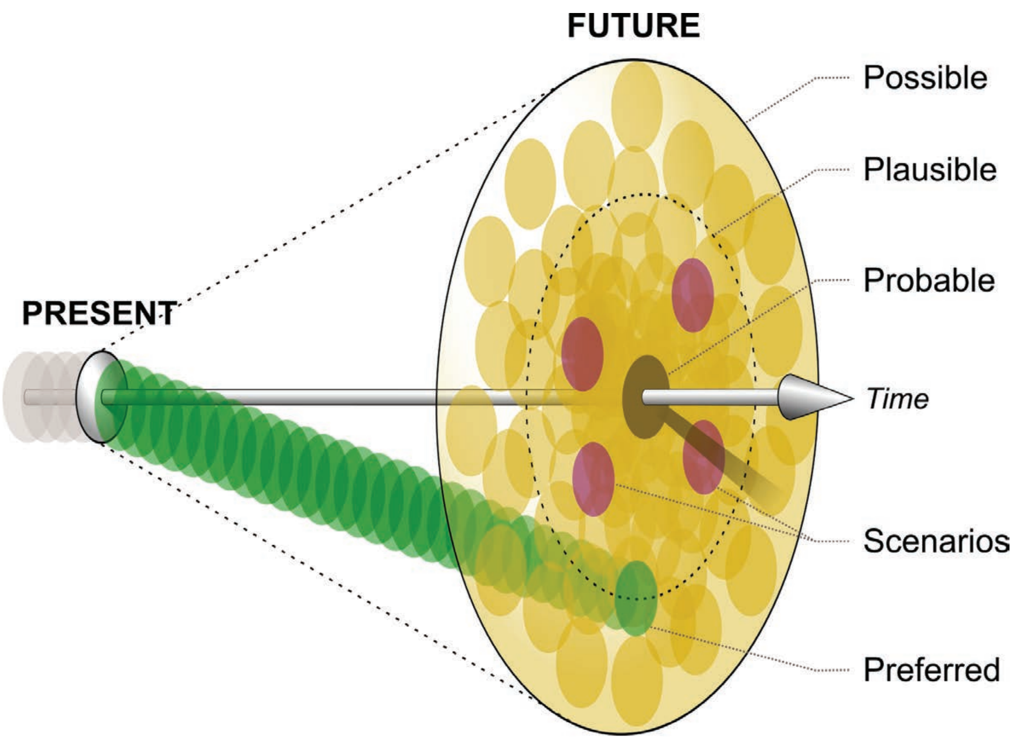


Figure 10. The CCS scenario planning approach. The state of a territory in the present (solid gray circle to the left) is evolving through time (gray arrow). The state can change in many different ways as time passes (yellow circles to the right), and all these states form the possible future (large circle to the right). Within these possible future states, some are more plausible (within the dotted circle), and one is the most probable (brown circle), as it follows the trends observed in the present and near past (gray circles to the left). Scenario planning consists in exploring a handful of plausible future states that are called scenarios (purple circles). These states are inferred from present and recent past conditions, and extrapolated to the future. By exploring these scenarios, the method allows stakeholders to define a preferred future state (green circle) and the optimal trajectory (green tube) to transition from the present to the preferred state.

with mathematical models describing the relationships between indicators of success and key drivers of change (any natural or human-induced factor that directly or indirectly causes a change).

Working landscapes are productive territories where ecosystems are managed sustainably. Working landscapes include gray infrastructure (e.g., roads, cities, power lines) that provide economic services and green infrastructure (e.g., rivers, forests, marshes, protected areas) that provide ecosystem services and also support biodiversity. Green infrastructure is the interconnected network of natural and semi-natural areas that conserves natural ecosystem values, functions, and services, sustaining social and economic health (Benedict and McMahon 2012). When gray and green infrastructures are appropriately and jointly managed, the landscape can achieve sustainable development.

The Smithsonian Working Landscape Simulator combines these three approaches to uncover the probable results of alternative development paths on key economic, social, and environmental indicators using past regional trends, the current status of regional conservation and development, and the aspirations of stakeholders. The tool, thus, can inform decision makers about long-term consequences of their choices.

The Smithsonian Working Landscape Simulator

The Smithsonian Working Landscape Simulator (Figure 11) can be applied in any territory to support land-use planning decision making. It relies on the participation of stakeholders to precisely define the parameters of the quantitative model and development of a tailor-made model adapted to people's interests and the local territory. The framework comprises seven steps.

Step 1. Define Essential Ecosystem Services

Stakeholders are consulted to identify the key ecosystem services in their territory, and the drivers of change affecting them.

In our study, we first conducted a stakeholder mapping analysis (Golder and Gawler 2005, Kennon et al. 2009) to identify what stakeholders should be consulted, building on previous assessments in Madre de Dios (Alvarez et al. 2013, del Pilar Bustamante and Ochoa 2014, GOREMAD 2014a). We identified 51 stakeholders, of whom 26 agreed to participate. Stakeholders were from local, regional, and national governments, nongovernmental organizations (NGOs), community organizations, and the private sector. In May 2015, we conducted two-hour personal interviews in Puerto Maldonado and

Figure 11. The Smithsonian Working Landscape Simulator framework.

Lima. We also organized a workshop with NGOs in Puerto Maldonado (see appendix). We asked stakeholders to prioritize ecosystem services in the region, to identify the main drivers of change affecting them in the present and in the future (10–15 year timeframe), and to provide information on their relationships with other organizations. Based on the stakeholder mapping analysis, a social network analysis (Vance-Borland and Holley 2011), and a group relationship analysis derived from their declarations during the consultations, we assessed the representativeness of each participating stakeholder with respect to the following 13 groups: national government, regional government, indigenous communities, farmers, non-timber forest product (NTFP) extractors, loggers, formal and informal miners, hydrocarbon companies, hydropower managers, tourism companies, conservation NGOs, universities and research institutions, and civil society. We then used each stakeholder's representativeness to weight the group's priorities about ecosystem services and drivers of change, with the purpose of balancing the representativeness of each group equally to ensure the highest neutrality in the prioritization process: we weighted higher the groups under-represented, and weighted lower the groups over-represented.

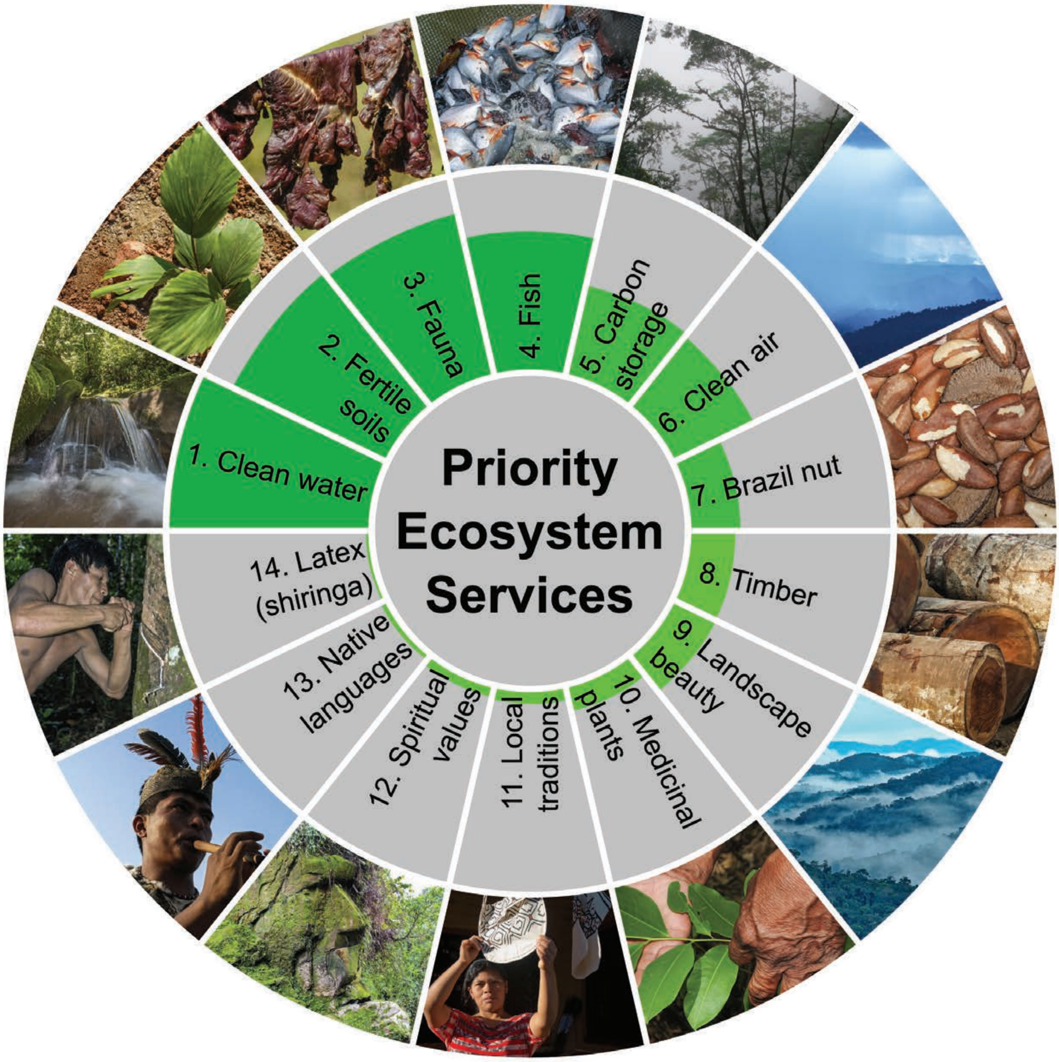


Figure 12. Priority ecosystem services identified by Madre de Dios stakeholders. In green are the priority scores obtained by each ecosystem service, from the highest priority (clean water) to the lowest (latex).

Stakeholders identified 14 relevant ecosystem services for Madre de Dios (Figure 12). From the water resources, soil fertility, and biodiversity categories, 4 were identified as high priority. From the air and carbon-capture and NTFP categories, 3 were classified as medium priority.

Stakeholders identified a total of 26 drivers of change (Figure 13), classifying 7 as high priority and 6 as medium priority. Illegal mining, mercury pollution of rivers, and highways and roads were classified as the three main drivers of change affecting ecosystem services in the region. Similarly, stakeholders

Figure 13. Most important drivers of change identified by Madre de Dios stakeholders. In orange are the importance scores obtained by each driver of change, from the most important (illegal mining) to the least important (oil and gas concessions). Other drivers of changes of lower importance include land-use overlaps, ineffective communication between ministries, solid-waste management, loss of traditional culture, nonregulated markets, hunting, urban expansion, economic development, cattle raising, transit of boats on rivers, fishing, and agriculture plagues.

considered the conversion of land for agriculture, immigration to the region, ineffective policies from the national government, and inadequate economic priorities as high priority drivers of change. We then used prioritized ecosystem services and drivers of change, as well as their perceived evolution in the future, to develop scenarios specific to Madre de Dios.

Step 2. Develop Qualitative Scenarios

Stakeholders' priority ecosystem services and their drivers of changes are combined into alternative future scenarios.

Priority ecosystem services and drivers of change identified in the previous step were included in a simple conceptual model (Margoluis et al. 2009) showing their interactions (Figure 14). The conceptual model allowed us to identify causal chains (Leemans et al. 2003) linking underlying forces of change (e.g., immigration) to proximate causes of change (e.g., gold mining and water pollution with mercury), to final ecosystem services (e.g., drinking water; Geist and Lambin 2002). Starting from the possible future states of underlying forces of changes described by the stakeholders, we evaluated the consequences they would have along our causal chains and built alternative chains. We selected the alternative causal chains that would most

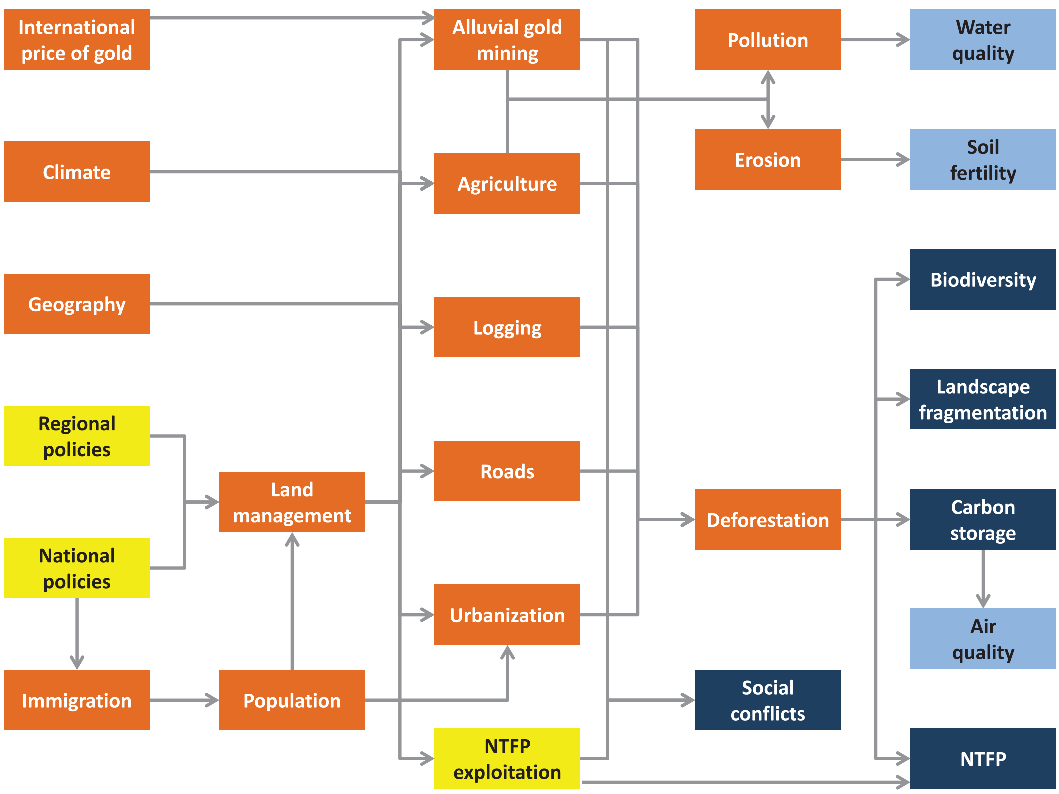


Figure 14. Conceptual model of interactions between priority drivers of change (underlying forces on the left to proximate causes at center-right) and relevant socioecological indicators (including priority ecosystem services). Orange boxes: drivers of change explicitly modelled; yellow boxes: drivers of change not explicitly modelled; dark blue boxes: indicators explicitly modelled; light blue boxes: indicators not explicitly modelled.

significantly affect the priority ecosystem services and combined them into eight future landscape scenarios for the Madre de Dios region, including a scenario with all positive outcomes and another with all negative outcomes. We then checked and adjusted the resulting scenarios to obtain internal consistency and plausibility (Schoemaker 1995, Mahmoud et al. 2009).

The resulting eight scenarios represented the sensitivities and priorities of the stakeholders interviewed in the first round of consultation. We consulted stakeholders again in June 2015 to refine the eight scenarios and select those most interesting and relevant (Reed et al. 2013). Although invitations were extended to all stakeholders initially contacted, only 14 confirmed their participation in the second round of consultation (see Appendix). The representativeness of the stakeholders consulted, calculated as in the previous step, was used to weight the individual priorities.

The four final scenarios include the three top scenarios for local stakeholders—Land Planning, Expansion of Alluvial Gold Mining, and Landscape Conservation—and Current Trends, as the baseline to which the other scenarios can be compared. The main hypotheses of these scenarios were refined to the final hypothesis used in the modelling process (see pages 41–57).

Step 3. Compile Historical Data

Quantitative data on key drivers of change and indicators of success are compiled to develop a statistical model of land-use and land-cover change in the territory.

For Madre de Dios, we compiled economic, social, and environmental data from many sources from both inside and outside the region, resulting in 258 references used to support our model. When multiple sources where available, we always gave priority to the most authoritative one based on data collected locally. When no local data were available, or when we had serious doubt about the quality of the data, we also used globally available databases or data from outside the region.

One key element for the modelling was a solid statistical understanding of land-cover changes in the region. For this, we created land-cover maps of Madre de Dios for years 1993, 2003, and 2013 using Landsat 7 and 8 satellite images (Roy et al. 2014). We used the Random Forest Classifier (Breiman 2001, Liaw and Wiener 2002) to sort Landsat image pixels into the most prominent and unequivocal land-cover classes in the study area: water, bare soil, wetland, forest, agriculture, gold mining, and urban. Final accuracy of the maps ranged from 73% (1993) to 80% (2003). We used the narratives developed with stakeholders and the results of our data collection and land-cover change analysis to derive quantitative hypotheses specific to each scenario.

Step 4. Develop a Quantitative Model of Land-Use Changes

A spatially explicit model is developed to predict future landscape changes from the expected evolution in the drivers of changes identified by stakeholders.

For modelling land-cover changes in Madre de Dios, we built a spatially explicit computer model based on the observed land-cover changes between 2003 and 2013. We calibrated and validated the model to ensure it was able to replicate into the future the observed changes that occurred in Madre de Dios. The model simulates changes in land cover on a yearly basis between 2013 and 2040. The outputs include maps of predicted land cover, location of primary and secondary roads, as well as settlement-specific population estimates in the simulated years. All drivers of changes are updated dynamically from one year to the next. All modelling in this step was done on the DINAMICA EGO platform (Soares-Filho et al. 2002).

The quantitative model used in Madre de Dios included different interconnected modules, or submodels, processing specific drivers of change used in the simulation (Figure 15).

1. **Land-Cover Changes:** Makes areas in the landscape change to forest-wetland, agriculture, and mining land covers. The probability that a pixel (a physical point in a raster image) changes its land-cover category over time is calculated from a suite of quantitative predictors representing the drivers of changes defined with stakeholders in the consultation process, following the Weights of Evidence method (Bonham-Carter et al. 1989, Goodacre et al. 1993, Soares-Filho et al. 2002, Soares-Filho et al. 2004). Predictors were related to land management (indigenous lands, protected areas, and concessions such as agriculture, NTFP, logging, reforestation, ecotourism, conservation, and gold mining), geography (geology, elevation, and slope), climate (temperature, precipitation), population, and specific land covers (roads, rivers, towns, and mining and agriculture areas). The surface area of land transitioning from one land cover to another was based on the changes observed between 2003 and 2013, with the exception of the transitions to mining (see mining module).
2. **Mining:** Calculates how much area we can expect to be taken over by mining (illegal and informal together) each year based on prevailing international gold prices. The relationship between the price of gold and the surface area of new mining area is based on observed curves from our 1993–2013 maps. Future price of gold was based on hypotheses derived from the World Bank Commodities Price Forecast.
3. **Land Management:** Adds rules altering the probability of some land-cover transitions in certain areas, to mimic the enforcement of a land management plan in given scenarios. By focusing on the land management plan, our model

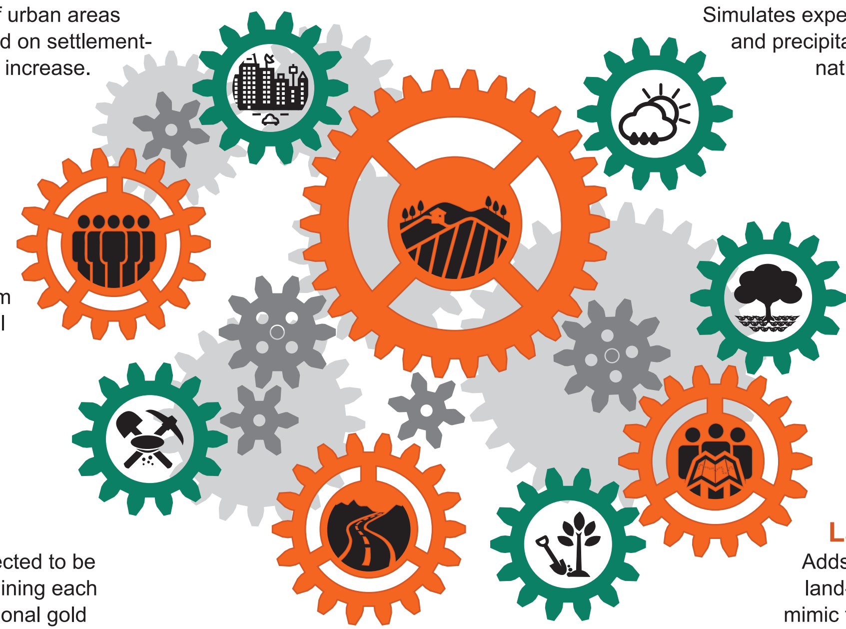


Figure 15. Modules of the quantitative model used in Madre de Dios.

is unable to predict the effect of particular national and regional policies, and acknowledges that different policies can result in the enforcement of the same management plan. A discussion of the most effective policies for supporting a sustainable development plan is provided in chapter 5.

4. **Population:** Calculates population increments from natural growth and immigration for all settlements in the region. Immigration rates are hypothesized for each scenario from historical immigration rates, whereas natural growth is derived from the observed settlement-specific linear growth rates observed in population census between 1993 and 2007.

5. **Urbanization:** Handles the growth of urban areas (transition to urban) based on settlement-specific population increases. The relation between population and urban area size is derived from observed settlement populations and sizes in the region and in Amazonia more broadly.

6. **Roads:** Handles the creation of new primary roads in each scenario from current roads projects found at the Peruvian Ministry of Transport and Communication. It also generates a network of secondary and tertiary roads branching from primary roads to connect development areas. Rate of growth of secondary roads is based on 1993–2013 observed rates in the region.

7. **Climate Change:** Simulates expected climate changes (increase in temperature and precipitations; Box 4) until 2040 based on national projections (Obregón et al. 2009).

8. **Reforestation:** Handles transitions from agricultural and mining lands to reforested land, and the growth of vegetation in subsequent years. The area reforested is hypothesized from the provisional budget for reforestation in Madre de Dios's land management plan (GOREMAD 2014c), and the probability map is derived from the location of actual reforestation concessions with respect to predictors. Regrowth dynamics of the reforested areas are derived from the literature (Elliott et al. 2013).

9. **Agroforestry:** Handles transitions from agriculture to agroforestry land, and the growth of vegetation in subsequent years. The area converted to agroforestry is hypothesized from the provisional budget for agroforestry in Madre de Dios's land management plan (GOREMAD 2014c), and the probability map is derived from the location of actual agroforestry projects with respect to predictors.

Box 4. Global, National, and Local Effects of Climate Change

The increase of greenhouse gas emissions from human activities globally is affecting climate systems by increasing mean temperatures. This global change affects local climates everywhere in different ways. The Intergovernmental Panel on Climate Change (IPCC) predicts an increase of 0.9°C of global earth temperatures by 2025, causing a significant loss of ice cover in the Arctic Region, a rise of sea level between 28 and 59 cm, an increase in intensity of typhoons and hurricanes, an increase in precipitation at high latitudes, and a decrease in precipitation in most subtropical regions (IPCC 2007). These changes will likely increase extinction risk for numerous terrestrial and aquatic species, undermine human food security, exacerbate existing human health problems, and reduce renewable surface and groundwater resources (IPCC 2014).

Peru's *Servicio Nacional de Meteorología e Hidrología* (SENAMHI) evaluated climate projections at the national level to the year 2030, based on IPCC's global high emission climate scenario. The effect of global warming has already increased national climate variability, with more frequent and intense extreme climate events such as droughts, frosts, flooding, and snowfalls (Obregón et al. 2009). Maximum temperatures are expected to increase in Peru by 1.6°C by 2030. Projections of precipitation to 2030 show some shortages especially in the montane region (-10 to -20%) and in the northern and central rainforest (-10%). Increase in precipitation (+10% to +20%) will likely occur in the northern coast and southern rainforest. These changes are expected to cause the melting of glaciers, an increase in the frequency and intensity of El Niño, and a rise of sea level (Obregón et al. 2009), with consequences for human food and water availability and intensity of natural disasters. Climate change is expected to reduce Peru's GDP by 6.8% by 2030, and by 23% by 2050 if nothing is done to slow the rise of temperatures (Vargas 2009). Climate change is a major concern to Peru, which already developed a national strategy to adapt to this issue with a requirement for all regions to develop their own climate change plans (MINAM 2015). Madre de Dios's climate has already changed, with more frequent waves of heat and cold, severe droughts like those in 2005 and 2010, and floods (GOREMAD 2017). National projections estimate temperatures could increase by 0.8°C by 2030 in Madre de Dios, with between 10% and 20% increase in annual precipitations (Obregón et al. 2009).

Step 5. Evaluate Scenario Success with Quantitative Indicators

Quantitative indicators of human well-being, economic development, and environmental success of interest to stakeholders are evaluated for each scenario.

Beyond land-cover changes, the Smithsonian Working Landscape Simulator evaluates the performance of scenarios in each of the three dimensions of sustainable development (Figure 16): human well-being, economic development, and environment (Passet 1979, Hassan et al. 2005). For Madre de Dios, we selected five indicators in each dimension that both reflected the drivers of change and ecosystem services prioritized by stakeholders and could be evaluated quantitatively using the outputs of our model.

Figure 16. The three dimensions of sustainable development and the 15 quantitative indicators used to evaluate scenarios.

Human Well-Being Indicators: Evaluating the performance of each scenario in contributing to the well-being of a region's inhabitants

Social Conflicts (sources of conflicts/ha): Measures the average number of sources of conflicts per hectare in the region between 2013 and 2040. Sources of conflicts considered include incompatible concession overlaps, loss of rights-of-use on previously attributed concessions, invasion of concessions by incompatible land uses, and government-imposed reforestation of agricultural and mining lands (GOREMAD 2009, Hugo Pachas 2013, Esley Huatangare et al. 2014, GOREMAD 2014c, Scullion et al. 2014). We assumed more sources of conflict lead to higher numbers of real social conflicts in the region and reduce human well-being.

Unplanned Urban Sprawl (% urban population growth/year): Measures the annual population growth in towns (settlements with more than 2500 inhabitants, law 27795 *Demarcación y Organización Territorial* 2003) between 2013 and 2040. We assumed a high population growth rate in towns leads to a higher chance of poorly planned urbanization and the development of *pueblos jovenes* (slums) that lack basic infrastructure and services, threatening the health and security of its inhabitants (Dourojeanni 2006, Gast 2014, Dupont et al. 2015), thereby reducing human well-being.

Mining Towns (% miner population growth/year): Measures the annual population growth in mining settlements (within 1 km from mining areas) between 2013 and 2040. We assumed a high population growth in mining towns leads to higher levels of exposure of people to social and health issues typically associated with these towns (Álvarez et al. 2011), thereby reducing human well-being.

Mercury Exposure (normalized ha of mining upstream): Measures the average surface area of mining situated upstream from the region's inhabitants in 2040, accounting for the distance between the mining area and the inhabitants. We assumed mining areas larger and closer upstream from the average inhabitant lead to a higher risk of mercury exposure and its associated health problems (Diringer et al. 2015), which reduces human well-being. Our indicator should be considered a minimum risk, as air contamination (Gómez Agurto 2012) and contamination by consuming contaminated fish (Chasar et al. 2009) would increase the risk further, but could not be modelled.

Agriculture Pollution (tons of nitrogen/year): Measures the expected increase in the annual quantity of nitrogen exported to surface waters in 2040 compared to 2013. Nitrogen washes away from agricultural lands due to a lack of vegetation cover, and it accumulates in surface water, reducing quality of water for human consumption (Schoumans et al. 2014), affecting human health, thereby reducing human well-being.

Economic Indicators: Evaluating the performance of each scenario in contributing to the region's economy

Accessibility (%): Measures the percentage of the region within 10 km of a road of any type. We assumed this indicator represents the extent of the region in which natural resources can be exploited easily and that is accessible to development (Queiroz and Gautam 1992).

Mining (km^2/year): Measures the expected surface area of mining gained or lost on average each year in the region between 2013 and 2040. We assumed greater surface area dedicated to mining represents more ore produced, and hence higher revenues for the mining sector and the people involved.

Agriculture (km^2/year): Measures the expected surface area of agriculture land cover gained or lost on average each year in the region between 2013 and 2040. We assumed greater surface area dedicated to agriculture represents more agricultural products produced, and hence higher revenues for the agriculture sector and the people involved in it.

Standing Wood (1000s of tons or Mg): Measures the expected loss of aboveground vegetation biomass due to agriculture, mining, and urban expansion in logging concessions between 2013 and 2040. We considered that higher losses in biomass are reflected in the pool of exploitable trees for the logging industry, and represent a loss of revenue for the sector.

Brazil Nut Production Forest (km^2): Measures the change in the surface area of high quality forest (quality ≥90%) in Brazil nut concessions between 2013 and 2040. The Brazil nut tree (*Bertholletia excelsa*) requires very specific pollinators and seed dispersers to be able to reproduce, and thus its production depends on intact or nearly intact forest (Ortiz 2002). We assumed larger areas of intact forest in Brazil nut concessions guaranteed the continuity of production and therefore the economic revenues of the people relying on the industry.

Environmental Indicators: Evaluating the performance of each scenario in preserving the environment and the ecosystem services associated with it (Smith et al. 2013).

Deforestation (km^2/year): Measures the expected annual loss of forested cover in the region between 2013 and 2040. Deforestation affects the environment by causing erosion, changes in hydrological regimes, loss of biodiversity, and fragmentation of landscapes, and by contributing to local and global warming through emissions of greenhouse gases (Fearnside 2005).

Biodiversity Loss (%): Measures the expected change in biodiversity in 2040 compared to 2013. A decreasing biodiversity indicates local disappearance of species, which can affect the functioning of ecosystems and make important living resources unavailable for fishing, hunting, and gathering (Cardinale et al. 2012). The loss of ecological function of a species can happen long before its extinction (Valiente-Banuet et al. 2015), so any sharp decrease in this indicator should be considered a great risk for ecosystems.

Landscape Fragmentation (m): Measures the expected increase in the mean distance between forest patches for animals that need to disperse to find food resources and mates. When landscape fragmentation increases, the capacity of species to disperse and survive in the fragments decreases, affecting overall biodiversity and ecosystem functioning (Lindenmayer and Fischer 2013).

Carbon Emissions (millions of tons): Measures the expected loss of carbon storage capacity in vegetation and soil due to land-cover changes in the region between 2013 and 2040. The carbon released in the atmosphere significantly contributes to local and global warming (Lashof and Ahuja 1990).

Erosion (tons of sediments/year): Measures the increase in the annual quantity of sediments washed into rivers in 2040 compared to 2013. More sediment washed away indicates more erosion and loss of soil fertility, and higher concentration of sediments in streams, which affects the survival of freshwater species and water quality (Durán Zuazo and Rodríguez Pleguezuelo 2008).

To quantitatively evaluate these indicators in each scenario, we created specific models using software R (R Development Core Team 2013), ArcGIS (ESRI 2012), and InVEST (Sharp et al. 2015).




Figure 17. Scenes from the consultation process, including definitions of essential ecosystem services and drivers of change, selection of the most important qualitative scenarios, and development of recommendations from lessons learned.





BLES DE CAMBIO
CONTAMINACION
MULTURACION
CCNN
PLANIFICACION
DEFICIENTE


WWF

Step 6. Develop Recommendations from Lessons Learned

The results of the study are presented to stakeholders, who are consulted to develop operative lessons learned and recommendations toward the sustainable development of the territory.

In Madre de Dios, we invited all previously contacted stakeholders to a third round of consultations in Puerto Maldonado and in Lima during March 2017 (Figure 17). The 53 individuals who participated in the workshops represented 23 organizations (see Appendix). After a presentation of the main results, we invited participants to provide feedback and recommendations on the study.

Stakeholders were, in general, satisfied about the results presented and interested in the approach. Many indicated the results presented agreed with their experience in the field. Most stakeholders believed the study results could help with the development and implementation of a better land management plan for Madre de Dios. A summary of the recommendations and the consultation process are presented in chapter 5.

Step 7. Communicate Results and Recommendations

The results and recommendations from the study are communicated to a wide audience.

In Madre de Dios, the Smithsonian Working Landscape Simulator has been a powerful tool to educate stakeholders and help them realize that their active participation in a coordinated sustainable regional management is needed. Beyond this realization, the consultation process embedded in the tool has initiated a regional discussion around the creation of a common vision for Madre de Dios. Nevertheless, more efforts are needed to share the results of this study with a wider audience. Transparent scientific information is essential to decision makers, but also to journalists, lobbyists, and citizens who want to take part in the sustainable development of the region and to initiate a more democratic decision-making process. This open access report is the Smithsonian's contribution to that effort.

FOUR SCENARIOS FOR MADRE DE DIOS UNTIL 2040

Hypotheses Common to All Scenarios

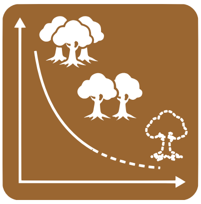
The four scenarios developed with stakeholders represent contrasting views of the future of Madre de Dios. Each was simulated using advanced land cover and ecosystem services models. Each scenario presents its assumptions and results based on the three dimensions of sustainability: economy, human well-being, and environment.

All scenarios share the following assumptions:

- Local climate is affected by global changes resulting in a steady increase in temperatures and precipitation after 2020;
- Natural forest regeneration occurs in abandoned agriculture lands, influenced by various factors, as observed between 1993 and 2013;
- Agriculture lands expand into forested areas as observed between 2003 and 2013;
- Human population growth follows 1993–2007 settlement-specific linear rates;
- Secondary and tertiary roads are built to connect settlements, mining, and agriculture lands to primary roads; and
- Low persistent oil and gas prices on global markets makes exploration and development of the region's hydrocarbon reserves inviable between 2013 and 2040.

Table 1. Quantitative hypotheses common to all the scenarios for Madre de Dios.

	Temperature increase	Precipitation increase	Forest natural regeneration	Agriculture expansion	Population natural growth
Assumptions	**+0.8 °C** *every 10 years after 2020*	**+16.7 mm** *every 10 years after 2020*	**+0.04 %** *of 2013 forest area / year*	**+2.7 %** *of 2013 agriculture area / year*	**+2.0 %** *of 2013 population / year*



CURRENT TRENDS SCENARIO

The Current Trends scenario maintains present-day political, economic, and social trends. Informal and illegal extractive activities drive the economy without active regional management. Madre de Dios experiences an increase in economic development led by gold mining and agriculture, at the cost of increased deforestation, degradation of ecosystem services, mercury pollution, public health issues, and social conflicts.

Assumptions

» National and regional governments don't implement the regional *Plan de Ordenamiento Territorial*.

» Informal and illegal gold mining continues to expand with limited controls. The vast majority of informal gold miners don't formalize their activity.

» Abandoned agricultural and mining lands are slowly recolonized by vegetation, and no large-scale active reforestation programs to restore soil productivity are implemented.

» Private agroforestry initiatives struggle to survive in a landscape dominated by slash and burn agriculture and pastures dedicated to cattle production.

» Economic activity in Madre de Dios continues to attract immigrants from neighboring regions at the same rate as in the past 20 years. Immigrants settle mainly in mining areas and along the roads in search of economic opportunities with short-term benefits.

» Road infrastructure is a development priority for the region. As a consequence, several large-scale road projects are carried out, including the highway from Nuevo Edén to Boca Colorado (completed in 2021); the Carretera Longitudinal de la Selva southern sector (PE-5S) from Boca Manu to the border with Bolivia (completed in 2024); and the MD-104 road project from Iñaparí to Purús (completed in 2028).

Table 2. Assumptions of the Current Trends scenario.

	In the absence of a land management plan, area of the region where activites are tolerated			Mining expansion	International gold price
Assumptions	Mining	Agriculture	Urban & roads		
	100 % of the region	**100 %** of the region	**100 %** of the region	**+6.0 %** of 2013 mining area / year	**-30 %** decrease between 2013 and 2040
	Active reforestation	Agroforestry expansion	Immigration		Primary roads
			Migrants	Miners	
	0 km² between 2013 and 2040	**+12.4 km²** between 2013 and 2040	**+1176** people settling in the region / year	**+10 %** more migrants settle in mining towns	**+803.3 km** of primary roads built by 2040

Table 3. Values of the indicators of success for the Current Trends scenario.

Economy	**71.0 %** of the region within 10 km of roads	**+25 km²** of mining land gained / year	**+29 km²** of agriculture land gained / year	**-15,743 Mg** of vegetation lost in logging concessions	**-759 km²** of intact forest lost in Brazil nut concessions
Well-Being	**5.4** sources of conflicts per ha until 2040	**+2.96 %** town population growth / year	**+2.79 %** miner population growth / year	**596 ha** normalized area of mining upstream	**1298 tons** of nitrogen exported / year
Environment	**-54.5 km²** of forest lost / year	**-11.4 %** of 2013 biodiversity lost	**+0.88 m** between neighbor forest patches	**-37 G tons** of carbon lost due to deforestation	**5258 tons** of sediments eroded / year

Madre de Dios by 2040

- The southeast part of the region is covered with a dense network of primary, secondary, and tertiary roads, putting 71% of the region within 10 km of a road and, therefore accessible to development.
- Opening of new lands for mining and agriculture (264% and 155% expansion, respectively) allows the production of more agriculture products and gold, and directly and indirectly employs the majority of the region's workforce.
- Logging and Brazil nut concessions are invaded by agriculture and mining, resulting in significant loss of wood biomass in logging concessions, and extended forest degradation in Brazil nut concessions that affect the production of the Brazil nut tree (*Bertholletia excelsa*).
- Overlaps between concessions and incompatible land uses trigger social conflicts among farmers, communities, ecotourism entrepreneurs, loggers, and miners. Invasions of land by newcomers for mining and agriculture threaten native cultures and knowledge.
- Rapid growth of population in towns and cities put urban areas at high risk of developing *pueblos jovenes* (slums) as urbanization plans are outflanked. These unplanned urban areas typically lack basic infrastructure and services, threatening the health and security of their inhabitants. With even poorer infrastructure, health, and social conditions, the mining towns undergo a rapid population growth in lands heavily polluted with mercury.
- Expansion of mining in the landscape results in an important exposure of the population to mercury washed away from mining areas. Similarly, nitrates and phosphates used in agriculture pollute superficial water consumed by the population.
- Deforestation (1472 km^2 or 1.7% of the region) for new roads, mining, agriculture, and urban lands spreads to previously undisturbed areas.
- Loss of forest cover creates smaller isolated patches where the rich regional biodiversity struggles to survive, leading to a global biodiversity loss of 11.4% compared to 2013. Mining and agriculture encroachment fragments the landscape with patches of native forest being further apart from each other, threatening the entire ecosystem and the connectivity of the Vilcabamba–Amboró conservation corridor.
- Loss of forest cover in Madre de Dios between 2013 and 2040 releases an estimated 36.7 million tons of carbon into the atmosphere, contributing to local and global climate change.
- Removal of vegetation cover in agricultural and mining areas associated with climate changes accelerates soil erosion (142,000 more tons of sediments lost compared to 2013), which limits soil fertility for agriculture, as well as increases river turbidity and damages freshwater ecosystems.

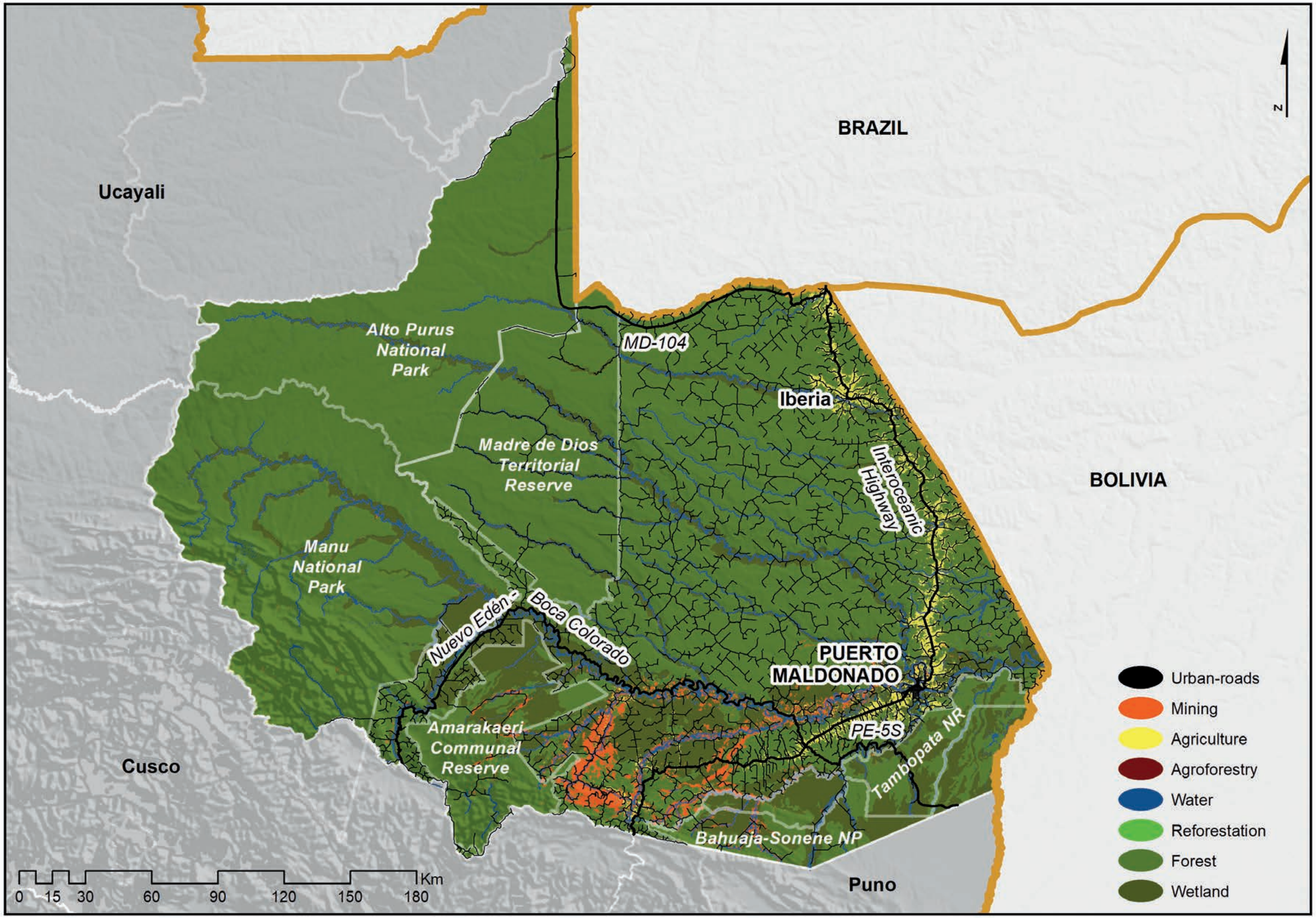


Figure 18. Madre de Dios landscape in 2040 in the Current Trends scenario.

EXPANSION OF ALLUVIAL GOLD MINING SCENARIO

Informal and illegal gold mining expands due to poor land management, weak law enforcement, increased immigration, and high international gold prices. Economic productivity is high in the mining and agriculture sectors, associated with reduction of legal logging and Brazil nut productivity, alarming degradation of the environment, and reduction of human well-being.

Assumptions

- A lack of sectorial regulations at the national level, limited budget and staff at the regional level, and the absence of a regional *Plan de ordenamiento territorial* lead to a complete deregulation of the mining sector in the region. Mining expands without constraints, including in protected areas.
- Surfaces prospected for informal and illegal mining increase due to the rise in gold prices on international markets. The vast majority of informal gold miners don't formalize their activity.
- As in the Current Trends scenario, no large-scale active reforestation program is implemented, and forest growth relies only on natural regeneration.
- Agroforestry initiatives almost disappear from the region's landscape.
- Mining activities attract 22% more migrants from neighboring regions than in the Current Trends scenario. Immigrants settle in large numbers in mining areas.
- The same three primary roads as in the Current Trends scenario are built.

Table 4. Assumptions of the Expansion of Alluvial Gold Mining scenario.

Assumptions	In the absence of a land management plan, area of the region where activites are tolerated			Mining expansion	International gold price
	Mining	Agriculture	Urban & roads		
	100 % *of the region*	**100 %** *of the region*	**100 %** *of the region*	**+8.0 %** *of 2013 mining area / year*	**+2 %** *increase between 2013 and 2040*
	Active reforestation	Agroforestry expansion	Immigration: Migrants	Immigration: Miners	Primary roads
	0 km^2 *between 2013 and 2040*	**+2.3 km^2** *between 2013 and 2040*	**+1429** *people settling in the region / year*	**+20 %** *more migrants settle in mining towns*	**+803.3 km** *of primary roads built by 2040*

Table 5. Values of the indicators of success for the Expansion of Alluvial Gold Mining scenario.

Economy	**87.3 %** *of the region within 10 km of roads*	**+32 km^2** *of mining land gained / year*	**+29 km^2** *of agriculture land gained / year*	**-16,698 Mg** *of vegetation lost in logging concessions*	**-767 km^2** *of intact forest lost in Brazil nut concessions*
Well-Being	**5.4** *sources of conflicts per ha until 2040*	**+3.15 %** *town population growth / year*	**+2.93 %** *miner population growth / year*	**721 ha** *normalized area of mining upstream*	**1526 tons** *of nitrogen exported / year*
Environment	**-61.9 km^2** *of forest lost / year*	**-13.6 %** *of 2013 biodiversity lost*	**+1.12 m** *between neighbor forest patches*	**-53 G tons** *of carbon lost due to deforestation*	**7494 tons** *of sediments eroded / year*

Madre de Dios by 2040

- The expansion of roads spreads farther west than in the Current Trends scenario and deeply encroaches on protected areas. Most (87%) of the region is within 10 km of a road.
- While agriculture expansion (154%) is comparable to the Current Trends scenario, mining expansion increases steeply (317%), allowing the production of more gold and employing, both directly and indirectly, the majority of the region's workforce.
- Logging and Brazl nut concessions are invaded by mining and agriculture land uses, resulting in significantly increased losses of wood biomass in logging concessions (16.7 millions of tons), and forest degradation in Brazil nut concessions (loss of 767 km^2 of intact forest), compared to the Current Trends scenario.
- The uncontrolled expansion of mining triggers social conflicts, as in the Current Trends scenario, mainly among farmers, communities, ecotourism entrepreneurs, loggers, and miners. Invasions of land by newcomers for mining and agriculture threaten native cultures and knowledge.
- The growth of populations in large towns and in mining settlements is higher than in the Current Trends scenario, with higher risks of developing *pueblos jovenes* (slums) and greater numbers of people exposed to poor infrastructure, health, and social conditions.
- Mercury exposure of the region's population is the highest among all scenarios, representing a significant public health issue. Similarly, nitrates pollution is the highest among scenarios, with nitrates accumulating in superficial water consumed by the population.
- Deforestation (1671 km^2 or 2.0% of the region) for roads and new mining, agricultural, and urban lands is significantly higher than in the Current Trends scenario.
- Similarly, biodiversity loss increases by 19% and fragmentation by 27% compared to the Current Trends scenario, threatening the functioning of the entire ecosystem and the connectivity of the Vilcabamba–Amboró conservation corridor.
- Contribution of the region to local and global climate change is significantly higher in this scenario, with 45% more carbon released than the Current Trends scenario.
- The expansion of mining areas significantly accelerates the erosion of soils compared to the Current Trends scenario (+43%), with consequences for soil fertility, as well as increased river turbidity, and damages to freshwater ecosystems.

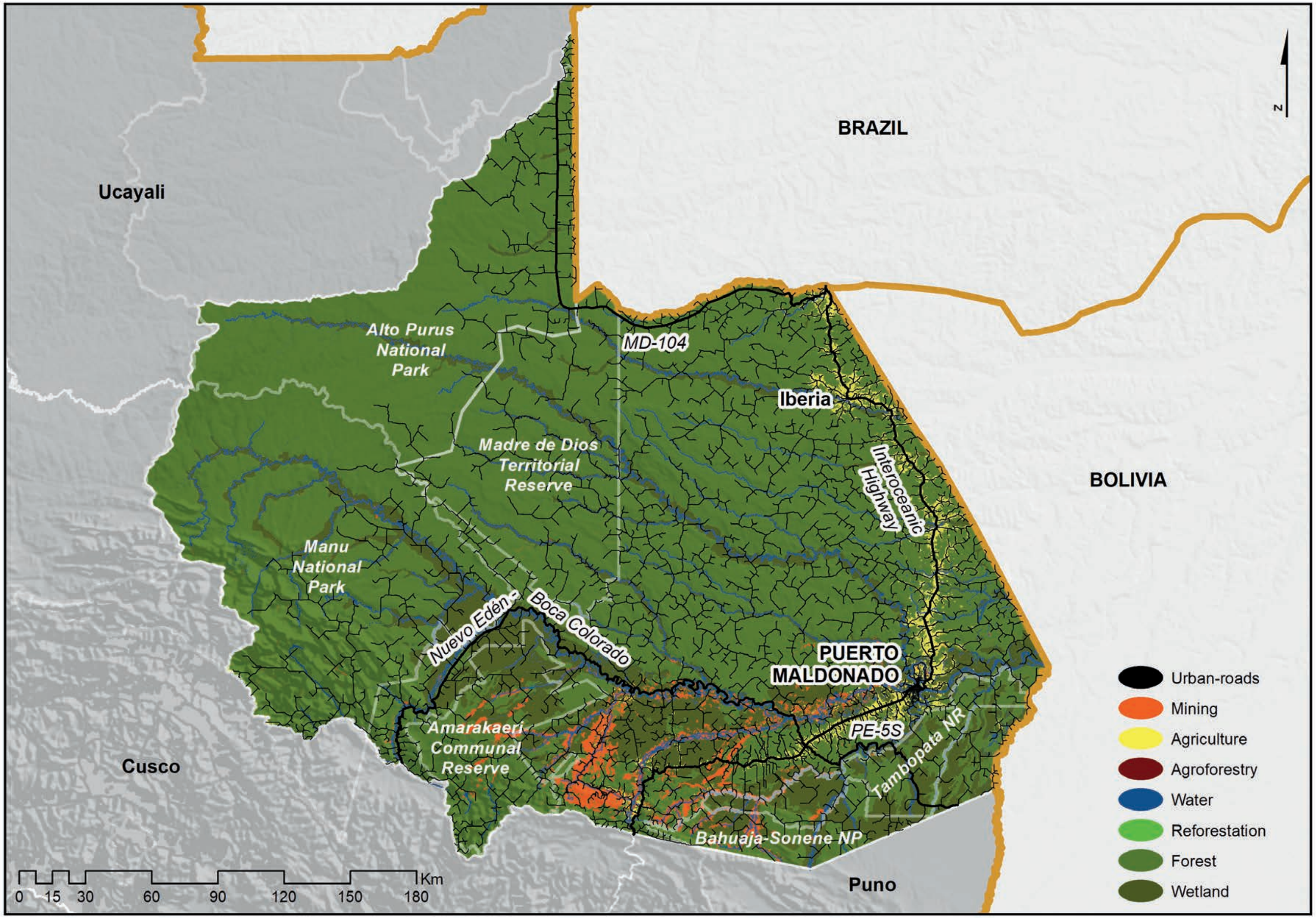


Figure 19. Madre de Dios landscape in 2040 in the Expansion of Alluvial Gold Mining scenario.

LAND PLANNING SCENARIO

The land management plan for the region's sustainable development is enforced after 2020. All economic activities are formalized and carried out within the zoning of the plan, successfully slowing down the expansion of mining. These actions result in good economic performance of the other sectors, and improved ecosystem services and human well-being.

Assumptions

- The regional and national governments work together to implement the regional Land Use plan (*Plan de ordenamiento territorial*; GOREMAD 2014c) and the macro-zoning of the region (GOREMAD 2009) by 2020. Illegal mining is formalized and incompatible land-use overlaps are resolved to guide the development of the region. Mining and agriculture development is restricted to zones representing 12% and 11% of the region, respectively.
- Surfaces of land prospected for mining are the same as in the Current Trends scenario. All miners formalize their activity.
- The land management plan includes a reforestation program that restores 139 km^2 of forest in mining areas outside the land management zoning.
- Agroforestry is promoted by the national and regional government on agriculture land outside the zoning of the plan to limit adverse effects on the environment. More than 220 km^2 of agricultural land is converted to agroforestry.
- The economic opportunities offered by the land management plan attract more migrants to the region, resulting in 22% more immigration than in the Current Trends scenario. Because other economic opportunities are available, only a small fraction of these migrants settle in mining towns.
- The same three primary roads as in the Current Trends scenario are built.

Table 6. Assumptions of the Land Planning scenario.

	Area in land management plan authorized for:			Mining expansion	International gold price
	Mining	Agriculture	Urban & roads		
Assumptions	**12 %** *of the region*	**11 %** *of the region*	**46 %** *of the region*	**+6.0 %** *of 2013 mining area / year*	**-30 %** *decrease between 2013 and 2040*
	Active reforestation	Agroforestry expansion	Immigration		Primary roads
			Migrants	Miners	
	+138.6 km² *between 2013 and 2040*	**+223.3 km²** *between 2013 and 2040*	**+1429** *people settling in the region / year*	**+5 %** *more migrants settle in mining towns*	**+803.3 km** *of primary roads built by 2040*

Table 7. Values of the indicators of success for the Land Planning scenario.

Economy	**68.9 %** *of the region within 10 km of roads*	**+20 km²** *of mining land gained / year*	**+29 km²** *of agriculture land gained / year*	**-15,448 Mg** *of vegetation lost in logging concessions*	**-157 km²** *of intact forest lost in Brazil nut concessions*
Well-Being	**1.5** *sources of conflicts per ha until 2040*	**+3.17 %** *town population growth / year*	**+2.85 %** *miner population growth / year*	**451 ha** *normalized area of mining upstream*	**1030 tons** *of nitrogen exported / year*
Environment	**-54.5 km²** *of forest lost / year*	**-8.8 %** *of 2013 biodiversity lost*	**+0.85 m** *between neighbor forest patches*	**-32 G tons** *of carbon lost due to deforestation*	**4247 tons** *of sediments eroded / year*

Madre de Dios by 2040

- Accessibility is slightly limited compared to the Current Trends scenario, with the proportion of the region within 10 km of a road reduced by 3.0%.
- While agriculture expansion (155%) is equivalent to that in the Current Trends scenario, mining expansion in the Land Planning scenario is limited (231%; -19.9%), significantly reducing the volume of gold mined in the region.
- Loss of wood biomass in logging concessions is comparable to that of the Current Trends scenario, but intact forest loss in Brazil nut concessions is significantly reduced (-79.3%).
- The authoritative resolution of concessions and land uses overlaps, and forced reforestation of mining areas triggers conflicts, but over the 27-year period, these represent 72.5% fewer sources of social friction than observed in Current Trends, the best score among all scenarios.
- Population growth in large towns and mining settlements is significantly higher (+7.1% and +2.2%, respectively) than in the Current Trends scenario, putting people at risk of living in *pueblos jovenes* (slums). This risk is probably at least partially mitigated by the development of a strong urban development plan, in particular for the town of Puerto Maldonado, but our model does not allow for the quantification of this mitigation.
- Mercury exposure of the region's population is the lowest among all scenarios (-24.4% compared to Current Trends), thanks to a careful zoning of the mining activities downstream of populated towns, reducing the risk of mercury contamination for people. The amount of mercury entering rivers is also probably lower in this scenario, due to enforcement of new legislation introducing enhanced amalgamation techniques. The effects of the changes of mining practices, however, were not integrated in our indicator. Similarly, nitrates pollution is significantly lower (-20.6%) compared to the Current Trends scenario, increasing the quality of the water consumed by the population.
- Deforestation (1472 km^2 or 1.7% of the region) is equivalent to that in the Current Trends scenario.
- Biodiversity loss significantly decreases by 22.3% but fragmentation by only 3.4% compared to the Current Trends scenario, still threatening the connectivity of the Vilcabamba–Amboró biological corridor.
- Contribution of the region to local and global climate change is significantly lower in this scenario with 11.6% less carbon released than the Current Trends scenario.
- The zoning slows the erosion of soils compared to the Current Trends scenario (-19%), with improved soil fertility and decreased river turbidity, and less damages to freshwater ecosystems.

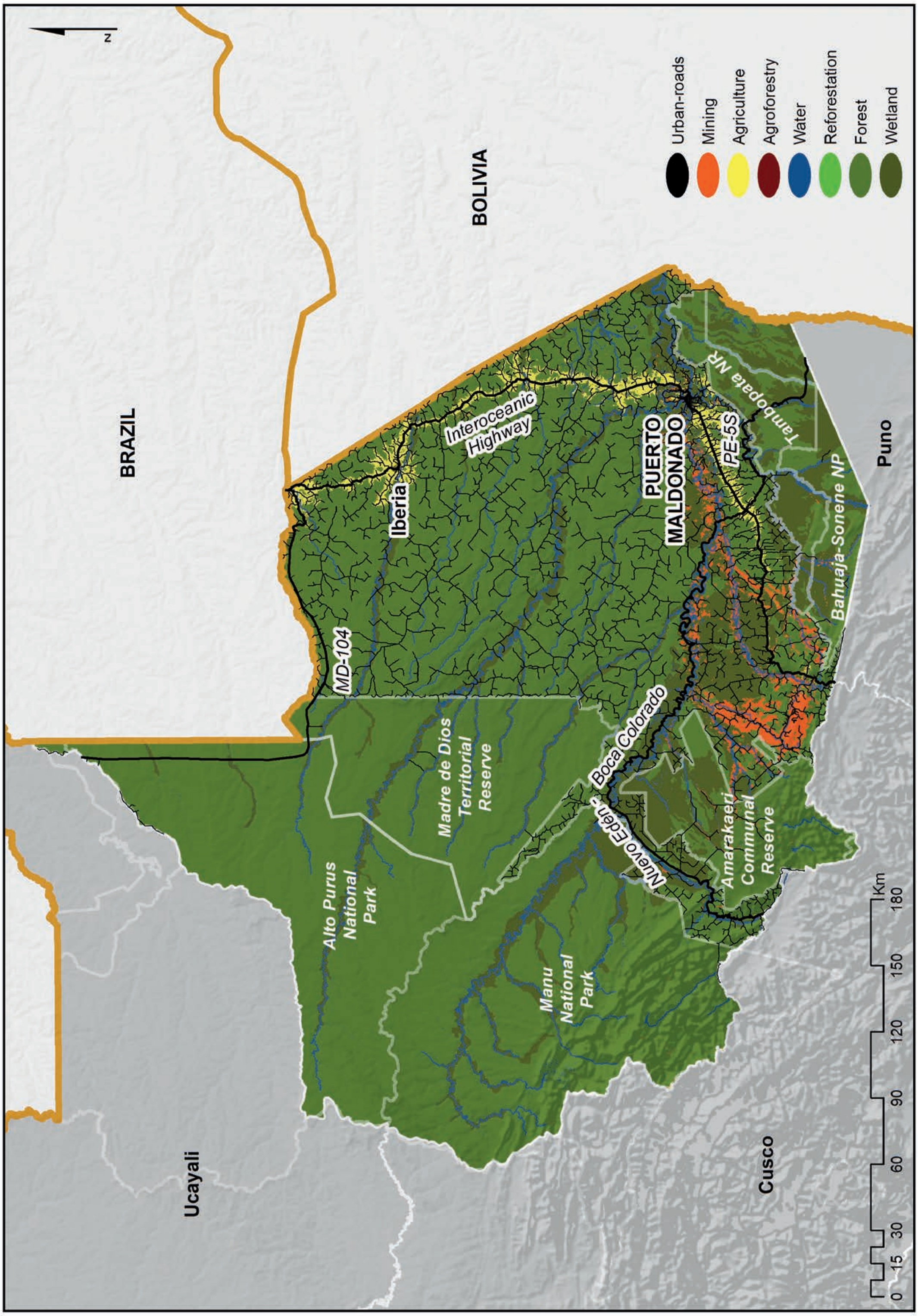


Figure 20. Madre de Dios landscape in 2040 in the Land Planning scenario.

LAND CONSERVATION SCENARIO

A new land management plan focused on biodiversity and landscape conservation is enforced after 2020. Protected areas are considered sanctuaries, deforestation is strongly limited, and degraded lands are restored. These actions result in limited economic growth in the agriculture and mining sectors, good human well-being performance, and optimal environmental performance.

Assumptions

- The regional and national governments work together to protect Madre de Dios's biodiversity and landscapes. They create a new land management plan that restricts agriculture and mining expansion to the sectors where formal active concessions exist (4% and 1% of the region's surface, respectively). Incompatible land-use overlaps are resolved.
- Surfaces prospected for mining are the same as in the Current Trends scenario. All miners formalize their activity.
- An ambitious reforestation program is initiated by the government to restore 273 km^2 of forest in agriculture and mining areas outside the land management zoning.
- New norms require all agriculture concessions within the land management zoning to progressively adopt agroforestry practices resulting in more than 440 km^2 of agricultural land converted to agroforestry.
- The limitation of economic opportunities related to mining and agriculture result in a reduction of the number of migrants to the region (-26% compared to the Current Trends scenario).
- To avoid opening up protected areas and indigenous reserves, only the priority regional integration highway connecting Nuevo Edén, Boca Manu, and Boca Colorado is constructed (completed in 2021), resulting in 67.8% fewer primary roads built compared to the Current Trends scenario.

Table 8. Assumptions of the Landscape Conservation scenario.

Assumptions	Area in land management plan authorized for:			Mining expansion	International gold price
	Mining	Agriculture	Urban & roads		
	4 % *of the region*	**1 %** *of the region*	**46 %** *of the region*	**+6.0 %** *of 2013 mining area / year*	**-30 %** *decrease between 2013 and 2040*
	Active reforestation	Agroforestry expansion	Immigration: Migrants	Immigration: Miners	Primary roads
	+273.0 km² *between 2013 and 2040*	**+443.8 km²** *between 2013 and 2040*	**+869** *people settling in the region / year*	**0 %** *more migrants settle in mining towns*	**+258.5 km** *of primary roads built by 2040*

Table 9. Values of the indicators of success for the Landscape Conservation scenario.

Economy	**64.4 %** *of the region within 10 km of roads*	**+23 km²** *of mining land gained / year*	**-5.4 km²** *of agriculture land lost / year*	**-16,014 Mg** *of vegetation lost in logging concessions*	**-270 km²** *of intact forest lost in Brazil nut concessions*
Well-Being	**1.6** *sources of conflicts per ha until 2040*	**+2.87 %** *town population growth / year*	**+2.67 %** *miner population growth / year*	**634 ha** *normalized area of mining upstream*	**931 tons** *of nitrogen exported / year*
Environment	**-28.1 km²** *of forest lost / year*	**-7.1 %** *of 2013 biodiversity lost*	**+0.44 m** *between neighbor forest patches*	**-22 G tons** *of carbon lost due to deforestation*	**4117 tons** *of sediments eroded / year*

Madre de Dios by 2040

- Accessibility of the region is the lowest of all scenarios, with a proportion of the region within 10 km of a road reduced by 9.3%.
- The surface of agricultural land is significantly reduced compared to 2013 (-10%), limiting the contribution of this sector to the region's economy. Formalization of the agricultural sector and governmental incentive could increase crop productivity and mitigate this loss of economic performance, but our indicator doesn't account for this aspect. Mining expansion is limited (253%; -6.5% compared to the Current Trends scenario), and this modest change in the surface of mining will likely not affect much the volumes of gold extracted from Madre de Dios mining areas.
- Loss of wood biomass in logging concessions is comparable to that in the Current Trends scenario, but intact forest loss in Brazil nut concessions is significantly reduced (-64.4%).
- The authoritative resolution of concessions and land-use overlaps, and forced reforestation of agriculture and mining areas triggers conflicts, but over the 27-year period, these represent 69.9% fewer sources of social friction than observed in Current Trends.
- Population growth in large towns and mining settlements is the lowest among all scenarios (-3.0 and -4.3% compared to Current Trends), allowing more time for the cities to absorb new arrivals, enforce a solid urban development plan, and provide all needed infrastructure to their inhabitants.
- Mercury exposure of the region's population is significantly higher (+6.2%) than in the Current Trends scenario, because authorized mining concessions are still in the headwaters serving major towns. Nevertheless, the amount of mercury entering the rivers is probably lower in this scenario, thanks to the enforcement of a new legislation introducing enhanced amalgamation techniques; the effects of the changes in mining practices, however, were not integrated in our indicator. Nitrates pollution is the lowest of all scenarios (-28.3% compared to current trends), due to a strict limitation of agriculture, resulting in a significant reduction of agriculture pollutants in the water consumed by the human population.
- Deforestation (758 km^2, or 0.9% of the region) is the lowest among scenarios (-48.5% compared to Current Trends).
- Biodiversity loss and forest fragmentation are the lowest of all scenarios (-37.9 and -50.0% compared to Current Trends), enabling optimal functioning of the ecosystem and the connectivity of the Vilcabamba–Amboró conservation corridor.
- Contribution of the region to local and global climate change is the lowest in this scenario, with 40.2% less carbon released than the Current Trends scenario.
- The zoning slows the erosion of soils compared to the Current Trends scenario (-21.7%), with improved soil fertility and river turbidity, and less damage to freshwater ecosystems.

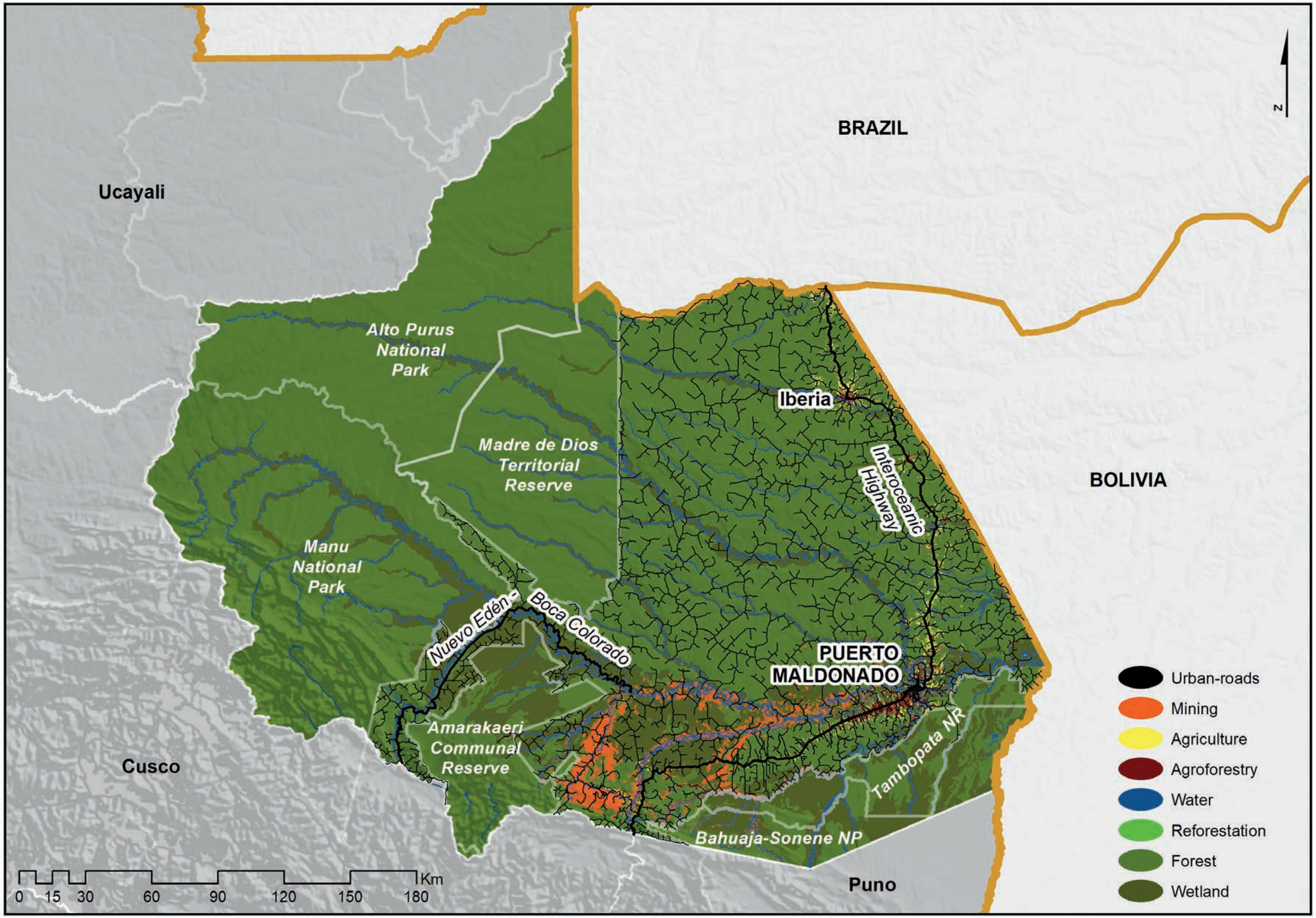


Figure 21. Madre de Dios landscape in 2040 in the Landscape Conservation scenario.

COMPARING WORKING LANDSCAPES IN EACH SCENARIO

The Smithsonian approach for Madre de Dios offers contrasting visions of the future based on real and accurate qualitative and quantitative data, and a variety of balanced stakeholder viewpoints, to offer a holistic view of the region's future. The four scenarios show what opportunities and challenges decision makers are facing when promoting sustainable development. This study is the first to model the future consequences of human development on a range of ecosystem services and socioeconomic indicators at the landscape level in the Peruvian Amazon. The scenarios, as well as their indicators of success, were developed collaboratively with stakeholders using an innovative structured consultation process. The modelling was based on observable changes in the landscape and on published data on the main drivers of change. It combines state-of-the-art quantitative methods to incorporate a large number of factors relevant to the territory. The scenario evaluation process jointly considers the three critical dimensions of working landscape sustainability: economic development, human well-being, and the environment (Adams 2006; Box 5; Table 10).

In the following sections, we present how each scenario compares in terms of:

- Surfaces of land cover changes between 2013 and 2040. In 2040 in all scenarios, more than 90% of the region is not affected by land-cover change, remaining the natural forest, wetlands, rivers, and sand banks visible in 2013. For this reason, we only show the 10 % of the landscape where change is expected to occur.

- Projection of the landscape in 2040 around the Interoceanic Highway, where most of the changes are concentrated in all scenarios.
- Performance of the scenarios for each indicator. For this, we developed a performance index (Box 5). It is scaled between 0 and 1 (the best indicator value), and is higher when the scenario evaluated is more successful for the given indicator. With this index, the success of each indicator or of any of the three dimensions of sustainable development (economy, well-being, and environment) can be compared across scenarios.

Finally, we provide a graphical illustration of how each scenario would look.

Box 5. Calculation of Performance from Our Indicators

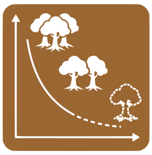
We used the following formula to calculate performance for each of the 15 indicators:

$$\begin{cases} \dfrac{I_s}{I_{max}} & \text{, if indicator increases with performance (n=3)} \\ \dfrac{I_{min}}{I_s} & \text{, if indicator decreases with performance (n=12)} \end{cases}$$

With I_s: the indicator value of scenario *s*; I_{min}: the minimum indicator value across scenarios; I_{max}: the maximum indicator value across scenarios.

Performance values are between 0 and 1 (the best indicator value). Performance values are averaged across economic, well-being, and environment dimensions and across all indicators.

Land-Cover Changes between 2013 and 2040 in the 10% of the Landscape Impacted



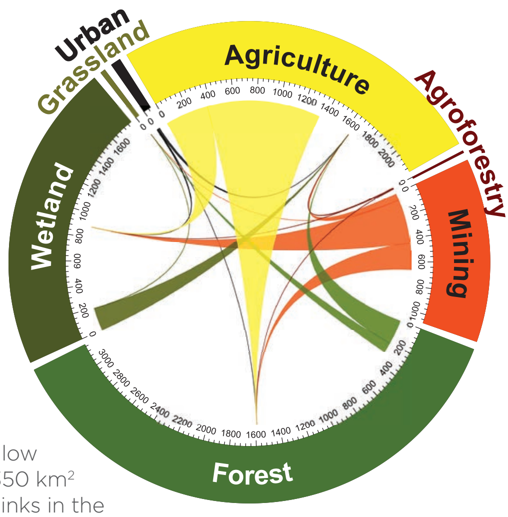


Figure 22. Current Trends scenario (scale in km²). In the area affected by changes (represented by the outer ring in the figure), 54.5 km² of forest are converted to developed land each year between 2013 and 2040. Agriculture is the most commonly developed land cover (2.6% of region in 2040 – yellow sector of the outer ring) and expands by around 1350 km² between 2013 and 2040 (broad end of the yellow links in the inner ring). Most agricultural lands expand into forest and wetlands (narrow ends of the yellow links in the inner ring). Mining is the second most commonly developed land cover (1.3% of region in 2040 – orange sector of the outer ring) and expands mostly into wetlands (large ends of the orange links in the inner ring).

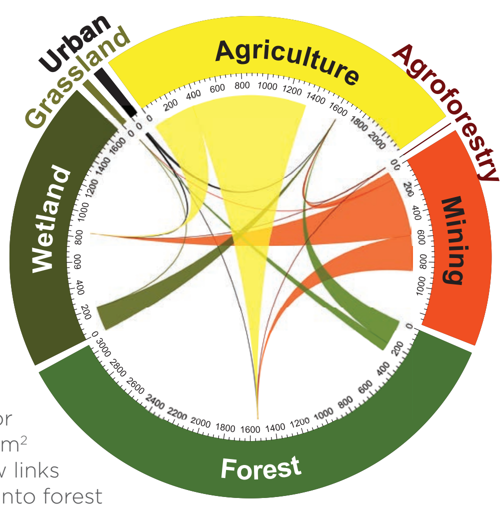


Figure 23. Expansion of Alluvial Gold Mining scenario (scale in km²). In the area affected by changes (represented by the outer ring in the figure), 61.9 km² of forest are converted to developed land each year between 2013 and 2040. Agriculture is the most commonly developed land cover (2.6% of region in 2040 – yellow sector of the outer ring), and expands by around 1350 km² between 2013 and 2040 (broad end of the yellow links in the inner ring). Most agriculture lands expand into forest and wetlands (narrow ends of the yellow links in the inner ring). Mining is the second most commonly developed land cover (1.5% of region in 2040 – orange sector of the outer ring, +213 km² compared to Current Trends scenario), and expands mostly into wetlands (orange links in the inner ring).

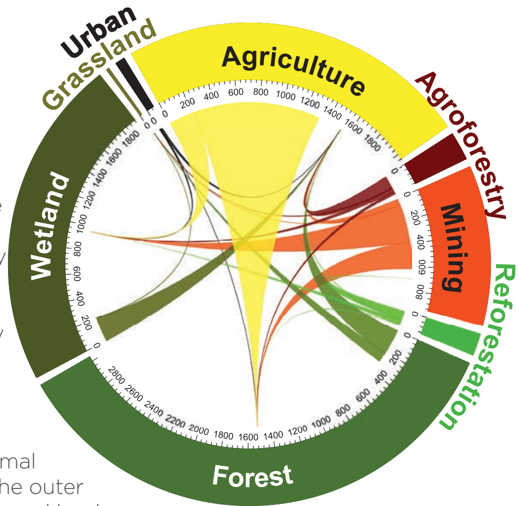


Figure 24. Land Planning scenario (scale in km²). In the area affected by changes (represented by the outer ring in the figure), 54.5 km² of forest are converted to developed land each year between 2013 and 2040. Agriculture is the most commonly developed land cover (2.4% of region in 2040; -143 km² compared to the Current Trends scenario – yellow sector of the outer ring), expanding by around 1300 km² between 2013 and 2040 (broad end of the yellow links in the inner ring). Most agriculture lands expand into forest and wetlands (narrow ends of the yellow links in the inner ring). Agroforestry covers 166 km², mostly replacing formal traditional agricultural lands (deep red sector of the outer ring). Mining is the second most commonly developed land cover (1.1% of region in 2040 – orange sector of the outer ring) and expands mostly into wetlands (orange links in the inner ring). The reduction of 131 km² of mining land compared to the Current Trends scenario mainly comes from the reforestation initiatives covering 132 km² in 2040 (lightest green sector of the outer ring).

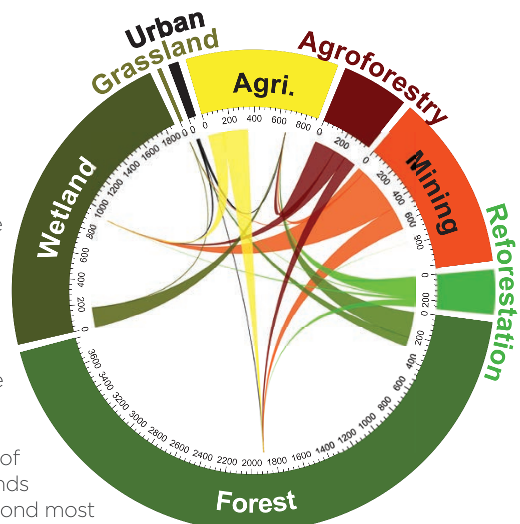


Figure 25. Landscape Conservation scenario. In the area affected by land-cover changes (represented by the outer ring in the figure), 28.1 km² of forest are converted to developed land each year between 2013 and 2040. Mining is the most commonly developed land cover (1.2% of region in 2040; -43 km² compared to Current Trends scenario – orange sector of the outer ring), and expands by around 650 km² between 2013 and 2040 (broad end of the orange links in the inner ring). Most mining lands expand into wetlands and forest (narrow ends of the orange links in the inner ring). Agriculture (1.0% of region in 2040; -1297 km² compared to Current Trends scenario – yellow sector of the outer ring) is the second most commonly developed land cover, and expands mostly into forest land (yellow links in the inner ring). Agroforestry covers 388 km², mostly replacing formal traditional agricultural lands (deep red sector of the outer ring). Agricultural lands located outside of the land management plan zoning are reforested, mostly contributing to the 260 km² of reforested lands in the region in 2040 (lightest green sector of the outer ring).

Projection of the Landscape in 2040 around the Interoceanic Highway

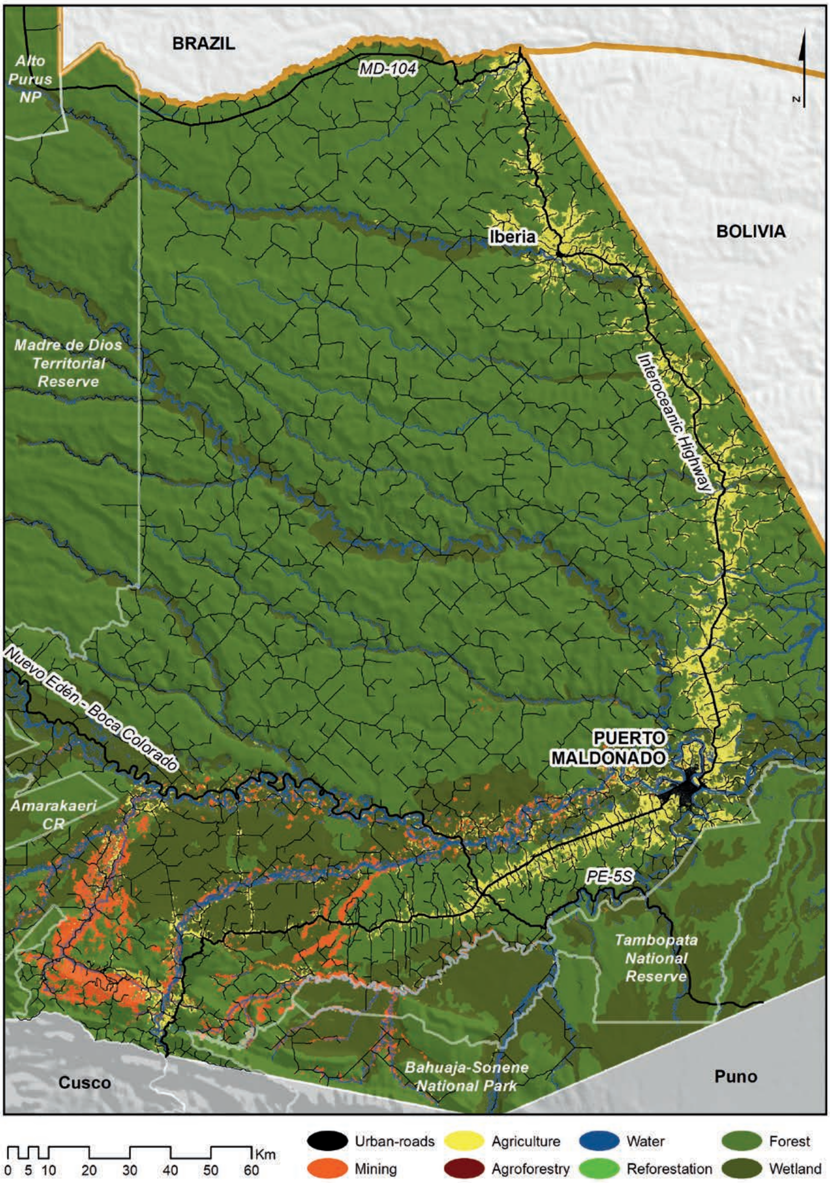


Figure 26. Current Trends scenario.

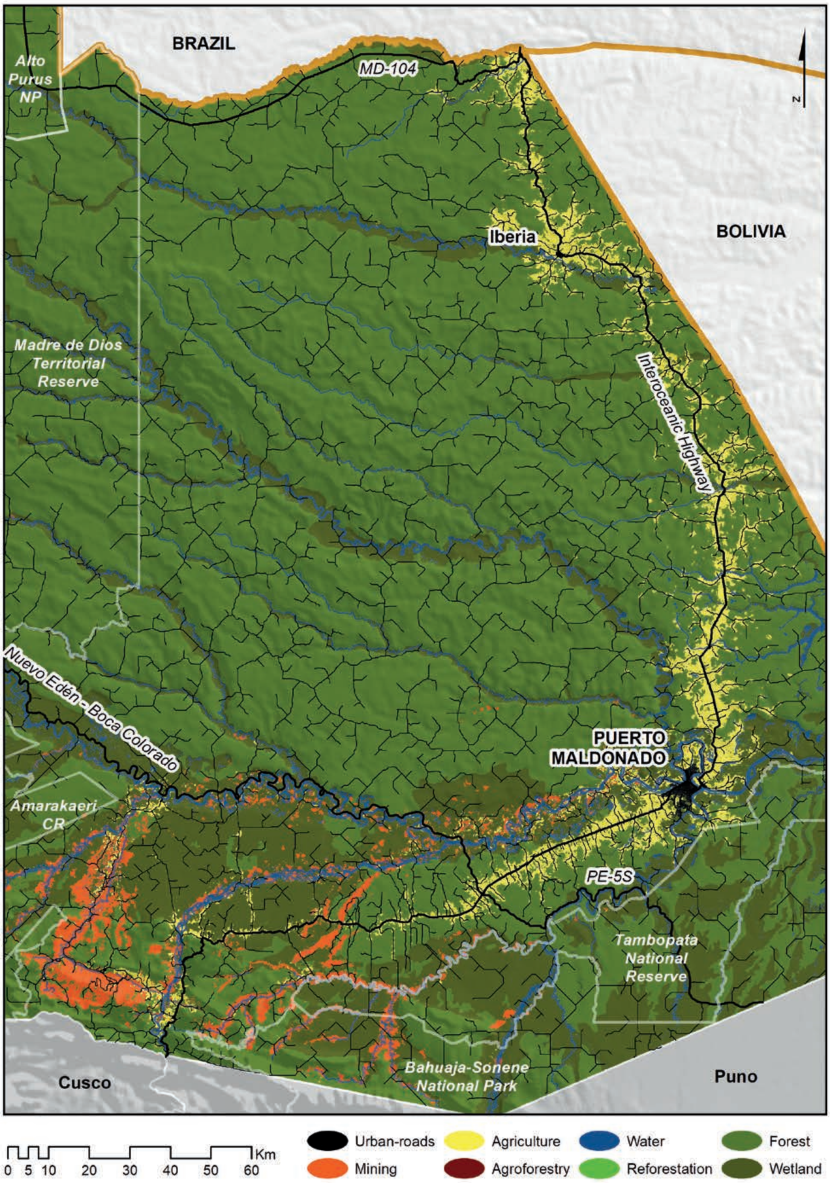


Figure 27. Expansion of Alluvial Gold Mining scenario.

Projection of the Landscape in 2040 around the Interoceanic Highway

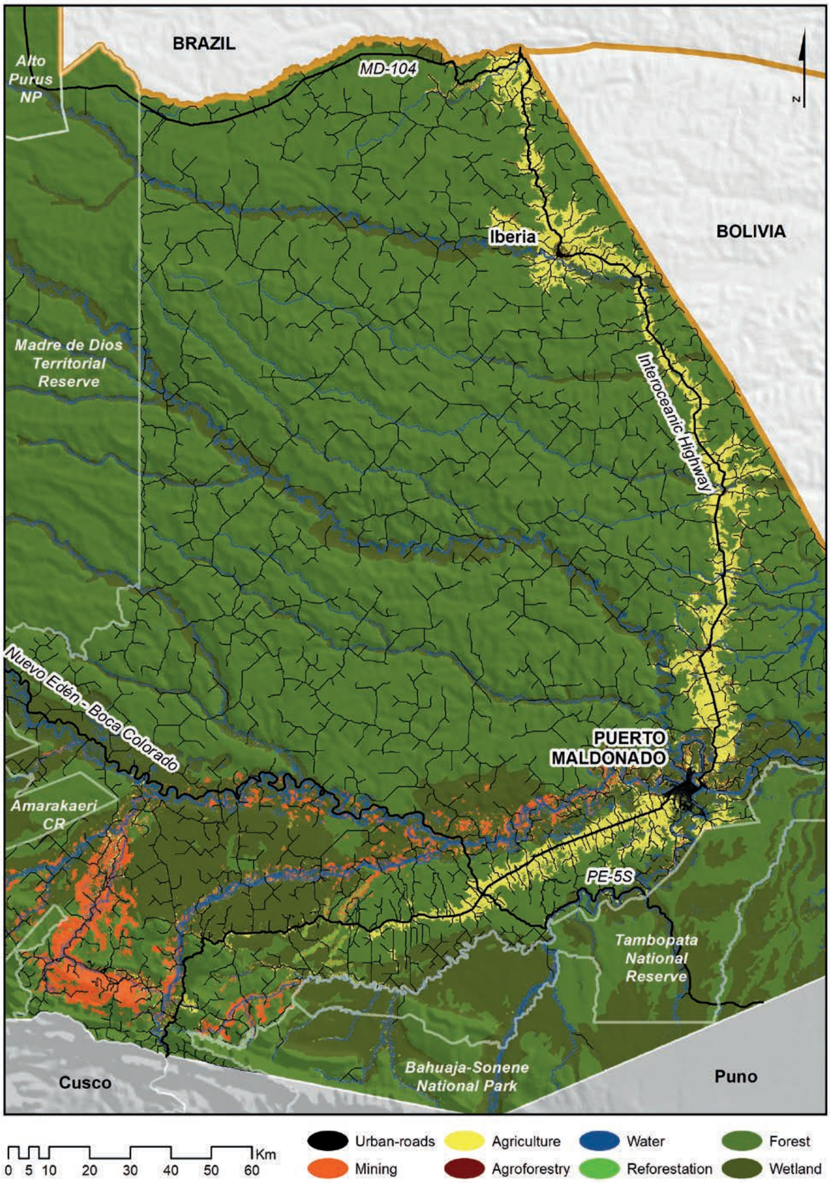


Figure 28. Land Planning scenario.

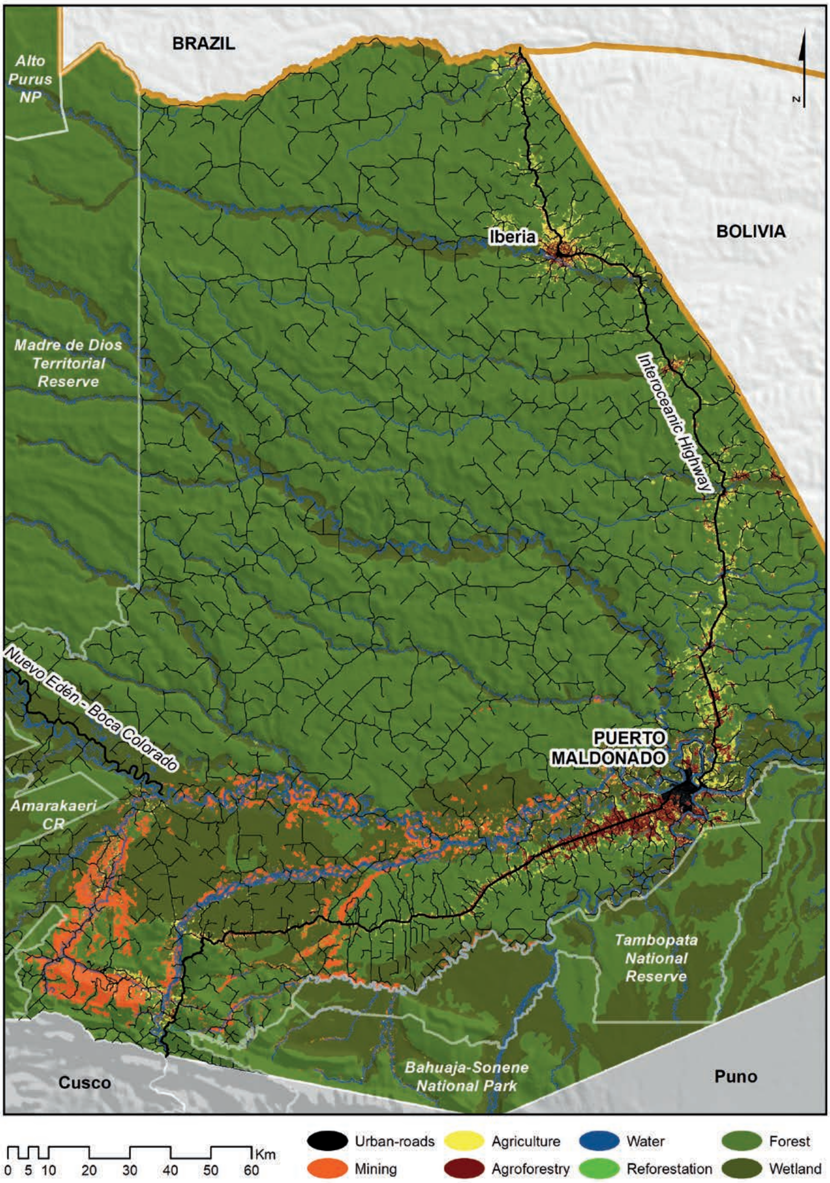
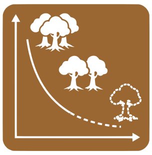


Figure 29. Landscape Conservation scenario.

Performance of the Scenarios for Economy, Well-Being, and Environment Indicators



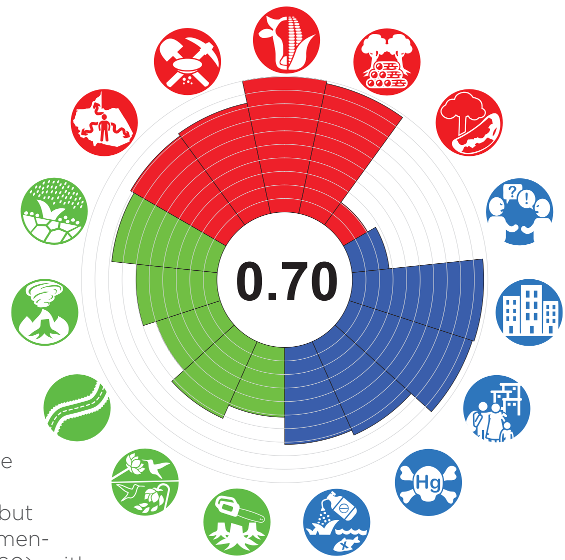


Figure 30. Current Trends scenario. The scenario performs well in the economic dimension (average performance 0.77 out of 1), particularly in the agriculture sector, even though massive deforestation in this scenario impacts the Brazil nut sector. Human well-being performance is also good (0.74), mainly due to a slow growth in urban and mining populations, but with high risks of social conflicts. Environmental performance of the scenario is low (0.60), with high deforestation affecting the region's biodiversity and producing fragmentation, release of carbon, and erosion.

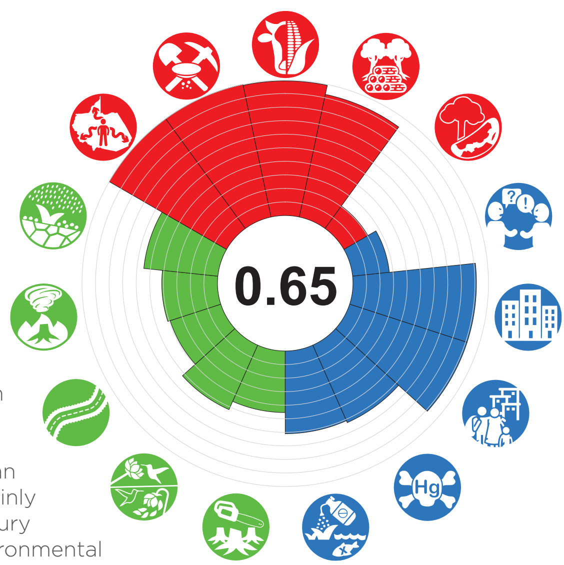


Figure 31. Expansion of Alluvial Gold Mining scenario. The scenario performs well in the economic dimension (average performance 0.82 out of 1), particularly in the mining and agriculture sectors, even though massive deforestation in this scenario impacts the Brazil nut sector. Human well-being performance is low (0.67), mainly due to high risks of social conflicts, mercury exposure, and agricultural pollution. Environmental performance is the lowest among scenarios (0.47), with high deforestation rates affecting the region's biodiversity, and producing fragmentation, release of carbon, and erosion.

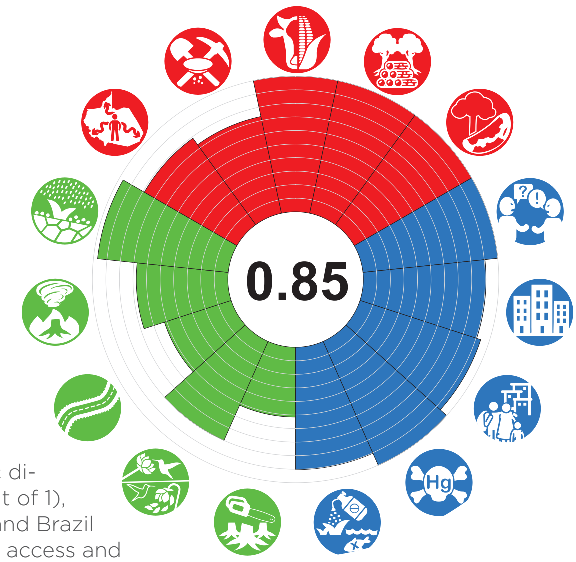


Figure 32. Land Planning scenario. The scenario performs best in the economic dimension (average performance 0.90 out of 1), particularly in the agriculture, logging, and Brazil nut sectors, with lower performances in access and mining sectors. Human well-being performance is also the best among scenarios (0.95), with no performance score below 0.90. Environmental performance is good (0.70), particularly in reducing biodiversity loss and erosion.

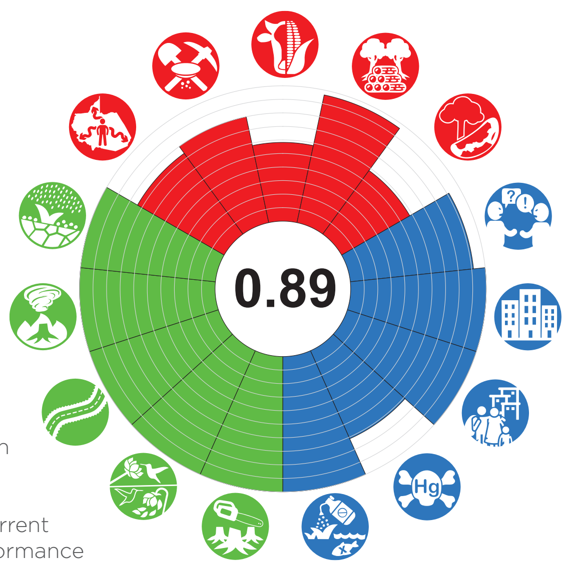


Figure 33. Landscape Conservation scenario. This scenario performs lowest in the economic dimension (average performance 0.73 out of 1), particularly in terms of accessibility and in the agriculture sector, with better performances in the Brazil nut sector than seen in the Current Trends scenario. Human well-being performance is good (0.93), with the exception of the mercury exposure indicator. Environmental performance is the best among scenarios (1.00) for all indicators.

Artist's Vision of the Scenarios

Figure 34. Current Trends scenario.

Figure 35. Expansion of Alluvial Gold Mining scenario.

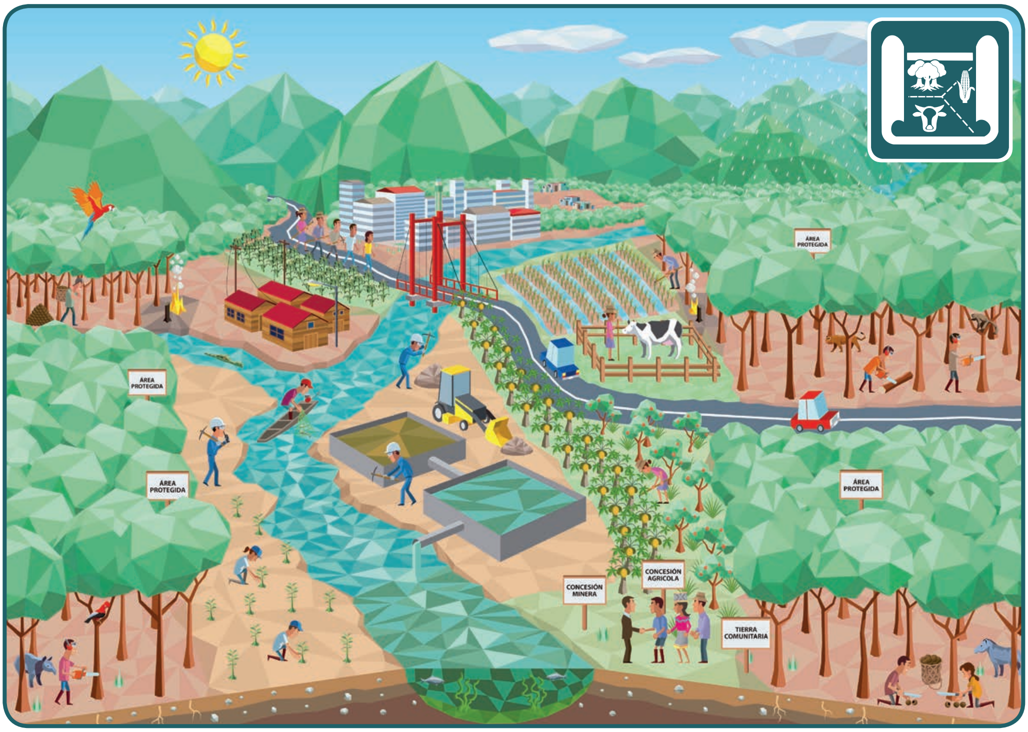


Figure 36. Land Planning scenario.

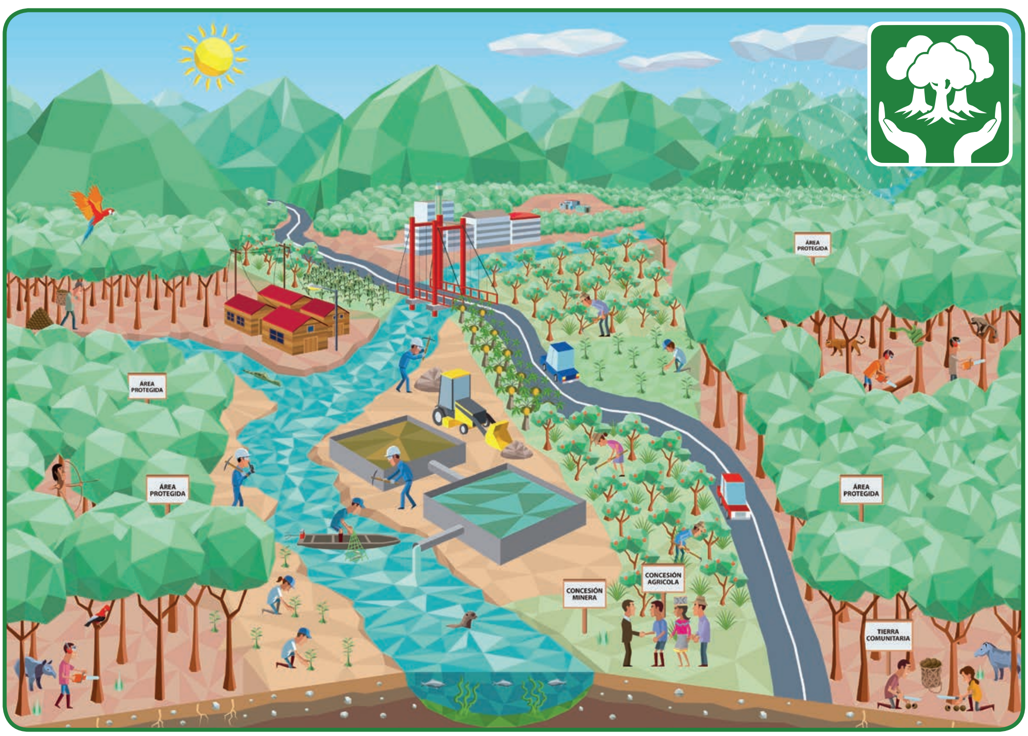


Figure 37. Landscape Conservation scenario.

Lessons Learned from the Scenarios

Economic Development

The highest economic performance in 2040 is expected for the Land Planning scenario (Table 10), which effectively balances access, mining, agriculture, logging, and exploitation of Brazil nuts within a coordinated zoning plan that results in a strong, diversified economy favoring environmentally friendly industries. With an opposite strategy based on deregulated exploitation of natural resources, the Expansion of Alluvial Gold Mining scenario achieves high economic performance as well in all sectors except the exploitation of Brazil nuts, which suffers from the ecological impacts of other economic sectors. The reduced immigration rate, lower price of gold, and the concurrence between conservation objectives and deregulated economic activities result in a similar but slightly lower economic performance of the Current Trends scenario compared to the Expansion of Alluvial Gold Mining scenario. Finally, the Landscape Conservation scenario ranks lowest in terms of economic performance as a result of its highly regulated economic policies restricting

Table 10. Performance index values across scenarios. Scale 0–1 (1 = most successful)

Indicators	Current Trend	Expansion of Gold Mining	Land Planning	Landscape Conservation
Economy				
Access to resources	0.81	1.00	0.79	0.74
Mining activity	0.83	1.00	0.73	0.80
Agriculture activity	1.00	0.99	1.00	0.58
Logging potential	0.98	0.93	1.00	0.96
Brazil nut potential	0.21	0.20	1.00	0.58
Mean performance:	**0.77**	**0.82**	**0.90**	**0.73**
Well-Being				
Avoided conflicts	0.28	0.27	1.00	0.91
Urban planning	0.97	0.91	0.91	1.00
Contained growth of mining pop.	0.96	0.91	0.94	1.00
Avoided mercury exposure	0.76	0.63	1.00	0.71
Avoided agriculture pollution	0.72	0.61	0.90	1.00
Mean performance:	**0.74**	**0.67**	**0.95**	**0.93**
Environment				
Avoided deforestation	0.52	0.45	0.52	1.00
Biodiversity	0.62	0.52	0.80	1.00
Landscape connectivity	0.50	0.39	0.52	1.00
Avoided carbon emissions	0.60	0.41	0.68	1.00
Avoided erosion	0.78	0.55	0.97	1.00
Mean performance:	**0.60**	**0.47**	**0.70**	**1.00**
All indicators:	**0.70**	**0.65**	**0.85**	**0.89**

agriculture, mining, and road expansions in favor of ecosystem conservation. The low economic performance in the Landscape Conservation scenario would not necessarily mean poverty would progress in the region, as such drastic policy would be associated with efforts to promote other sustainable economic activities, such as ecotourism (Kirkby et al. 2010) and the development of services economy that were not considered in our indicators.

Human Well-Being

The highest well-being performance is expected for the Land Planning scenario (Table 10), which most effectively contains land-use conflicts and limits human downstream exposure to mercury by enforcing a thoughtful land plan. The Land Planning scenario also ranks among the best in terms of regulating urban and mining town growth and in limiting agricultural contamination of superficial waters. Almost as effective as Land Planning, the Landscape Conservation scenario ranks second in terms of well-being performance. The Landscape Conservation scenario ranks best in controlling urban and mining town growth, thanks to its strict control of mining expansion. It also ranks best in limiting agricultural pollution with its systematic restriction of agricultural expansion. The Landscape Conservation scenario falls short in reducing human mercury exposure, because although expansion of authorized mining concessions is restricted, concessions are still located in the headwaters of major human settlements. In contrast, the Land Planning scenario's ecological and economic zoning allows for more surface area dedicated to mining, but promotes mining downstream from major human settlements, resulting in lower mercury exposure. The Current Trends scenario ranks significantly lower in terms of well-being than the first two scenarios despite good performances in regulating urban and mining town growth. The unplanned development in the Current Trends scenario favors overlaps between land users, generating social conflicts. The absence of planning and control also increases mercury exposure and agricultural pollution of superficial waters. The Expansion of Alluvial Gold Mining scenario ranks lowest in well-being performance for the same reasons as the Current Trends scenario, although these reasons are exacerbated by the greater deregulation, immigration, and mining expansion hypothesized in this scenario.

Environment

The highest environmental performance is expected for the Landscape Conservation scenario (Table 10), which is the most effective to avoid deforestation, maintain biodiversity, preserve landscape connectivity, and avoid increased carbon emissions and erosion. The scenario achieves these outcomes by severely restricting the development of all destructive economic activities and enforcing the highest environmental best practices. With its land management plan oriented toward production, the Land Planning scenario ranks second in environmental performance. The scenario projects much higher rates of deforestation for agriculture and mining than does the Landscape Conservation scenario, resulting in lower performance scores in terms of landscape fragmentation and carbon emissions. The Land Planning scenario manages to contain erosion though, through the development of agroforestry, and to preserve high levels of biodiversity. With a comparable deforestation rate to that in the Land Planning scenario, the Current Trends scenario shows more severe environmental damages, with much lower biodiversity, higher carbon emission, and much greater erosion. The Expansion of Alluvial Gold Mining scenario ranks lowest in environmental performance, with the indicators reduced by about half compared to Landscape Conservation. Beyond the negative consequences for biodiversity and ecosystem services of this anarchic development, we would expect such severe environmental degradation to have effects beyond the indicators considered, such as outbreaks of pests and diseases or severe disturbance of local climate, as observed in the most deforested parts of the Brazilian Amazon. The development option chosen for Madre de Dios also contributes to meeting national objectives and international agreements. For example, the reduction in carbon dioxide emission that we expect to obtain by switching from the Current Trend to the Landscape Conservation scenario represents 2% of the annual objective of Peru in reducing Greenhouse Gas Emissions (Republic of Peru 2015). In contrast, choosing the Expansion of Alluvial Gold Mining scenario would drive the country away from the reduction in Greenhouse Gas Emissions objective by 2%, in addition to all the other negative environmental and social impacts encountered in this scenario.

Across scenarios, protected areas are very effective at slowing down agriculture, mining, and road invasions. In the Current Trends scenario, protected areas are significantly less impacted than the rest of Madre de Dios for all environmental indicators in 2040. In this scenario, most of the adverse impacts on protected areas occurred in the Amarakaeri Communal Reserve and Tambopata National Reserve, probably because they are very close to the Interoceanic Highway, major mining areas, and cities, and are therefore more exposed and vulnerable to development than the more distant parks like Manu, Bahuaja Sonene, and Alto Purus. Nevertheless, without proper management of nonprotected areas through a regional land management plan, protected areas alone are not able to contain the rapid development that will continue to occur in Madre de Dios in the next 20 years. The degradation of protected areas in 2040 would have consequences reaching well beyond the region and needs to be avoided (see page 89).

Sustainable Development in Madre de Dios

This study provides numerous insights regarding the development mechanisms at play in the Madre de Dios region and the way to achieve sustainable development:

» No one scenario brings the highest performance in all indicators, and all represent different trade-offs between economic development, human well-being, and environmental sustainability. These dimensions of sustainability are interdependent, and a decision about one dimension affects the success of the others, calling for a holistic management approach considering the three simultaneously.

» Madre de Dios needs a sustainable development pathway that achieves economic development, population well-being, and environmental and ecosystem services integrity.

» Not all economic choices bring the same economic, well-being, and environmental benefits. For instance, unregulated and informal mining has a great cost for society and the environment in the short term and as a wasted opportunity for the future of the region.

» The development of the economy of a region does not necessarily imply increased well-being or environment damages. The Land Planning scenario has higher aggregated economic indicator values than the Expansion of Alluvial Gold Mining scenario and also has better aggregated well-being and environmental indicator values. Based on their aggregated economic scores (0.77 and 0.73; Table 10), the Current Trends and Landscape Conservation scenarios have comparable economic performances, but well-being and environmental performance are clearly higher in the Landscape Conservation scenario.

» Important drivers of changes such as immigration, climate change, fluctuation of international gold prices, and the national legal framework occur at scales larger than the region of Madre de Dios and need to be managed accordingly.

» Impacts of landscape development decisions are often long term and cumulative; territorial planning should therefore also be long-term and holistic.

» Indicators should consider not only the surface area deforested, but also where deforestation occurs, as this aspect has important consequences for other indicators.

» Costs of economic development are unequally distributed among stakeholders, and it is the role of policy makers to protect the most vulnerable from the adverse effects of development.

- The economy of the region relies on a diversified set of extractive and non-extractive sectors that compete for access to resources. Trade-offs need to be found to maintain economic development and integrity of ecosystem services and biodiversity.
- Active territorial management and good governance of the region's working landscapes provides higher performance than unmanaged development, stressing the need for an integrated approach to land zoning, considering economic, well-being, and environmental processes. Good governance has the potential to grow the economy and increase well-being vastly more than any other development choice and beyond what we could capture in the indices used in this study. In addition, where good governance prevails—as in the Land Planning and Landscape Conservation scenarios—formalized mining would provide tax revenues to the regional and national governments. Currently, the mining sector is mostly informal and illegal, and contributes only marginally to the formalized economy. If formalized, the tax revenues would slow the unregulated expansion of mining, encourage professionalization of the sector, and finance social and environmental projects that would benefit society.

RECOMMENDATIONS FOR ACHIEVING SUSTAINABLE WORKING LANDSCAPES

Principles

First and foremost, all stakeholders should share a common vision for the development of the region if they are to overcome the challenges facing Madre de Dios. Common principles of action should include:

- **Sustainability** based on economic development, human well-being, and conservation of the environment.
- **Equity**, based on stakeholder consultations and participation in shaping the future of the region. This requires systematic stakeholders' engagement (Dourojeanni 2006, MINCETUR 2007, GOREMAD 2009, 2014c, 2014a, Zelli et al. 2014, Pacha 2015).
- **Cultural respect**, based on the recognition, respect, and valorization of the culture and rights of the region's inhabitants (Valqui et al. 2015).
- **Holistic view**, including all economic sectors, public and private participation, and the national, regional, and local scales (Redwood 2012, Little 2014).
- **Transparency and probity** of the state, based on honest agents communicating Madre de Dios's vision regionally and nationally and making the region's management information easily available.

> "Politics should be viewed as a service, not a business."

Responsibility of Territorial Planning

Administrative roles and responsibilities must be well defined to efficiently drive the territorial planning process. This responsibility is shared among various administrations in Peru (Figure 38):

- **Local Governments** (provinces and districts) are responsible for the management of their territories, in particular regarding infrastructure and urban planning (Municipalities Organic Law #27972 2003).
- **Regional Governments** (GORE) are responsible for the territorial planning of the agricultural, energy, mining, and hydrocarbon sectors as well as proposing new protected areas and building roads. They are also responsible for enforcing the national environmental plans and the law in those sectors (Regional Government Organic Law #27867 2002).
- ***Viceministerio de Gobernanza Territorial*** (VMINGT) [Viceministry of Territorial Governance], created in February 2017, is an agency dependent directly on the Minister Council (Supreme Decree #022-2017-PCM), responsible for territorial development, decentralization, social dialogue and consultation, and territorial delimitation.
- ***Centro Nacional de Planeamiento Estratégico*** (CEPLAN) [National Center for Strategic Planning] is a technical agency dependent on the Minister Council in charge of national strategic planning (National System of Strategic Planning and CEPLAN Law #28522 2005, Legislative Decree #1088-2008-PCM; Supreme Resolution #197-2016-PCM). This agency provides technical support to regional, provincial, and district governments.
- ***Infraestructura de Datos Espaciales del Perú*** (IDEP) [Spatial Data Infrastructure of Peru] is a virtual online structure dependent on the Minister Council created to facilitate the production, use, and access to the geographic information of the state (Supreme Decrees #133-2013-PCM, #086-2012-PCM, and #069-2011-PCM).
- ***Ministerio del Ambiente*** (MINAM) [Ministry of the Environment], with its *Dirección General de Ordenamiento Territorial* (DIGOT) [General Bureau of Territorial Planning], is in charge of promoting the balanced and competitive development of the territory by supporting Regional Governments in their territorial planning activities. The technical instruments to support territorial planning are the ecological and economical zoning (ZEE), the specialized studies (EE), the integrated diagnostic of the territory (DIT), and the territorial management plan (POT).
- ***Servicio Nacional de Áreas Naturales Protegidas por el Estado*** (SERNANP) [National Service of Natural Protected Areas by the State] is a technical agency dependent on the MINAM and in charge of managing the national protected areas (Legislative Decree #1013 2008).

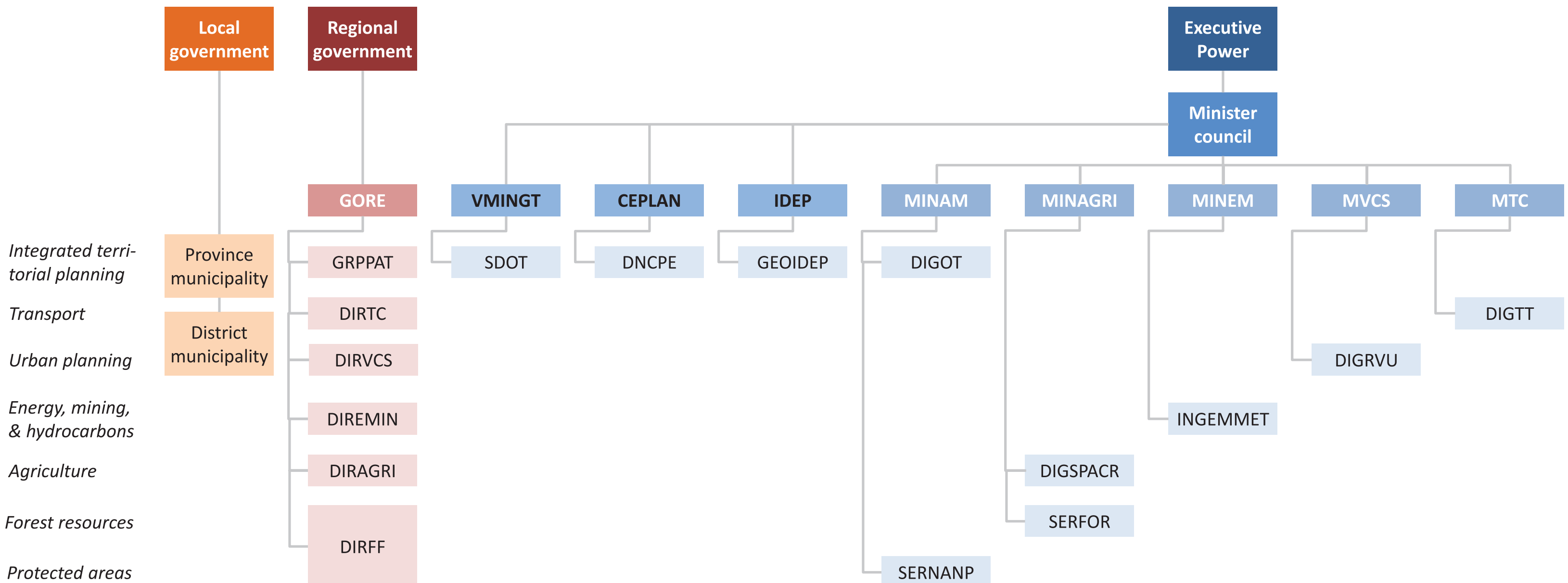


Figure 38. Main institutions in charge of integrated and sectorial territorial planning in Peru. CEPLAN: *Centro Nacional de Planeamiento Estratégico*; DIGOT: *Dirección General de Ordenamiento Territorial*; DIGRVU: *Dirección General de Políticas y Regulación en Vivienda y Urbanismo*; DIGSPACR: *Dirección General de Saneamiento de la Propiedad Agraria y Catastro Rural*; DIGTT: *Dirección General de Transporte Terrestre*; DIRAGRI: *Dirección Regional de Agricultura*; DIREMIN: *Dirección Regional de Energía, Minas, e Hidrocarburos*; DIRFF: *Dirección Regional Forestal y de Fauna*; DIRTC: *Dirección Regional de Transporte y Comunicaciones*; DIRVCS: *Dirección Regional de Vivienda, Construcción, y Saneamiento*; DNCPE: *Dirección Nacional de Coordinación y Planeamiento Estratégico*; GEOIDEP: *Portal de la Infraestructura de Datos Espaciales del Perú*; GORE: *Gobierno Regional*; GRPPAT: *Gerencia Regional de Planeamiento Participativo y Acondicionamiento Territorial*; IDEP: *Infraestructura de Datos Espaciales del Perú*; INGEMMET: *Instituto Geológico Minero y Metalúrgico*; MINAGRI: *Ministerio de Agricultura y Riego*; MINAM: *Ministerio del Ambiente*; MINEM: *Ministerio de Energía y Minas*; MTC: *Ministerio de Transportes y Comunicaciones*; MVCS: *Ministerio Vivienda, Construcción y Saneamiento*; SDOT: *Secretaria de Demarcación y Organización Territorial*; SERFOR: *Servicio Nacional Forestal y de Fauna Silvestre*; SERNANP: *Servicio Nacional de Áreas Naturales Protegidas por el Estado*; VMINGT: *Viceministerio de Gobernanza Territorial*.

- ***Ministerio de Agricultura y Riego*** (MINAGRI) [Ministry of Agriculture and Irrigation], with its *Dirección General de Saneamiento de la Propiedad Agraria y Catastro Rural* (DIGSPACR) [General Bureau of Sanitation of Agrarian Property and Rural Cadastre], is in charge of preparing technical norms and guidelines regarding the formalization of agrarian property, including the lands of agricultural and native communities, and centralizing the rural cadastre (Law #30048 2013, Supreme Decree #008-2014-MINAGRI).
- ***Servicio Nacional Forestal y de Fauna Silvestre*** (SERFOR) [National Forest and Wildlife Service], dependent on the MINAGRI, is responsible for forest and fauna resource management in Peru (Forest and Wildlife Law #29763).
- ***Instituto Geológico Minero y Metalúrgico*** (INGEMMET) [Mining and Metallurgy Geological Institute], dependent on the ministry of energy and mines (MINEM), is responsible for ordinary mining procedures, including authorizing mining concessions.
- ***Ministerio Vivienda, Construcción y Saneamiento*** (MVCS) [Ministry of Housing, Construction and Sanitation], with its *Dirección General de Politicas y Regulacion en Vivienda y Urbanismo* (DIGRVU) [General Bureau of Policies and Regulation in Housing and Urban Planning], is in charge of elaborating and applying the National Plan for the Ordering and Integration of Populated Centers.
- ***Ministerio de Transportes y Comunicaciones*** (MTC) [Ministry of Transport and Communications] is in charge of developing transportation systems in Peru, including roads.

Territorial management in Peru is carried out by local and regional governments, within limits dictated by the laws, norms, and regulations provided by designated ministries. In practice, several problems arise:

- The transition of the responsibility for territorial planning from the national government to the regions, provinces, and districts took years, and local and regional governments often still lack expertise, funds, and interest in carrying out this activity.
- NGOs have often been supporting territorial planning at local scale when local government could not provide support. Unfortunately, these efforts often have been lost when NGO projects ended.

"Territorial planning does not work at the provincial and district levels."

"The regional future is being planned now, but where are the management budgets at the district level?"

- Numerous functions of regions, provinces, and districts overlap and tend to work in parallel, reducing institutional and economic efficiency of actions (GOREMAD 2014c).
- Ministries still develop and manage territorial planning projects at the national level with sometimes incomplete involvement of the local and regional governments, creating confusion.
- Under the direction of MINAM, territorial planning has been formalized and stronger norms now better define the process. Unfortunately, this change in the rules has delayed the territorial planning process in Madre de Dios, which started in 2009. The Plan de Ordenamiento Territorial published in 2014 was never approved due to the new norms.
- National territorial planning projects are often elaborated by sector, with no integrated approach of development. Three entities could currently assume the role of integrating sectorial approaches in a national plan: MINAM, VMINGT, and CEPLAN. These current overlapping responsibilities bring confusion to the territorial planning process.
- For proper territorial planning, it is essential to properly manage cadastral data. Concession and permit data are often kept in the corresponding ministries where they are inaccessible to the public and without integration between sectors and across scales.

> "The 2015 regulations from MINAM destroyed the land planning efforts started since 2009 in Madre de Dios."

> "Peru has an abundance of plans, one for each sector, but an integrated vision for the country is lacking."

Peru's government has started ambitious reforms of its structure, including the decentralization of responsibilities and increasing emphasis on the need for integrated territorial planning. Implementing four activities would support these efforts.

1. **Designate a unique agency in charge of integrating the sectorial efforts of territorial planning** into a national plan (Dourojeanni 2006, Dourojeanni et al. 2009, GOREMAD 2009, Cárdenas Panduro 2010, Chavez et al. 2012, GOREMAD 2014c, Valencia et al. 2015). This agency must have representatives from other agencies and civil society to facilitate communication and processes, and to ensure governance, land-use planning, networking, education, research, and other aspects of territorial planning are properly implemented across sectors and scales. MINAM, VMINGT, and CEPLAN could assume this role, but all overlapping responsibilities should be clarified.

2. **Centralize all the geographic information generated by the territorial planning process** in real time and make it publicly available (see page 88). The GEOIDEP portal could be the structure for this.
3. **Reform the regional and local government structures** to facilitate territorial planning processes by integrating the three levels of government, differentiating their roles and responsibilities, and centralizing the information they generate (GOREMAD 2014c).
4. **Provide incentives as well as training, technical, and financial support to regional and local governments** to complete the trans-sectorial territorial planning process following current standards and national plans. Incentive could include provide funding based on the completion of tasks measured with reliable indicators.

Revision of the Legal Framework

"The legislation itself generates the problems."

According to the stakeholders consulted, the current legal framework is limiting the capacity of the governments to implement territorial planning in Madre de Dios. In some cases, laws and regulation have perverse effects, and end up promoting invasions and deforestation. Very often, institutional overlap of responsibilities and unclear norms promote informality and make the path to legal exploitation very difficult. There is a great need to revise the current legal framework and to propose updated policies that will facilitate implementation of the regional sustainable development vision. We suggest **creating technical multidisciplinary groups of experts** (lawyers, land planners, sociologists, economists, engineers, biologists, ecologists) **that would examine the law and make proposals to the ministries concerned** (Mateo and Cornejo Arana 2006). Proposals may include, among others, the following:

1. **Promote a new law** incentivizing governments to carry out plans validated by previous administrations to ensure the continuity and efficiency of actions. Any change or abandonment of a plan should be supported by solid technical study proving its inefficiency and be accompanied by a replacement plan complying with current norms and regulations.

"The rules are restrictive for the 20% people who have rights while the 80% of informal and illegal activities are not controlled."

2. **Standardize and simplify** the requirements and data needed for validating the territorial plans.
3. **Create a Peruvian Amazonian land planning law** that will support sustainable development for Madre de Dios with planning and financial resources (Dourojeanni et al. 2009, GOREMAD 2014c).
4. **Recognize that alluvial gold mining is not compatible with sustainable forest** and conservation management and that rezoning is needed (Mosquera et al. 2009, Valencia et al. 2015).
5. **Close legal loopholes** (perverse laws) that are used to facilitate deforestation of highly biodiverse areas of primary forest for mining, logging, and palm oil plantations (Valqui et al. 2015).
6. **Create an interregional program** to alleviate poverty in the Andean regions around Madre de Dios (Zelli et al. 2014).
7. **Create partnerships with the Brazilian and Bolivian administrations** to exchange information and capacities, and to coordinate development (GOREMAD 2014c).
8. **Expand the requirements of any development project** to incorporate feasibility and impact studies applying the mitigation hierarchy (Dourojeanni 2006, Pilla 2014). This requires Environmental and Social Impact Assessments (ESIAs) to include cumulative and large-scale environmental and social externalities (Dourojeanni et al. 2009, Redwood 2012, Hardner et al. 2015), and couple these with ecosystem services evaluations (Landsberg et al. 2013). The law should also promote the realization of Strategic Environmental and Social Assessment instead of ESIA when feasible (Redwood 2012, Little 2014).

Territorial Planning

The sustainable management of a working landscape with multiple uses of territorial space and resources requires active and effective planning and participation of stakeholders with the enforcement of a territorial management plan. Several challenges currently make sustainable working landscape management ineffective in Madre de Dios:

> "More than a law, we need a national policy on territorial planning and its implementation."

- There is no consensus on the development goals for the region that would guide public and private investments;
- Many land uses are informal or in various stages of formalization;
- Proper geo-referencing of existing formalized concessions is lacking;
- Concessions of incompatible land uses are overlapping;

- The productive potential of the land is not taken into consideration in land-use management; and
- The legality of practices of concession owners is rarely enforced.

According to the stakeholders consulted, five activities would contribute to addressing these challenges:

> "They tell us that we cannot develop agriculture, although the demand for products is not met."

1. Unify development goals. A Madre de Dios land management plan needs unifying development goals aligned with the aspirations of the region's stakeholders and national priorities. Both bottom-up and top-down approaches are needed to define these goals, with systematic participation of stakeholders of all economic sectors at the district, regional, and national levels. The two processes will converge into manageable and measurable objectives, actions, and indicators. The territorial footprint allowed for agriculture, formalized mining, conservation, urbanization, and other uses needs to be clearly defined and to align with the development goals. Large infrastructure projects, such as roads, telecommunications, electricity, and running water, could then be planned as an integrated approach with the financing institutions and the development sector (MINCETUR 2007, Redwood 2012).

> "Politicians must get their shoes dirty to understand the problems in the region."

2. Pursue land-use zoning for sustainability. Land-use zoning and enforcement is essential for an optimal sustainable development of the region. For example, around the Interoceanic Highway, large tracts of agriculture lands are abandoned because they were established on land that was not appropriate for agricultural uses (Dourojeanni 1976, Róssi et al. 1983, Dourojeanni 2013). Peruvian supreme decree #087-2004-PCM requires that this zoning be executed at three scales from the larger (macro) to the smaller (micro). Madre de Dios already completed its macro-zoning (regional ordinance #032-2011-GRMDD-CR), which proved effective to mitigate ecological impact of the region's development in our results. Micro-zoning has already started in the Tambopata province but is not yet integrated in the regional management practices. Technical studies required for the zoning process should be better standardized using existing norms (e.g., MINAM 2013) to expedite their approbation.

> "The Ecological and Economic Zoning [tool] has proven its usefulness in the scenarios."

3. Establish a unique cadastre. The overlap of concessions and properties with sometimes incompatible land uses creates conflicts among owners and paralyzes territorial planning and management. The regional government of Madre de Dios therefore created the *Catastro Unico Regional* (CUR; regional ordinance #002-2009-GRMDD-CR), which unfortunately has not been implemented to date. Concessions of various ages were defined with different methods, from topographic surveys and interpretation of aerial imagery for the oldest (typically native communities), to georeferenced areas for the most recent (typically new immigrants). Older concessions were typically defined using landmarks, such as rivers that change course through time. Consequently, it is essential to standardize cadastre delineation methods with those recommended by the *Sistéma Nacional Integrado de Informacion catastral predial* (SNCP: www.sncp.gob.pe). Using SNCP's norm, the CUR needs to inventory all land rights that were ever granted in the region to identify land-use conflicts. In these areas of conflict, the government could facilitate mediation between title owners, so only one of the incompatible land uses remains. The involvement of local organizations (municipalities, associations of miners, farmers, and indigenous federations) in this mediation is essential (MINAGRI 2005, Dourojeanni 2006, Meza et al. 2006, GOREMAD 2014c, Peña Alegría 2014, Valencia et al. 2015). When granting the right to operate to one of the competing land owners, the CUR could take into account several criteria on a case-by-case basis: permanence of the activity, sustainability of proposed use (Chavez et al. 2012, Zelli et al. 2014), compatibility with regional plan and zoning, if the concession title is formalized, and which title was established first. In some cases, formalizing existing arrangements or an equal division among owners could also be proposed.

> "When you look at the cadastre, you want to declare a state of emergency."

4. Temporarily suspend and update the process for granting new concessions. Despite the issues in Madre de Dios with the definition of the region's development goals, the incomplete zoning process, and the absence of a functioning unique cadastre, new titles and concessions are granted each year. This situation aggravates the issues and strongly argues for the establishment of a moratorium suspending the granting of new rights pending their resolution (Valencia et al. 2015). During this moratorium, entities in charge of attributing concessions should revise their processes to ensure new concessions are not overlapping with other incompatible land uses (see page 88), comply with the regional and local zoning, and are revised by all relevant institutions and stakeholders. The revision process would also be a good occasion for harmonizing and simplifying

> "Plans cannot be executed at that level of bureaucracy."

procedures across institutions (MINAGRI 2005, MINCETUR 2007), continuing the efforts started by the national government.

5. Control and monitor the territorial plan. Even with proper planning and sufficient funds, sustainable development can fail if proper monitoring of projects and practices is not enforced. In particular, it is essential that public development projects are submitted regularly to a financial audit during their execution to control for the proper allocation of funds. At the end of a project, the government agency that requested the work could conduct a formal liquidation including a report indicating how funds were spent, the activities realized, and the percentage of work completed. Similarly, regular controls of concessions owners could be realized, to monitor the extent to which land-use practices conform to the law and regional planning (Dourojeanni 2006, Dourojeanni et al. 2009), and request or apply sanctions when necessary, like the *Organismo de Supervisión de los recursos forestales y de fauna silvestre* (OSINFOR) is doing for loggers and Brazil nut producers. The constant monitoring of invasions of formal concessions by incompatible land uses needs to be a priority to prevent irreversible damages to the ecosystems utilized by lawful owners. Concession owners and territory managers could assist the government with this task, for example, by empowering native communities to monitor their territories.

> "The owners cannot do what they want with their own land."

Trans-Sectorial Good Practices

Most of the economic activity in Madre de Dios is informal and artisanal. This reality leaves a great deal of room for improvement of practices to increase profitability and reduce social and environmental impacts. A coordinated plan across sectors should implement the following activities:

> "The roundtable on conflict resolution was the most controversial."

1. Organize sectorial roundtables to brainstorm proposals of best practices and improvements from the bottom up. Proposals should then be integrated in the development plans at a higher level and transformed into actions.

2. Provide technical support to small-scale economic operators (miners, farmers, loggers, ecotourism operators, managers of protected areas) for their operations, formalization, and certifications (Kuramoto 2002, MINAGRI 2005, Meza et al. 2006, MINCETUR 2007, Mosquera et al. 2009, Hugo Pachas 2013, Zelli et al. 2014, Valencia et al. 2015). Miners and Brazil nut producers in particular typically lack the technical expertise and funds to comply with the requirements associated with their concessions, such as soil sampling and reforestation plans. Support could be provided in the form of sectorial cooperatives sharing materials and best practices.

3. Implement restoration and reforestation programs on degraded lands, in conformity with the *Plan Nacional de Reforestación* (MINAGRI 2005, MINCETUR 2007, GOREMAD 2015), particularly in illegal gold mining areas and headwaters (Mateo and Cornejo Arana 2006, MINAM 2009a, Vargas 2009, MINAM 2010a, 2010b, Goremad 2014b). An effective regeneration process also needs healthy populations of plants and animal dispersers in the vicinity of degraded forest (Gorchov et al. 1993), which depends on the implementation of better practices in all sectors (see item 5 below).

4. Integrate the production chains of wood, Brazil nut, and other products derived from native biodiversity and sustainable use; and facilitate their certifications, local transformation, and exportations (MINAGRI 2005, Mateo and Cornejo Arana 2006, MINCETUR 2007, Goremad 2014b, 2014a, 2015). The production chain logic could also open the possibility to develop new products.

> "Marzipan with Brazil nut is made in Arequipa. It should be done in Madre de Dios!"

5. Develop, experiment, and promote sectorial best practices and innovations, including the following:

a. Sustainable agroforestry (Meza et al. 2006, MINCETUR 2007);
b. Limitations of the extirpation of biodiversity by setting and enforcing collection seasons and quotas for forest product recollection, fishing, and hunting;
c. Better technologies restricting air and water contamination with mercury from mining (Mosquera et al. 2009, Valencia et al. 2015); and
d. Affordable techniques to restore degraded lands.

Adaptation to Change

The results of this study show that whatever decision is made for Madre de Dios, the lifestyle of the average person in the region will be different in 2040. Population is expected to more than double in all scenarios, with a concentration of people in urban areas. The productive system of the region that supports this population will also expand in all scenarios, making the forest recede further from major population centers. Climate will also be affected, with an increase in mean temperatures and precipitation, and greater risk of natural disasters (Obregón et al. 2009). All these changes will have social consequences with higher risks of conflicts and environmental consequences on biodiversity and ecosystem services. Such challenges require proactive management and integrated adaptation mechanisms.

1. Plan urban areas and social services. The expected population increase in urban areas calls for the development of urban zoning and development plans, particularly for Puerto Maldonado (Mateo and Cornejo Arana 2006, Goremad 2014b). Providing access to basic services, such as running water, electricity, health care, and education, should remain the priority, anticipating where population will most likely increase based on the development decisions made. Urban areas should be planned in a way that preserves natural areas that are essential to biodiversity and the provision of ecosystem services to Madre de Dios inhabitants.

2. Prepare for climate change. Madre de Dios is in the process of validating its regional plan for adapting to climate change, following the national strategy (MINAM 2010b). Key activities in this plan could include:

- Preserve the natural capital of the region as much as possible, as it is the most effective way to reduce climate change locally and globally.
- Incorporate hazards and risks of floods and landslides in land-use planning (MINAM 2010a, Goremad 2014b).
- Enforce the norms limiting carbon emissions in industrial processes (MINAM 2009a, 2010a, 2010b).
- Encourage cleaner vehicles by enforcing mandatory technical control and promote alternative clean vehicles and public transportation (MINAM 2009a, 2010a).
- Enforce energy efficiency policies in all sectors, including wasted energy in the electrical network (MINAM 2009a), with potential funding through the Clean Development Mechanism (MINAM 2009a, Vargas 2009, Ometto et al. 2013).
- Diversify the sources of energy using cleaner technologies, such as mini-dams, biogas, geothermic energy, wind turbines (MINAM 2009a, Vargas 2009).
- Implement water and solid-waste treatments and use these processes to produce energy (Vargas 2009, MINAM 2010a, Goremad 2014b).
- Take advantage of new financing methods related to climate change, such as payment for ecosystem services (MINAGRI 2005, GOREMAD 2014a, Peña Alegría 2014), projects generating Certified Emission Reductions through REDD+ (MINAM 2009a, Vargas 2009, MINAM 2010a, 2010b, Entenmann 2012, Goremad 2014b), and Investment in Natural Capital (Ometto et al. 2013).

3. Embrace adaptive management. To date, the Madre de Dios regional land management plan initiated in 2009 has not been validated. The complexity of preparing and validating this plan may be counterproductive in the context of rapid socioecological changes. Our study shows significant land-cover changes since 1993, and even more are expected by 2040 that will affect the economy, human well-being, and the environment in the region. In the context of global climate change, those landscape alterations are

> “Management policies, in the best case, focus on the past without considering the future and without adapting to the social and environmental changes to come.”

expected to be even more unpredictable and require management flexibility. A proven way to adjust inadequate policies in the face of an uncertain future is to implement an adaptive management approach (Figure 39) where the vision and resulting regional management plan are updated regularly in a simplified administrative process (Valqui et al. 2015).

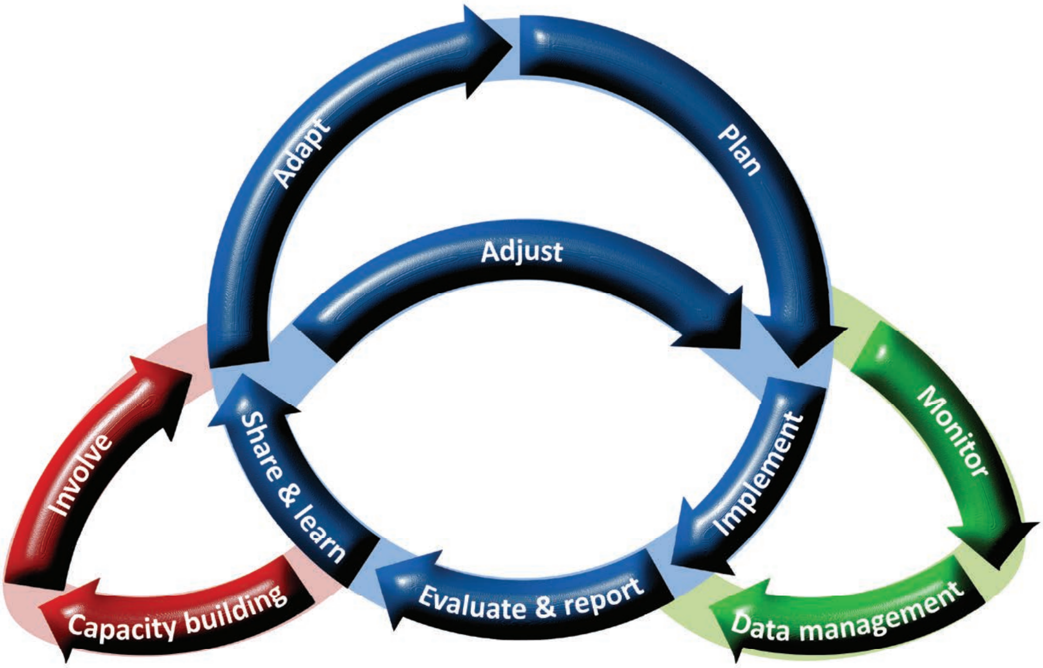


Figure 39. Adaptive management cycle, adapted from Vugteveen et al. (2015). The first step in adaptive management is making a plan including clear objectives, key desired outcomes, performance indicators, strategies, and actions. Then the plan is implemented. During implementation, data on activities and indicators are collected to monitor progress. Then results are evaluated and reported. Reports and lessons are shared and used to learn. This should trigger an effort to build capacity and involve the right stakeholders in the project. Based on what is learned, some components of the plan and implementation can be adjusted to enhance effectiveness. Finally, the entire project is reviewed periodically, to adapt it to changing conditions, and the cycle initiates again.

Research

Because it is located at the heart of one of the most biodiversity rich region of the world and undergoing rapid changes with severe environmental and social consequences, Madre de Dios has been the focus of numerous academic studies. Nevertheless, essential data needed for the models of this study were often lacking. There is an urgent need to **support applied research and training in the region**, in particular for master's and PhD students associated with the *Universidad Nacional Amazónica de Madre de Dios* (MINAGRI 2005, MINCETUR 2007, GOREMAD 2014c). Such graduate-level students are needed to help better understand the environmental and social consequences of development, and to invent new solutions for increasing economic productivity while limiting harmful impacts. Topics of interest for research include the ones presented in other recommendations, as well as the following:

1. Adapt innovative and affordable technologies that reduce mining environmental damages (Mateo and Cornejo Arana 2006).
2. Understand the impact of land use and climate changes on Brazil nut tree productivity.
3. Conduct applied research on botany, zoology, and community-based natural resource management to increase knowledge of Madre de Dios nature and culture, and to support the protection of intellectual rights related to traditional knowledge (Mateo and Cornejo Arana 2006, Goremad 2014b, 2015).
4. Create a network of hydrological and weather stations and support sustained water testing and biological inventories to understand the region's hydrology and the impact of land use and climate changes on freshwater contamination and biodiversity (Mateo and Cornejo Arana 2006, Obregón et al. 2009, Cárdenas Panduro 2010, Ometto et al. 2013).
5. Support the development in the region of laboratories able to perform quantitative food and water analysis for monitoring and certification (MINCETUR 2007), following the example of the *Centro de Innovación Científica Amazónica* (CINCIA) mercury laboratory.

Outreach and Communication

Territorial planning is the concern of all stakeholders in the region, as it will likely impact their lives and those of their children. For a democratic decision-making process to happen, all decisions and the information that support them need to be publicly available. Authorities should therefore **make information related to territorial planning freely and easily accessible**.

> "Projects do not have to be uncontrolled variables."

An option would be to create online, up-to-date georeferenced databases following the GEOIDEP model (see page 81). Policies could even require the use of the system to improve territorial planning efficiency. Layers of data presented could include the following:

- Land cover, deforestation, and forest degradation (Mateo and Cornejo Arana 2006, MINAM 2009b, Ometto et al. 2013, Goremad 2014b, 2015, Vargas Gonzáles et al. 2015);
- Concessions and large infrastructure projects, including land-use overlaps (Dourojeanni et al. 2009, Hugo Pachas 2013, GOREMAD 2014c, Valencia et al. 2015);

- Areas of activity of current and past development projects, to reduce the risk of duplicating efforts and to align project actions with the territorial plan;
- Regional biodiversity, allowing the research of species and locations (Mateo and Cornejo Arana 2006, GOREMAD 2015);
- Vulnerabilities to natural disasters and other risks (Goremad 2014b).

Other information that needs to be disseminated widely includes best practices manuals for agroforestry, forestry, alluvial mining, eco-tourism, reforestation, and restoration of degraded land (Meza et al. 2006). Environmental education programs should be implemented in schools (Mateo and Cornejo Arana 2006, GOREMAD 2014a), with an emphasis on the consequences of environmental degradation on health and the economy (Mateo and Cornejo Arana 2006, Cárdenas Panduro 2010, GOREMAD 2015). In addition, information campaigns should be developed on all the topics mentioned (Dourojeanni 2006, GOREMAD 2009, 2014c, 2014a), using the most popular communication channels, such as radio and television, but also in-person conferences in isolated communities and online media. These campaigns should be carefully controlled for their content to reduce the risk of spreading misinformation and to ensure greater impact.

> "Only liars are seen on television."

Managing Madre de Dios's Green Infrastructure: The Way Forward

The recommendations made by the stakeholders include institutional and legal changes, the update and validation of the territorial plan, the dissemination of sectorial good practices, and research. Most of these recommendations require significant changes to current decision-making and management processes, and they will take time to implement. While these actions are being taken, we suggest conducting pilot experiments of new policies in the green infrastructure of the region. These experiments could help test innovative sustainable solutions to preserve the important places, biodiversity, and ecosystem services threatened by unplanned development. The effective management of green infrastructure is the missing piece to achieve long-term management of Madre de Dios as a unified sustainable working landscape.

Core areas for Madre de Dios's green infrastructure include the region's protected areas, which preserve some of the world's richest biodiversity and provide important ecosystem services. The integrity of these protected areas has been threatened in recent years, with the invasion of miners in the Tambopata National Reserve (Finer et al. 2016b) and the Amarakaeri Communal Reserve (Finer and Novoa 2015), and the construction of a new road in the buffer zone of Manu National Park (Finer et al. 2016a). Protected areas remain, however, in excellent condition compared to areas along the Interoceanic Highway, the region's development front. Protected areas also have low human densities and are actively managed territories, with SERNANP implementing regularly updated and participative management plans. In contrast, ecosystems located outside protected areas are much more exposed to the risk of unsustainable development, with between 71% and 87% of the region projected to be accessible by road by 2040. In the Current Trends scenario, areas deforested for mining, agriculture, roads, and urban zones are mostly concentrated near the Interoceanic Highway, creating a human-modified matrix surrounding and isolating protected areas, threatening the connectivity of the entire Vilcabamba–Amboró corridor. We thus focus our green infrastructure recommendations on territories that are outside protected areas, promote connectivity, and support larger ecosystem functions.

Based on the data produced in the study, we evaluated what areas in Madre de Dios are the most likely to maintain landscape connectivity between protected areas of the Vilcabamba–Amboró corridor. The analysis (Box 6) identified four areas (Figure 40) essential to maintaining landscape connectivity among protected areas of the Vilcabamba–Amboró corridor in Madre de Dios.

Box 6. Corridor Modelling

We used a current flow model (McRae et al. 2008) implemented in the Connectivity Analysis Toolkit (Carroll et al. 2012) to determine what areas of the regional map would most likely be visited by randomly walking animals travelling between the centers of all protected areas in or adjacent to Madre de Dios. Suitability for the establishment of a corridor was calculated at the pixel level as a weighted average of:

- 2017 biodiversity in the Current Trend scenario (weighted ¼);
- 2040 biodiversity in each repetition of each scenario (weighted 1⁄160 each, n=40);
- A protection index evaluating the efficiency of different concessions in protecting biodiversity (weighted ½). The protection index of a pixel in a given concession was based on the mean biodiversity value in 2017 in all concessions of the same type, scaled across concession types between 0 and 1. We assumed concessions with higher average biodiversity value are more effective to protect biodiversity.

The proposed connectors can be extensions of protected areas (Higgins et al. 2009, Goremad 2014b, a) or receive another status, and they should serve as laboratories to test the practical implementation of sustainable development. These areas should be prioritized for the completion of the ecological and economic micro-zoning and curation of the regional cadastre, and local agreements should formalize territorial planning within their limits ahead of the validation of the regional plan. Sustainable uses of resources, such as ecotourism, agroforestry, certified logging, fish farming, and extraction of Brazil nut and other non-timber forest products, should be promoted in these areas. Traditional mining and agriculture should be targeted for testing new technologies, and the strict restriction of their expansion should be enforced. Restoration of degraded and abandoned lands should be a priority, with testing of different protocols that could benefit the regional reforestation efforts. In addition, biological monitoring should evaluate the effectiveness of the areas in maintaining the connectivity between the surrounding protected areas.

Numerous projects in the Peruvian Amazon have promoted sustainable development for years and participants have accumulated tremendous field experience. The development of a sustainable working landscape in Madre de Dios offers a great opportunity for managers to focus this experience in preserving one of the world's areas of greatest biodiversity and protecting ecosystem services that benefit the people of Madre de Dios, and the 4 million people living downstream in Bolivia and Brazil. From the experience gained in the connectors, Madre de Dios stakeholders could develop their own future scenario for the region, a balanced compromise between preserving ecosystem services and managing the extraction of natural resources. In this scenario, traditional infrastructure is planned alongside green infrastructure. This "Sustainable Infrastructure" scenario incorporates green infrastructure to avoid, minimize, restore, and offset (BBOP 2009) the potential impacts of all development projects in the region and to contribute to a net-positive impact for conservation and sustainable development. Green infrastructure also provides synergies between the economy and environment, and it contributes to diversifying the economy toward biotrade, a fast-growing economic sector worldwide (Jaramillo Castro et al. 2017). We hope the Smithsonian Working Landscape Simulator and this study will contribute to defining a better conservation and sustainable development future for Madre de Dios.

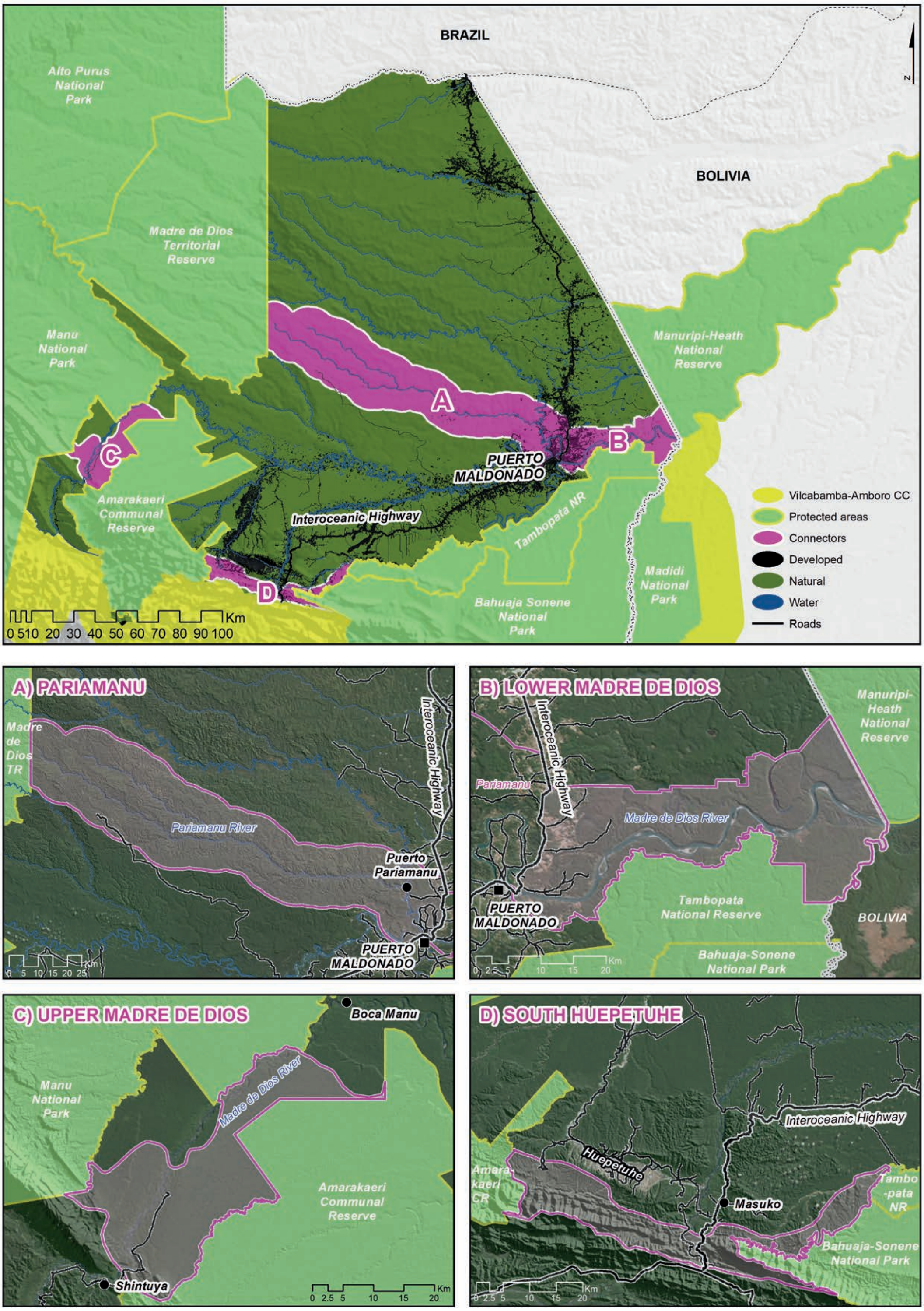


Figure 40. Madre de Dios's connectors for maintaining Vilcabamba–Amboró corridor's connectivity. A: Pariamanu connector. B: Lower Madre de Dios connector; C: Upper Madre de Dios connector; D: South Huepetuhe connector.

A. Pariamanu Connector

Centered on the Pariamanu River, this area connects the Lower Madre de Dios connector with Madre de Dios Territorial Reserve of uncontacted communities. The area is threatened by expansion of illegal and informal mining along local rivers and by development of a network of secondary roads. Establishing a connector in this area will slow and contain the degradation of the ecosystems and invasion of the Territorial Reserve by miners and farmers, and will benefit the Brazil nut concessions operating in the area.

B. Lower Madre de Dios Connector

Centered on the lower portion of the Madre de Dios River, this area connects the Manuripi-Heath National Reserve in Bolivia with the Tambopata National Reserve and the Pariamanu connector in Peru. The area is threatened by agricultural development and urban and road expansion around Puerto Maldonado on its western side. Establishing a connector in this area will slow the degradation of the ecosystems in the buffer zone of the Tambopata National Reserve and will benefit the tourism and Brazil nut concessions already operating in the area.

C. Upper Madre de Dios Connector

Centered on the higher portion of the Madre de Dios River in the region, this area connects the Amarakaeri Communal Reserve with Manu National Park. The area is threatened by several road projects at the national and regional levels, with the construction of a secondary road to connect Shintuya to Boca Manu already having begun. Establishing a connector in this area will contain the degradation of the ecosystems in the buffer zone of the park and Biosphere Reserve and will benefit the tourism concessions already operating in the area.

D. South Huepetuhe Connector

Located in the foothills of the Andes at the border of Madre de Dios, Cusco, and Puno regions, this area connects the Buhuaja Sonene National Park and Tambopata National Reserve with the Amarakaeri Communal Reserve. The area is threatened by the expansion of the Huepetuhe mining area and illegal activities such as hunting. Urban and road expansion around the mining town of Masuko is also a concern for the future of the connector. Establishing a connector in this area is critical to maintaining the connectivity of the Vilcabamba–Amboró corridor despite the fragmenting effect of the Interoceanic Highway. To facilitate the movement of animals across the road, wildlife-crossing structures can be planned in the connector as part of the sustainable infrastructure of the region.

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APPENDIX: ORGANIZATIONS AND STAKEHOLDERS CONSULTED

Stakeholders					Round of Consultation		
Type*	**Organization name**	**Organization, Office, Project**	**Participant**	**Position**	**I (2015)**	**II (2015)**	**III (2017)**
CO	Alto Mercedes Association	Alto Mercedes Association	Luz Marina Amasifuen	President	No	No	Yes
CO	Association of Brazil Nut collectors of the Tambopata Reserve	ASCART	Vilma Zegarra	Vice President	Yes	Yes	No
CO	Association of Brazil Nut collectors of Pariamanu and Tributaries	Association of Brazil Nut recolecters of Pariamanu and Tributaries	Nelson Belluna	Delegate	No	No	Yes
CO	Association of Timber and Non-Timber Forest Concessionaires of the Provinces of Manu and Tambopata	ACOMAT	Felix Vera	Secretary	No	No	Yes
CO	Association of Timber and Non-Timber Forest Concessionaires of the Provinces of Manu and Tambopata	ACOMAT	Gregorio Tamayo Tuya	Partner	No	No	Yes
CO	Association of Timber and Non-Timber Forest Concessionaires of the Provinces of Manu and Tambopata	ACOMAT	Gilberto Vela Cárdenas	Partner	No	No	Yes
CO	Pariamarca Association	Pariamarca Association	Abigail Sanz Salinas	Vice President	No	No	Yes
CO	Management Committee of the Tambopata National Reserve	CG-RNT	Víctor Zambrano	President	Yes	Yes	No

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Stakeholders					Round of Consultation		
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CO	Management Committee of the Tahuamanu River Forest	CG-BRT	Gilmer Gibaja	President	Yes	No	No
CO	Executor of the Administration Contract of the Amarakaeri Communal Reserve	ECA-RCA	Fermín Chimatani	President	Yes	Yes	No
CO	Tahuamanu Natural Latex Company	ECOMUSA	Edmundo Cuadros Cruz	Partner	No	No	Yes
CO	Departmental Agrarian Federation of Madre de Dios	FADEMAD	Vidal Salazar	President	Yes	Yes	No
CO	Native Federation of Madre de Dios River and Tributaries	FENAMAD	Klaus Quicque	President	Yes	No	No
CO	Federation of Producers of Brazil Nut in Madre de Dios	FEPROCAMD	David Asturima Huamantica	President	No	No	Yes
CO	Federation of Producers of Brazil Nut in Madre de Dios	FEPROCAMD	Walter Flores Casanova	Coordinator	No	No	Yes
CO	Federation of Producers of Brazil Nut in Madre de Dios	FEPROCAMD	Santiago Taipe Chuima	Vice President	No	No	Yes
LG	District Municipality of Iberia	MD-Iberia	Wilson Lancha	Head of the Environmental Management Office	Yes	No	No
LG	Provincial Municipality of Tahuamanu	MP-Tahuamanu	Wilfredo Meza	Lieutenant Mayor of Tahuamanu	Yes	No	No
RG	Madre de Dios Regional Government	GOREMAD CR	Octavio Caballero Jara	Regional Advisor for Manu	Yes	Yes	Yes
RG	Madre de Dios Regional Government	GOREMAD GRDE	Federico Rengifo	Sub Manager of Productive Development	Yes	Yes	No
RG	Madre de Dios Regional Government	GOREMAD GPPAT-SP-PP144	Edith Pipa Cruz	Technical Officer of the Budget Program 144	No	No	Yes
RG	Madre de Dios Regional Government	GOREMAD GPPAT-SAT	Luis Sanchez	Specialist of Land Management	Yes	Yes	No

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RG	Madre de Dios Regional Government	GOREMAD GPPAT-SAT	Javier Quispe	Sub Manager of Land Management	No	No	Yes
RG	Madre de Dios Regional Government	GOREMAD GPPAT-SAT	Aldo Sadi Ramirez Reyes	Supervisor of Land Management	No	No	Yes
RG	Madre de Dios Regional Government	GOREMAD GRRNGA-SMPE	Williams Miche	Sub Manager of Ecosystems Productive Management	Yes	Yes	No
RG	Madre de Dios Regional Government	GOREMAD GRDE-DRP	Jimmy Layche	Regional Director of Production	No	No	Yes
RG	Madre de Dios Regional Government	GOREMAD GRDE-DRA-AAT	Wilson ArévaloToren	Technician of the Tambopata Agrarian Agency	No	No	Yes
RG	Madre de Dios Regional Government	GOREMAD GRDE-DSFLPR	Amed Suren Paredes Moreno	Responsible for the Cadastre	No	No	Yes
RG	Madre de Dios Regional Government	GOREMAD GRDE-DSFLPR	Walter Richard Lopez Souza	Works in the Title of Property Areas	No	No	Yes
NG	Ministry of Environment	MINAM PNB	Melinda Panduro	Specialist of Forestry and Agroforestry Business	Yes	No	No
NG	Ministry of Environment	MINAM PNB	Javier David Loza Herrera	Head of the Unit of Incentives for the Conservation of Forests	No	No	Yes
NG	Ministry of Environment	MINAM Madre de Dios	Humberto Cordero	Coordinator of the Technical Office in Madre de Dios	Yes	No	Yes
NG	Ministry of Environment	MINAM DGEVFPN-ASBYSE	Salvador Morales Brown	Responsible of the Project ASBYSE	No	No	Yes
NG	Environmental Assessment and Inspection Agency	OEFA Madre de Dios	María Jesús Jeri Nieves	Head of the Decentralized Office in Madre de Dios	No	No	Yes
NG	Environmental Assessment and Inspection Agency	OEFA Madre de Dios	Hubert Vera Mendoza	Environmental Specialist	No	No	Yes
NG	Environmental Assessment and Inspection Agency	OEFA Madre de Dios	Wilfredo Cahuana Aroni	Environmental Specialist	No	No	Yes

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NG	Environmental Assessment and Inspection Agency	OEFA Madre de Dios	Jhon Medina Vargas	Legal Specialist	No	No	Yes
NG	Environmental Assessment and Inspection Agency	OEFA Madre de Dios	Katherine Quispe Romero	Intern	No	No	Yes
NG	National Service of Natural Protected Areas	SERNANP Amarakaeri	Ernesto Escalante	Head of the Amarakaeri Communal Reserve	Yes	Yes	No
NG	National Service of Natural Protected Areas	SERNANP Amarakaeri	Daniel Asvin Florez Gil	Head of the Amarakaeri Communal Reserve	No	No	Yes
NG	National Service of Natural Protected Areas	SERNANP Amarakaeri	Johana Salazar Castillo	Specialist of the Amarakaeri Communal Reserve	No	No	Yes
NP	Association for the Conservation of the Amazon Basin	ACCA Madre de Dios	Piero Rengifo	GIS Specialist	Yes	Yes	Yes
NP	Association for the Conservation of the Amazon Basin	ACCA CCLA	Carlos Castañeda	CCLA Coordinator	No	No	Yes
NP	Association for Integral Research and Development	AIDER Madre de Dios	Claudia Lebel	Responsible of the Ecosystem Service Area	Yes	No	Yes
NP	Cáritas	Cáritas Madre de Dios	Cesar Ascorra	Project Coordinator in Madre de Dios	Yes	No	No
NP	Inkaterra Asociation	ITA	Jose Purisaca	Manager	No	No	Yes
NP	Inkaterra Asociation	ITA	Ruth Torres	Coordinator	No	No	Yes
NP	Pronaturaleza	Pronaturaleza Madre de Dios	Julio Magán Roeder	Regional Coordinator in Madre de Dios	Yes	No	No
NP	Conservation RED in Madre de Dios	RCBMDD	Manuel Rubio Bermudez	President	No	No	Yes
NP	Peruvian Society of Environmental Law	SPDA Madre de Dios	Pablo Peña	Lawyer of the Forestry Program	Yes	No	No

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NP	Florida University	UFL Consortium Madre de Dios	Bruno Sanguinetti	Adviser	Yes	No	Yes
NP	Florida University	UFL Consortium Madre de Dios	Jhon Farfán	Director of the Madre de Dios Consortium	No	No	Yes
NP	Naval Medical Research Unit-6	NAMRU-6	Claudia Guezala	Researcher of the Unit of Ecology of the Department of Emergent Diseases	Yes	No	No
NP	Wake Forest University	WFU CINCIA	Francisco Román	Scientific Director	No	No	Yes
NP	Wake Forest University	WFU CINCIA	Jorge Martín Pillaca	GIS Specialist	No	No	Yes
NP	WWF Peru	WWF Peru Madre de Dios	Luis Ramirez	Social Specialist	Yes	Yes	No
NP	WWF Peru	WWF Peru Madre de Dios	Nelson Gutierrez	Carbon Specialist	Yes	Yes	Yes
NP	WWF Peru	WWF Peru Madre de Dios	Rudy Navarro	GIS Associate Officer	No	No	Yes
NP	German Cooperation	GIZ Peru	Hannes Hotz	Principal Advisor	No	No	Yes
NP	United Nations Development Programme, Peru	PNUD Peru EBA Amazonía	Pablo Dourojeanni	Coordinator of Knowledge Management	Yes	Yes	Yes
NP	United Nations Development Programme, Peru	PNUD Peru EBA Amazonía	Juan Carlos Vera Blass	Spatial Analyst	No	No	Yes
NP	United States Agency for International Development, Peru	USAID Peru	Mónica Romo	Regional Specialist in the Amazon	No	No	Yes
PS	Candela Peru	CANDELA PERU	Guadalupe Lanao	Manager	Yes	No	No
PS	Hunt Oil Exploration and Production Company of Peru	HOEP Peru	Romulo Corisepa Dreve	HOEP Community Relations Officer	No	No	Yes

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PS	Hunt Oil Exploration and Production Company of Peru	HOEP Peru	Manuel Ormachea	Head of Socio-Environmental Affairs in Madre de Dios	Yes	No	No
PS	Hunt Oil Exploration and Production Company of Peru	HOEP Peru	Erica Dholoo	Biodiversity Manager	Yes	No	No
PS	Hunt Oil Exploration and Production Company of Peru	HOEP Peru	Maritza Benites	HOEP Staff	No	No	Yes
PS	Hunt Oil Exploration and Production Company of Peru	HOEP Peru	Carlos Ponce de León	HOEP Staff	No	No	Yes
PS	Hunt Oil Exploration and Production Company of Peru	HOEP Peru	Jorge Paulino	HOEP Staff	No	No	Yes
PS	Hunt Oil Exploration and Production Company of Peru	HOEP Peru	Karen Cordova	HOEP Staff	No	No	Yes
PS	Hunt Oil Exploration and Production Company of Peru	HOEP Peru	Ivan Garayac	HOEP Staff	No	No	Yes
PS	Hunt Oil Exploration and Production Company of Peru	HOEP Peru	José Chirif	HOEP Staff	No	No	Yes
AI	College of Biologists in Peru	CBP	Alejandro Bernilla Roque	Vice dean	No	No	Yes
I	Independent	Independent	Esley Huatangare	Member of the team that developed the Territorial Arrangement Planning (POT)	No	No	Yes

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