1. Introduction

Panama occupies a unique geographical position as a land bridge between two continents. It encompasses a great range of environmental conditions and is home to globally unique biodiversity. The Isthmus of Panama acts as an important biogeographical link between the faunas and floras of Central and South America. Rainfall patterns combined with topographic variation has meant that Panama, like the rest of Central America, has extensive forest cover and a wealth of plant and animal species. In addition to being rich in biodiversity, Panama's forests provide important ecosystem services, including regulating hydrological flows and the supply of clean water, protecting against soil erosion and resulting sedimentation, providing food, medicine, and forest products (including timber and non-timber products), and serving aesthetic, recreational, and spiritual purposes. As a major carbon store and sink for carbon dioxide from the atmosphere, forests also play a major role in climate regulation. However, Panama's natural resources are subject to pressures from increasing infrastructure, agricultural expansion and logging, and many of Panama's forests are under threat of deforestation. Deforestation and forest degradation in Panama not only threaten biodiversity and the provision of ecosystem services, including climate regulation, but may also increase the country's vulnerability to climate change.

Indeed, forest loss plays a crucial role in climate change. Deforestation and forest degradation around the world contribute approximately 10% to total greenhouse gas emissions, which is second only to the burning of fossil fuels as the largest anthropogenic source of carbon dioxide in the atmosphere (IPCC 2013). Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are preparing to address this issue through REDD+: a climate change mitigation mechanism aiming to significantly reduce emissions from deforestation and forest degradation, and increase removals of carbon dioxide from the atmosphere, whilst promoting the sustainable development of the nations involved. REDD+ is expected to provide incentives for countries to implement actions relating to five main activities (Figure 1).

REDD+ =

Reducing emissions from
Deforestation and forest Degradation
+
Conservation of forest carbon stocks
Sustainable management of forests
Enhancement of forest carbon stocks

Figure 1. REDD+ activities agreed under UNFCCC.

Deforestation in Panama threatens a range of important ecosystem services.

While the main aim of REDD+ is to reduce greenhouse gas emissions and increase carbon dioxide sequestration from the atmosphere, it has the potential to deliver additional environmental and social benefits. Environmental benefits from securing the many ecological functions of forests can include biodiversity conservation and the provision of ecosystem services that people depend on, such as water regulation, erosion control and the supply of timber and non-timber forest products. Direct social benefits from national REDD+ implementation can include improved forest governance and participation in local decision-making on land use, and in some cases direct financial improvements to livelihoods. However, REDD+ also carries potential risks, for example if pressures on forests were merely displaced from one area to another, or if access rights of local communities were reduced as part of REDD+ implementation. The UNFCCC calls upon countries to promote and support the Cancun safeguards, which have been specifically developed to encourage benefits and address potential risks of REDD+. A REDD+ programme that delivers multiple benefits and avoids social and environmental risks can contribute to a range of policy goals beyond climate change mitigation.

2. Planning for multiple benefits of REDD+ in Panama

The government of Panama joined the UN-REDD Programme (United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) with the aim of implementing REDD+ in alignment with the country's conservation and development efforts. Panama's UN-REDD National Joint Programme (NJP) began in 2008; it is led by the National Environmental Authority of Panama (ANAM).

As for other countries, the development of a national REDD+ strategy in Panama will involve, among other challenges, prioritising actions, reconciling different demands for land use, identifying the potential for a range of benefits that can be achieved through REDD+ implementation, and planning to avoid or minimize possible risks. This report shows how spatial analyses can support REDD+ planning processes. The suitability of areas for the different

The Panama Canal, which is crucial to the country's economy, depends on forest cover in its watershed to reduce the risk of sedimentation and ensure stable supplies of water.

REDD+ activities and the characteristics associated with possible benefits and risks differ according to location. For example, deforestation pressures, forest carbon stocks, biodiversity importance and other forest values all are unevenly distributed. Spatial analyses can thus be very useful for understanding the potential for possible benefits from REDD+ and their distribution.

This report shows how spatial analyses can help support decisions about possible locations for REDD+ activities in Panama. Areas with potential to deliver multiple environmental and social benefits from REDD+ actions, as well as those under pressure from deforestation, are identified. The potential benefits examined here reflect as far as possible the priorities identified by local and national stakeholders in Panama, including participants from NGOs, the government sector, international organizations, and research and academic institutions. The criteria for prioritization were: potential for generating investment; contribution to quality of life; and relevance for Panama's national development strategy. Results of the spatial analyses were reviewed jointly with national counterparts in Panama during a series of technical workshops.

The spatial analyses presented in this report aim to support land-use planning for REDD+ by helping to identify the possible benefits and risks associated with actions to reduce deforestation in different places. Information on carbon stocks and other benefits from forests, such as biodiversity and ecosystem services, can help identify areas where conserving forest carbon stocks and reducing deforestation may yield multiple benefits. Further, consideration of the areas where forest carbon is most at risk of being lost through future deforestation can help to identify priority areas for action. Understanding how the distribution of biomass carbon relates to poverty and areas of high deforestation risk helps show where design of REDD+ actions needs to take into account local livelihoods needs.

This report first looks at maps that can be used in planning for multiple benefits of REDD+ in Panama, including through examining the important role of forests in storing and sequestering carbon and supporting biodiversity, soil erosion control and tourism in the country. Different data layers are then combined to identify areas simultaneously important for several of these benefits. Further analyses demonstrate where REDD+ actions could reduce deforestation or support local livelihoods. The resulting maps can inform REDD+ planning in Panama and serve as a basis for additional and more detailed analyses.

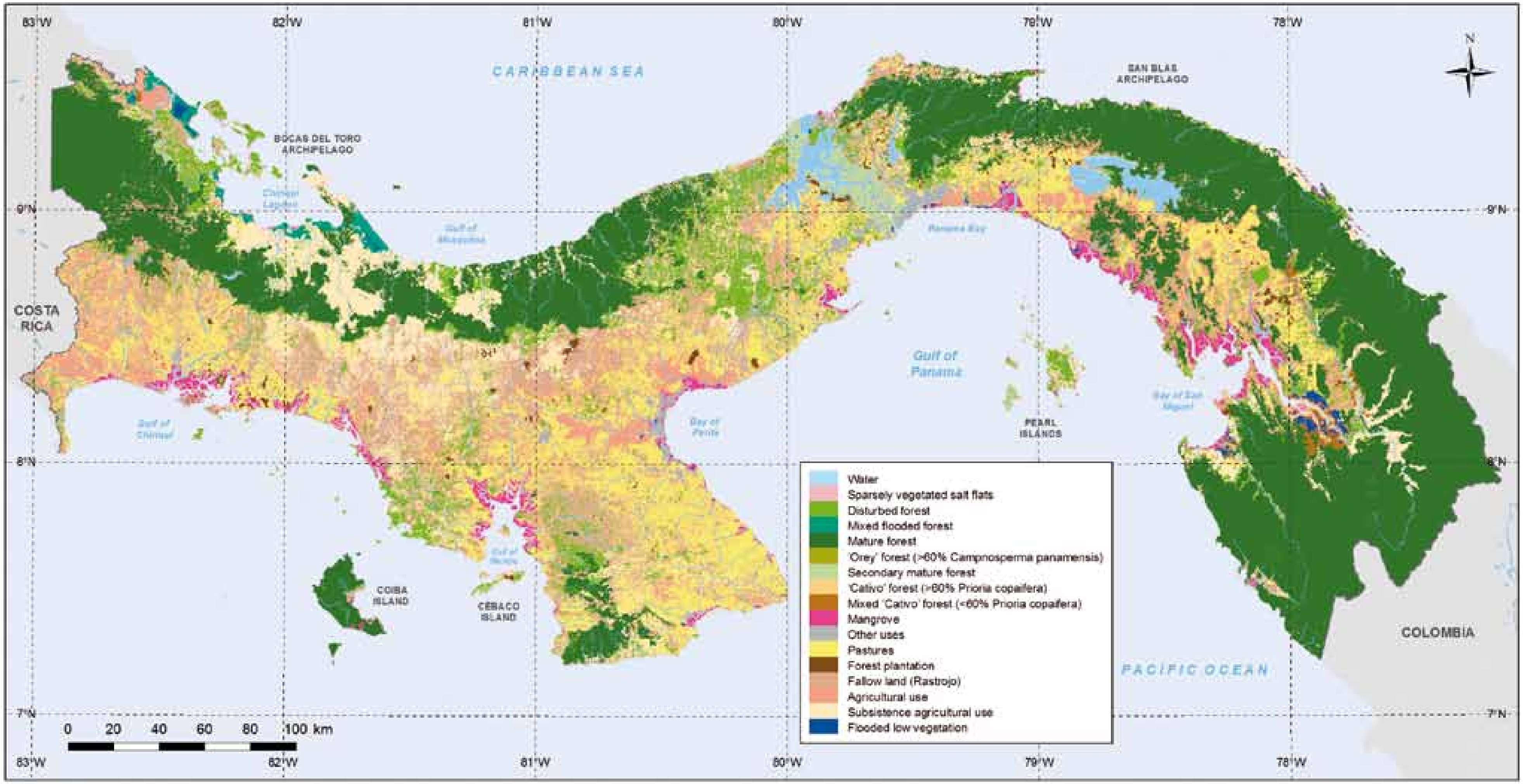
2.1 Forests in Panama

Panama is a tropical country with a surface area of 75 845 km^2 (ANAM 2011a); it is divided into 9 provinces, 77 districts and 640 "corregimientos", and has five indigenous "comarcas". Panama borders the Caribbean Sea to the north, the Pacific Ocean to the south, Colombia to the east and Costa Rica to the west. Lowlands, with elevation of less than 700 metres, cover 70% of the country and are home to most of the country's population (ANAM 2011a). The steep topography of the Cordillera Central, which includes mountains reaching nearly 3 500 m dominates the north western (Caribbean) part of the country, while lower hills and savannas are characteristic of the Pacific region. The Darién region in the east of the country is mostly lowland, but includes hills and mountains that reach 1 875 m.

Panama's diverse topography and climatic conditions (rainfall ranges from <1 300 to >3 000 mm per year, with a pronounced drier period of three to four months in most parts of the country) give it significant diversity of forest types and other ecosystems (Map 1). Mature forests are located mostly in the Caribbean lowlands and in the Darién. These are mostly wet forests with the tall trees and dense canopies typical of many rainforests. There are also mature forests in the montane regions, including tropical cloud forests in the lower montane zone (Holdridge 1971) and forests similar to temperate forests of North America in the upper montane zone (Condit et al. 2011). There are large areas of disturbed forest in the centre of the country and at the margins of agricultural areas. The moist forests of the Canal Zone are mostly mature secondary forests that have regenerated following previous clearing. Seasonal or more frequent flooding gives rise to several distinctive forest types, including mixed flooded forest in Bocas del Toro province in the northwest of the country, and forests of Orey (*Campnosperma panamensis*) and Cativo (*Prioria copaifera*), in Darién. Mangroves are important, especially along the Pacific coast. Nearly 40% of the country is now occupied by agricultural and fallow lands.

This diversity in forest types both reflects and is a factor in determining Panama's significant tree diversity; the country has an estimated 2 300 tree species (Condit et al. 2011). The area around the Panama Canal has particularly high tree diversity, with the dominant tree species changing over just a few kilometres (Condit et al. 2001). This variability not only heightens the importance of actions to conserve forest, but also potentially complicates the planning process, as it may affect the biodiversity conservation and ecosystem services impacts of any

Map 1. Land cover of Panama (CATHALAC 2011, based on Landsat data for 2008)



Method and data sources:
Land Cover: National dataset of 2008 land cover based on Landsat data (CATHALAC 2011)

given intervention. ANAM is currently working with FAO under the UN-REDD Programme to complete a National Forest Inventory (INF), which will update Panama's previous (1972) forest inventory, enhance understanding of variability within the country's forests and provide an improved basis for assessing forest biomass and carbon stocks.

Deforestation in Panama varies amongst the different climate zones in the country (Condit et al. 2001 and 2011). As people generally prefer to settle in tropical dry climates rather than tropical wet climates, there has been large-scale clearance of tropical dry forests on Panama's Pacific slope for settlements and agriculture. Some of the main drivers of deforestation and forest degradation in Panama include infrastructure development, the expansion of agriculture and cattle ranching, and logging operations. Forests have also been degraded through agricultural fires and mining in forested areas.

According to historical records, it is estimated that in 1850 forest covered 91% of Panama (Arias 2004); however, there has been rapid deforestation throughout the 20th and into the 21st centuries. In 1947 Panama was estimated to be 70% forested (Garver 1947), while estimates from the 1970s suggested that the country was by then only half forested (Falla 1978). ANAM reports that in 1992 forest cover was equivalent to 49% of Panama's total surface; however, by 2000 forest cover (not including disturbed forest) had fallen to 45% of land area (ANAM 2011a).

These are the most recent official figures for forest area in Panama. To derive a more up to date estimate, the forest classes in the 2008 land cover (Map 1) were combined to form a forest cover layer (Map 2a). This map includes an estimated 37 000 km^2 of forest in total. This differs from Panama's recent reports to FAO, which have excluded the 'disturbed forest' category in calculating national forest extent (FAO 2010); excluding 'disturbed forest' from the cover in Map 2a yields an estimate of 30 700 km^2 of forest, equivalent to 40.5% of Panama's land area. A recent global study of forest cover change based on Landsat data estimates that from 2000 to 2012 tree cover declined in over 3% of Panama's land area (Hansen et al. 2013).

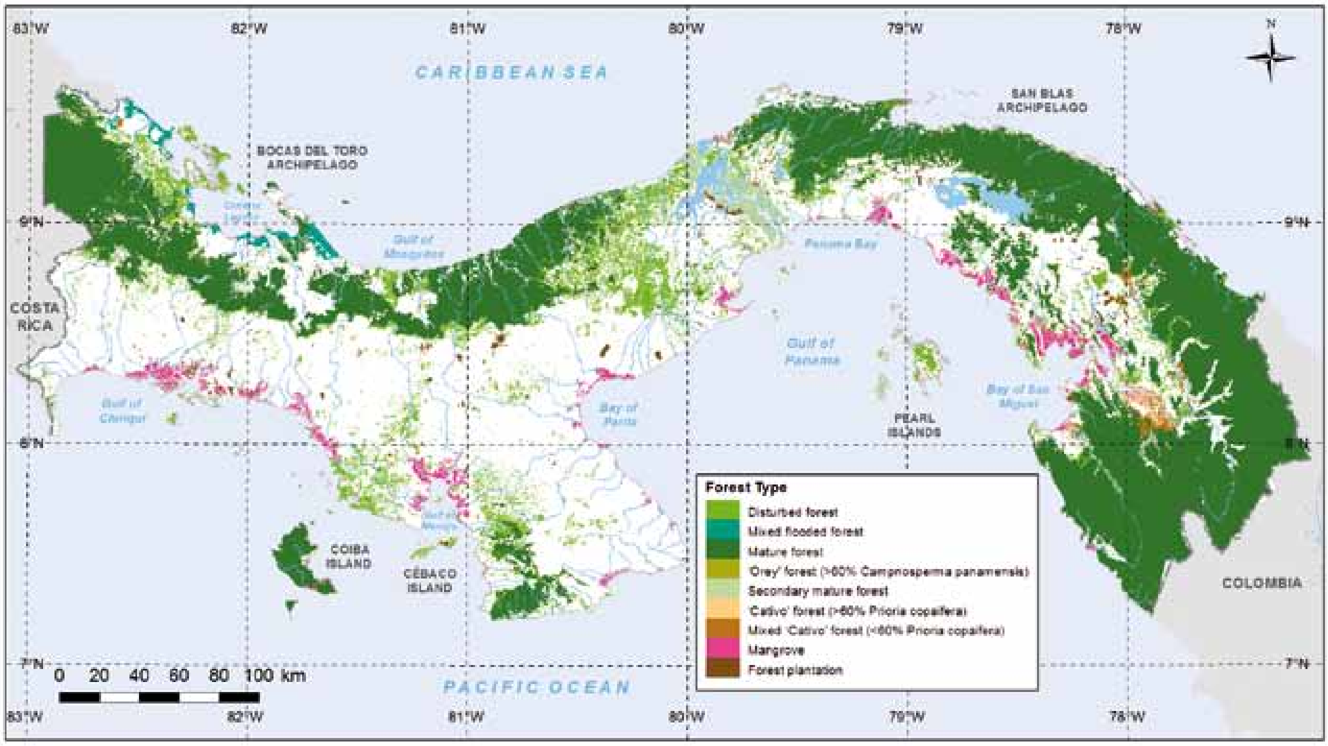
To address the UNFCCC's Cancun safeguards[1], countries will need to distinguish natural forest from other forest. Natural forest is often defined as forest that has not been planted, although national definitions

1 Safeguard (e) states that REDD+ actions should be 'consistent with the conservation of natural forests and biodiversity, ensuring that actions (...) are not used for the conversion of natural forests, but are instead used to incentivize the protection and conservation of natural forests and their ecosystem services, and to enhance other social and environmental benefits'.

Logging in Darién: deforestation in Panama is closely tied to logging and to the expansion of agriculture and infrastructure.

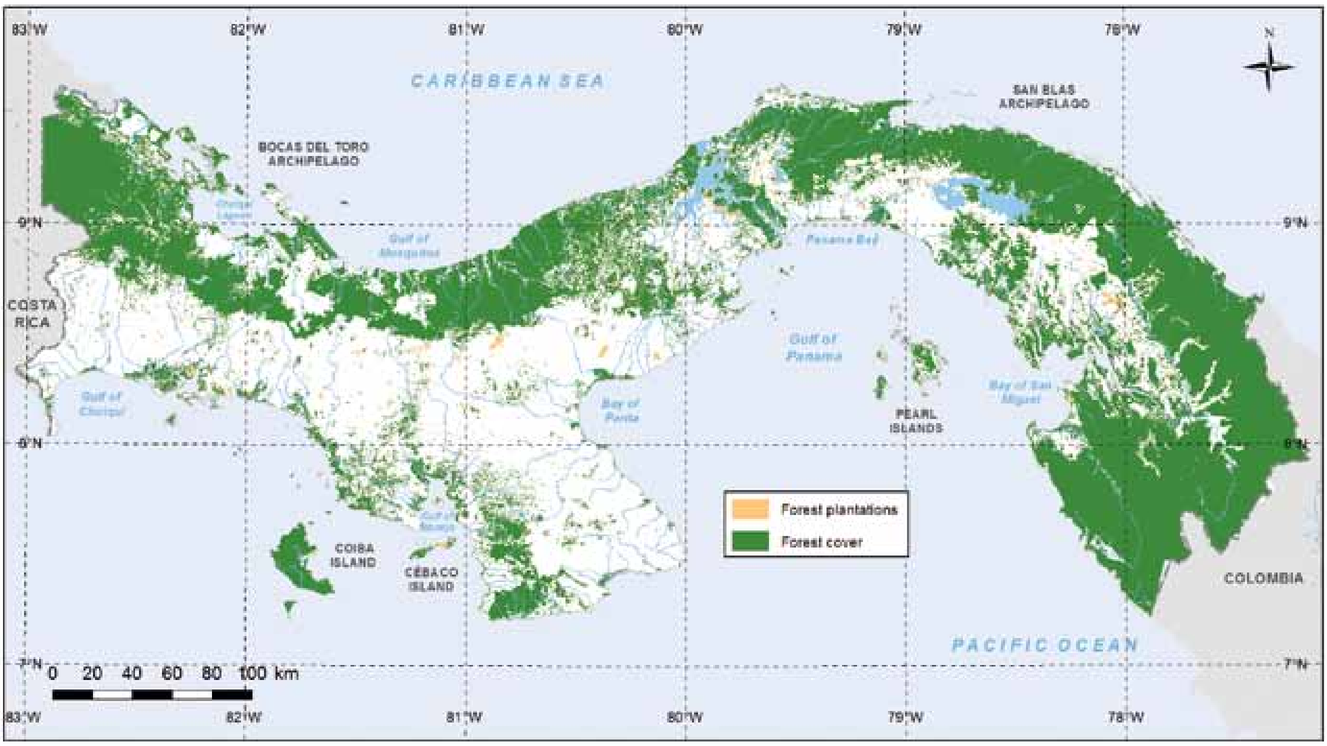
Map 2a. Forest cover of Panama showing major forest types (CATHALAC 2011, based on Landsat data for 2008)

An estimated 40–45% of Panama is currently forested.



Map 2b. Cover of natural forest types in Panama

In the absence of a specific definition of natural forest, the natural forest types identified by CATHALAC (2011) have been merged, and forest plantations from the same source are highlighted separately. Such information can help to inform Panama's efforts to promote and support the Cancun safeguards.



Methods and data sources:

Map 2a: Land Cover: National dataset of 2008 land cover (CATHALAC 2011).

Map 2b: Forest Cover: Derived from the national dataset of 2008 land cover (CATHALAC 2011). From the national dataset, the following land uses were selected to create a forest cover layer: 'bosque intervenido', 'bosque inundable mixto', 'bosque maduro', 'bosque orey homogeneo', 'bosque secundario maduro', 'cativo homogeneo', 'cativo mixto', 'mangle', and 'plantacion forestal'.

vary. In Map 2b, the relatively small area of plantation in Panama is shown separately from other, 'natural' forest. This is one possible approach for identifying natural forest in the context of the safeguards.

The government of Panama is committed to conserving the country's forests and rich biodiversity. For example, ongoing efforts in Panama to reduce deforestation have included strengthening environmental institutions; creating environmental management tools and private nature reserves; increasing awareness levels of the population and participation of private businesses with national and international capital; reducing forest concessions; reforestation efforts; creating new watershed restoration programmes; and specifying ecological compensation within development projects (ANAM 2011a).

In addition to REDD+, various forest development projects and sustainable forest management plans have been put in place to control and reduce deforestation (ANAM 2011a). Forests in Panama are governed by the National Forestry Law of 1994, which distinguishes three categories of forest. Production forests are primarily focused on yielding products of economic value. Protection forests are of national or regional interest for the regulation of water, the protection of watersheds, reservoirs, populations, agricultural crops, or infrastructure of public interest. It is a priority to prevent and control erosion and the harmful effects of natural elements such as wind, as well as to protect species and wildlife in these forests. Special forests are part of efforts to preserve scientific, educational, historic, cultural, or recreational places of interest. Many of these projects also aim to preserve and enhance forests and the services that they provide, the importance of which is discussed in the next sections.

2.2 Multiple benefits and their importance for different stakeholder groups

This report provides examples of areas where REDD+ action could potentially deliver individual specific benefits, in addition to the climate mitigation benefits of REDD+. However, there is wide range of environmental and social benefits related to forests; the importance of the individual benefits may vary for different stakeholder groups. For example, those whose income depends on farm productivity may see soil protection and hydrological regulation as key services to be secured by maintaining forests, while those whose income depends on a steady flow of visitors to natural areas in Panama may see the protection of forest in key tourism sites as a priority. Thus, the range and balance of environmental and social benefits to be sought from efforts to conserve and manage forests under REDD+ will need to be determined in relation to the particular needs and preferences of different stakeholders.

The UN-REDD Programme in Panama undertook a systematic process of consultations with stakeholders to understand what types of potential benefits from REDD+ are most important for different stakeholder groups. The process involved several rounds of meetings and discussions with government agencies, academia, private sector representatives, local communities and NGOs. The design of the consultation process benefited from the experience and work done by ANAM on the valuation of environmental services from forests. The process of consultations and discussion led to a participatory workshop in 2012 that identified and grouped social and environmental benefits from forest and discussed their importance using qualitative and quantitative criteria. This process resulted in the identification of the following broad groups of benefits from forest retention:

- timber products;
- non-timber forest products;
- biological and chemical products;
- soil protection;
- hydrological and climatic regulation services;
- ecological and biological regulation services; and
- cultural, educational/recreational and cognitive services.

As expected, the importance given to specific groups of environmental and social benefits from forest differed depending on the particular needs and perspectives of the stakeholder group. When potential benefits were viewed from a purely economic perspective, timber and non-timber forest products were ranked as having very high importance, whereas from a social perspective cultural services were considered key. Hydrological and climate regulation services were considered important from most perspectives, perhaps due to the impacts of recent flooding and droughts in Panama. The spiritual value of forest was of significance for forest-dependent communities. While industrial pharmaceutical prospecting did not rank as a high priority, the value of forests as sources of traditional medicine for local communities was considered significant.

While further work and consultation are needed to arrive at a final and definitive identification and prioritization of environmental and social benefits of forests in Panama (and are ongoing), the results of this exercise serve as a useful guide for targeting data selection and maps for multiple benefits in Panama. The sections that follow will explore the spatial distribution of different environmental and social benefits and how this data can be used for REDD+ planning.

2.3 Biomass carbon stocks

In making decisions on where REDD+ should aim to reduce deforestation and forest degradation and maintain or enhance forest carbon stocks, it is useful to consider where biomass carbon stocks are located and what land cover change pressures are anticipated over the period of REDD+ implementation. Biodiversity and ecosystem services map layers can be used to identify the likely additional benefits of REDD+ in different parts of the country. Biomass carbon stock is also a proxy indicator for the monetary benefits that forest can provide if carbon credits can be bought and sold in formal or voluntary exchanges. Therefore, comparing the economic cost of reducing these pressures with the potential carbon income from REDD+, and the value of the different benefits, would further help to estimate the viability of different locations for REDD+ implementation.

Forests, in particular tropical forests, are vast carbon stores and sinks (Trumper et al. 2009), immobilising carbon in their biomass both above-ground (in leaves, branches and stems) and below-ground (in roots) (Walker et al. 2011). The biomass of forests and other vegetation varies considerably, depending on local conditions and land-use history. Understanding the distribution of biomass carbon stocks in relation to other forest values and to land-use pressures is important for effective REDD+ planning. It is anticipated that countries will receive REDD+ income based on the overall reduction in emissions nationwide. Where forests are threatened by land-use change, forest carbon stock is also an indicator for the scale of the monetary benefits that could result from retaining them. If an estimate is made of the monetary value of these reduced emissions, the economic cost of reducing these pressures can be compared with the potential carbon income from REDD+. An understanding of the value of the different ecosystem services provided by the forest would further help to estimate the viability of different locations for REDD+ implementation.

An understanding of the distribution of these carbon stocks can be obtained from maps based on field data and/or remote sensing. Several global and regional scale maps provide information on biomass based on different data sources and methods (e.g. Ruesch and Gibbs 2008; Baccini et al. 2012; and Saatchi et al. 2011), but nationally specific data are likely to be more relevant for supporting decision making. Recently, Asner and colleagues (2013) have used extensive airborne LiDAR (Light Detection and Ranging) surveys combined with field verification to produce the most detailed map to date of above-ground biomass carbon stocks in Panama.

For the purposes of this study, below-ground biomass carbon was added to the Asner et al. (2013) map by applying root-to-shoot ratios to the above-ground carbon values as recommended by the Intergovernmental Panel on Climate Change (IPCC 2006; Annex I provides further technical information). The resulting map of total biomass carbon stocks (Map 3) shows that stocks vary significantly across Panama, with large carbon reserves found along the Caribbean side of the country, especially in the northwest, and in Darién. Understanding the spatial variation in biomass carbon is key for REDD+ planning, as greater mitigation impacts may be associated with actions in areas of high carbon stock, especially where they are at high risk. This map is the basis for all analyses in this report that involve biomass carbon stocks.

2.4 Biodiversity

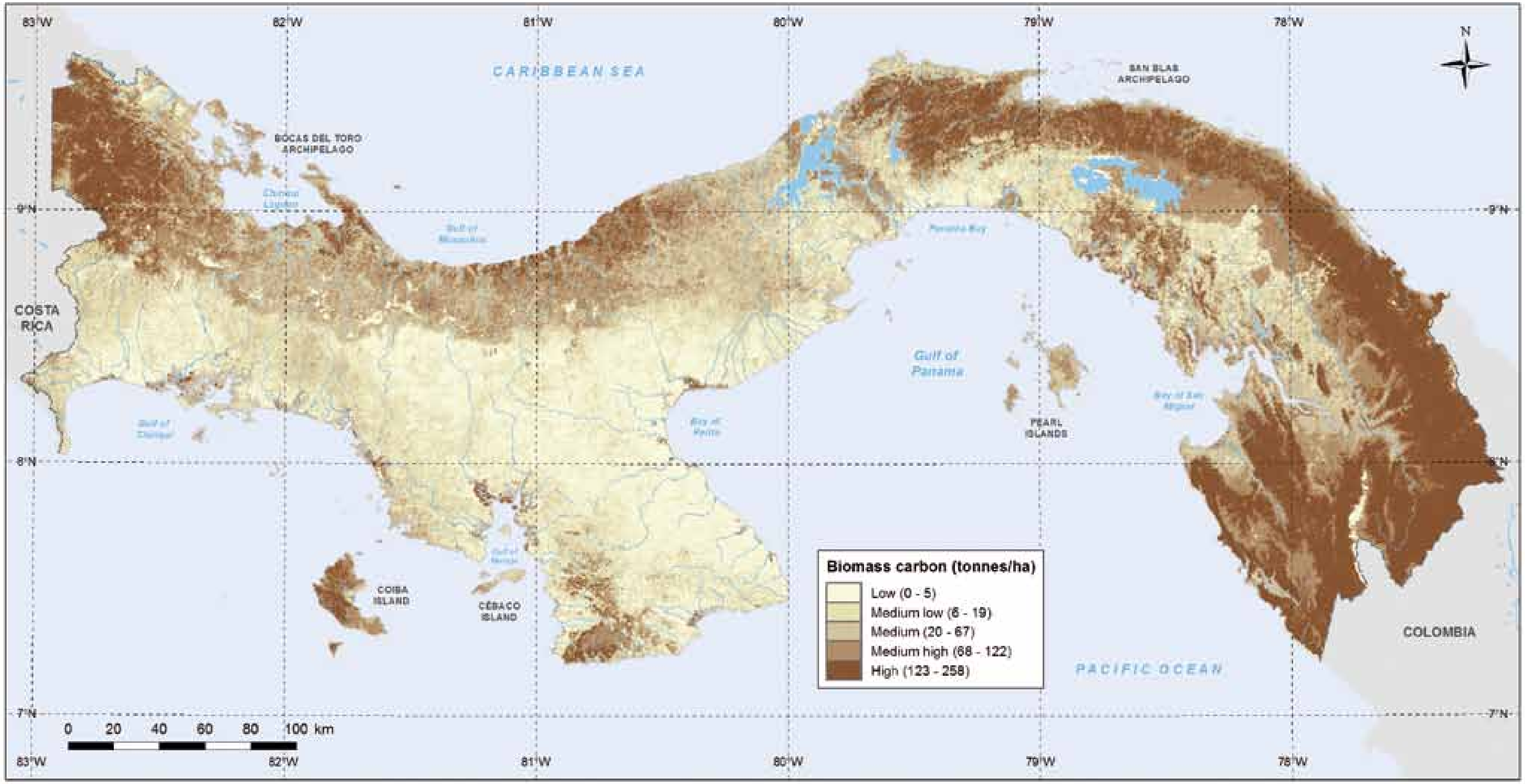
Biodiversity conservation is an important global objective to which countries (including Panama) have committed under the Convention of Biological Diversity (CBD). REDD+ actions can provide additional benefits for biodiversity conservation if efforts to maintain natural forest are prioritized in areas of high biodiversity value and/or in their surroundings, where they can contribute to providing buffer zones or maintaining connectivity with other forests. Restoration of degraded forests in such areas using appropriate methods (e.g. natural regeneration or enrichment planting with mixed native species) can also have significant benefits for biodiversity conservation, as well as for climate change mitigation. Spatial information on the location of areas that are important for biodiversity can therefore help to inform decisions on where to locate REDD+ actions in order to achieve such benefits.

An increasing body of evidence indicates that species diversity can promote forest ecosystem functioning (Gamfeldt et al. 2013); in addition, biodiversity is seen as having value in its own right, recognized through the CBD. Forest biodiversity is also linked to groups of services from forests that stakeholders identified as high priorities, including provision of of non-timber forest products, biological and chemical products, and cultural, educational and recreational services. While there are not appropriate data available to map the distribution of these services, data on biodiversity may help in identiying areas where these services may be important and should be investigated further.

Due in part to its location as a biogeographic bridge between the floras and faunas of Central and South America, Panama is home to approximately 4.2% of the world's amphibian species, 3.5% of its reptile species, 10.0% of known bird species, and

Map 3. Biomass carbon (above-and below-ground) based on recent work by Asner et al. (2013)

Panama's greatest stocks of biomass carbon are concentrated in the northwest of the country and in Darién.



Methods and data sources:
Biomass Carbon: Asner, G., Mascaro, J., Anderson, C., Knapp, D., Martin, R., Kennedy-Bowdoin, T., van Breugel, M., Davies, S., Hall, J., Muller-Landau, H., Potvin, C., Sousa, W., Wright, J., and Bermingham, E. (2013) High-fidelity national carbon mapping for resource management and REDD+. Carbon Balance and Management 8:7. http://www.cbmjournal.com/content/8/1/7. Ecosystem-specific conversion factors (IPCC 2006) were used to add below-ground carbon to this map.

5.6% of mammal species. It is also among the top 25 countries in the world in terms of diversity of flowering plant species (ANAM 2011b) and hosts a wide variety of ecosystems. In order to preserve this wealth of biodiversity, the government of Panama has established 89 protected areas, which according to ANAM (2011a) occupy 31.8% of the land surface and 5.53% of marine areas in the country. The National System of Protected Areas (SINAP) in Panama, which is regulated by ANAM, includes protected forests, terrestrial and marine parks, and wildlife reserves.

Protected areas are, by defintion, areas important for the retention of biodiversity. In protecting forests from land-use pressures, they may also play a role in the national achievement of REDD+ objectives. Further, REDD+ actions that prevent deforestation outside of protected areas may themselves help to conserve biodiversity, and may support or enhance the effectiveness of existing conservation areas by further buffering them from land-use change. Map 4 shows the occurrence of biomass carbon stocks within Panama's protected areas: 48% of Panama's biomass carbon is found within legally protected areas.

By its very nature, biodiversity is complex and difficult to quantify or capture in a single indicator.

*The Harpy Eagle (*Harpia harpyja*), Panama's national bird, prefers uninterrupted expanses of lowland tropical forest.*

As a result, a range of approaches and metrics may be used to measure and map a country's biodiversity and to identify areas important for its conservation and management. These approaches may focus on particular ecosystems, on overall measures of species richness or on ecosystems and species of conservation concern. In addition to its large overall species richness, Panama is home to a number of vertebrate species considered by the International Union for Conservation of Nature (IUCN 2013) to be globally threatened (Table 1).

REDD+ actions in areas with high carbon stocks and where threatened species are concentrated may yield benefits in relation to biodiversity conservation as well as climate change mitigation. Where concentrations of threatened species occur in areas of low carbon stock, monitoring may be particularly important to ensure that land-use change pressures, including those displaced by REDD+ actions, do not have adverse impacts on biodiversity. By displaying potential richness of threatened species in relation to biomass carbon stocks, Map 5 provides an initial basis for identifying areas of potential priority in relation to biodiversity benefits (and impacts).

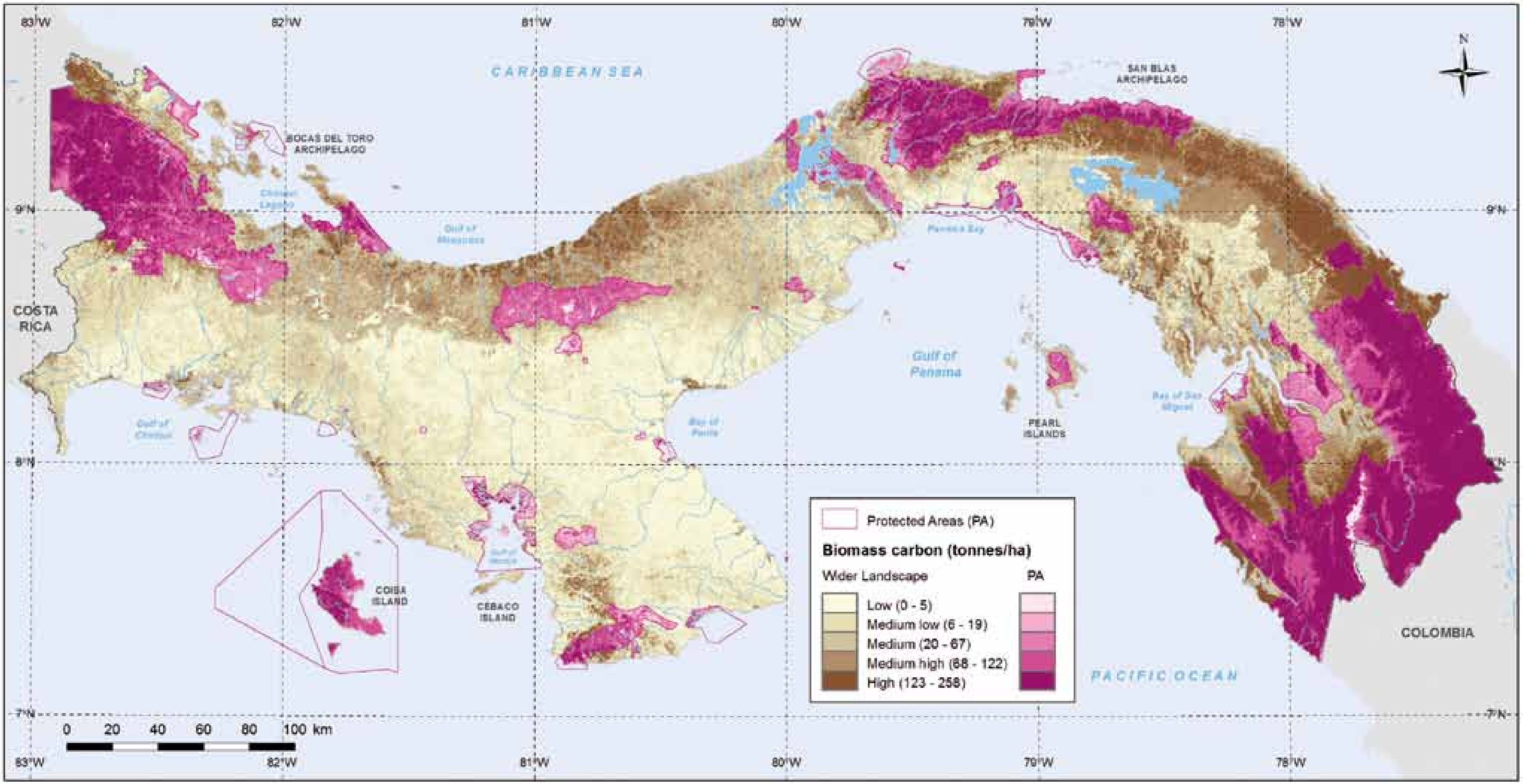
Another approach to identifying areas of importance for biodiversity conservation integrates several criteria in addition to species threat status. Key Biodiversity Areas (KBAs), sites of global significance for the conservation of biodiversity, are identified nationally based on internationally agreed criteria of vulnerability (the presence of threatened species) and irreplaceability (the overall importance of a site for achieving conservation of individual threatened species – e.g. a significant proportion of the global population of a given species occurs within a site) (Eken et al. 2004). Key Biodiversity Areas identified based on these criteria include IBAs ('Important Bird and Biodiversity Areas' BirdLife 2008) and Alliance for Zero Extinction sites (the ranges of single-site endemics). KBAs provide another basis for identifying areas where REDD+ could deliver conservation benefits and areas where reducing the risks of adverse impacts should be a priority. Key Biodiversity Areas in Panama are shown in relation to biomass carbon stocks in Map 6.

Table 1. Overall species richness of vertebrates in Panama, and numbers of species considered in the IUCN Red List of Threatened Species (IUCN 2013) to be globally threatened (i.e. assessed as Critically Endangered, Endangered, or Vulnerable).

Class	Total number of species	Number of globally threatened species	% Threatened
Mammals	246	16	6.1
Birds	877	19	2.2
Amphibians	198	50	25.3
Reptiles	87	6	6.9

Map 4. Protection of biomass carbon stocks

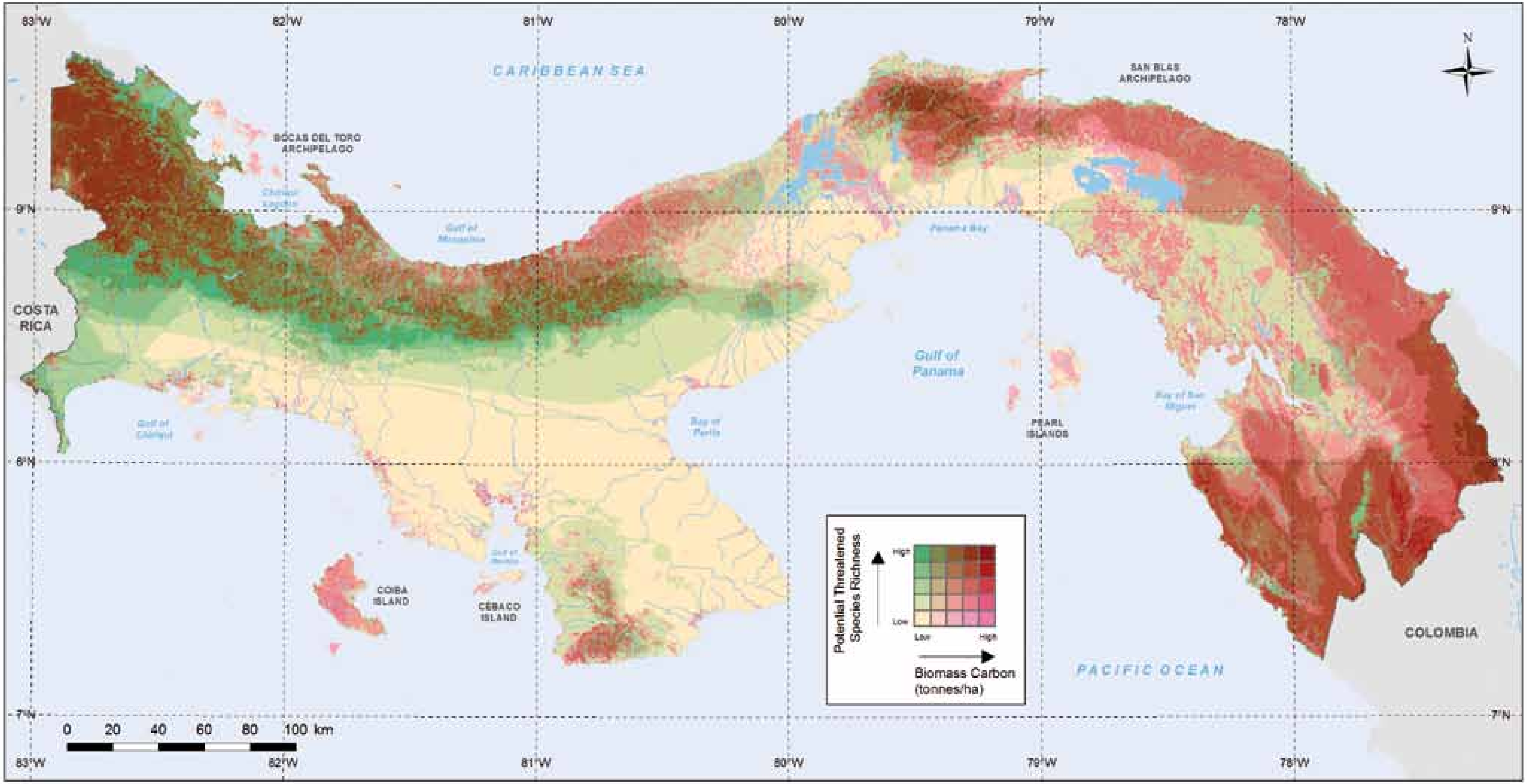
48% of Panama's biomass carbon is found within legally protected areas.



Methods and data sources:
Biomass Carbon: Asner, G., Mascaro, J., Anderson, C., Knapp, D., Martin, R., Kennedy-Bowdoin, T., van Breugel, M., Davies, S., Hall, J., Muller-Landau, H., Potvin, C., Sousa, W., Wright, J., and Bermingham, E. (2013) High-fidelity national carbon mapping for resource management and REDD+. Carbon Balance and Management 8:7. http://www.cbmjournal.com/content/8/1/7. Ecosystem-specific conversion factors (IPCC 2006) were used to add below-ground carbon to this map.
Protected Areas: Autoridad Nacional del Ambiente de Panamá (ANAM) (2006)

Map 5. Distribution of potential richness of threatened vertebrate species (mammals, birds and amphibians) in relation to biomass carbon

REDD+ actions in areas where both threatened species richness and carbon stocks are high (dark red) may yield biodiversity conservation as well as climate mitigation benefits. It may be especially important to monitor and avoid indirect land use change in areas with high potential richness of threatened species but low carbon stocks (green). In addition to threatened species, other aspects of biodiversity may also be of interest for informing REDD+ decision-making.



Methods and data sources:

Biomass Carbon: Asner, G., Mascaro, J., Anderson, C., Knapp, D., Martin, R., Kennedy-Bowdoin, T., van Breugel, M., Davies, S., Hall, J., Muller-Landau, H., Potvin, C., Sousa, W., Wright, J., and Bermingham, E. (2013) High-fidelity national carbon mapping for resource management and REDD+. Carbon Balance and Management 8:7. http://www.cbmjournal.com/content/8/1/7. Ecosystem-specific conversion factors (IPCC 2006) were used to add below-ground carbon to this map.

Biodiversity: Based on species classified as threat status 'Critically Endangered', 'Endangered' and 'Vulnerable' by the IUCN Red List of Threatened Species (2010) Version 2010.4. http://www.iucnredlist.org>. Downloaded October 2010.

BirdLife International (2012). IUCN Red List Assessement of Threatened Birds, received October 2010.

A 1km/sq hexagon grid covering Panama was generated using Jenness Enterprises repeating shapes tool in ArcGIS 10.0. Hawths Analysis tools were used to generate species richness. The number of species ranges intersecting each hexagon was counted to allow hexagons to be shaded by species number. Species richness was reclassed and split into 5 equal interval classes, and combined with biomass carbon reclassed and split into 5 quantile classes, to produce a matrix of potential threatened species richness and biomass carbon.

*The critically endangered Panamanian Golden Arrow Poison Frog (*Atelopus zeteki*) is dependent on montane cloud forests for its survival.*

2.5 Soil erosion control

Forests, especially those on slopes, play an important role in stabilizing soil and preventing soil erosion. Deforestation and forest degradation on slopes may diminish the capacity of the land to store water and cause greater surface runoff after heavy rains, with attendant erosion and sedimentation, increasing downstream flood risk and leading to water shortages at other times of the year. Over half of Panama's annual precipitation[2] results in surface runoff (ANAM 2011b). Soil erosion control was clearly identified in consultations and discussions with stakeholders groups as a key environmental and social service that forests provide, and therefore an important potential benefit of retaining forests as part of REDD+.

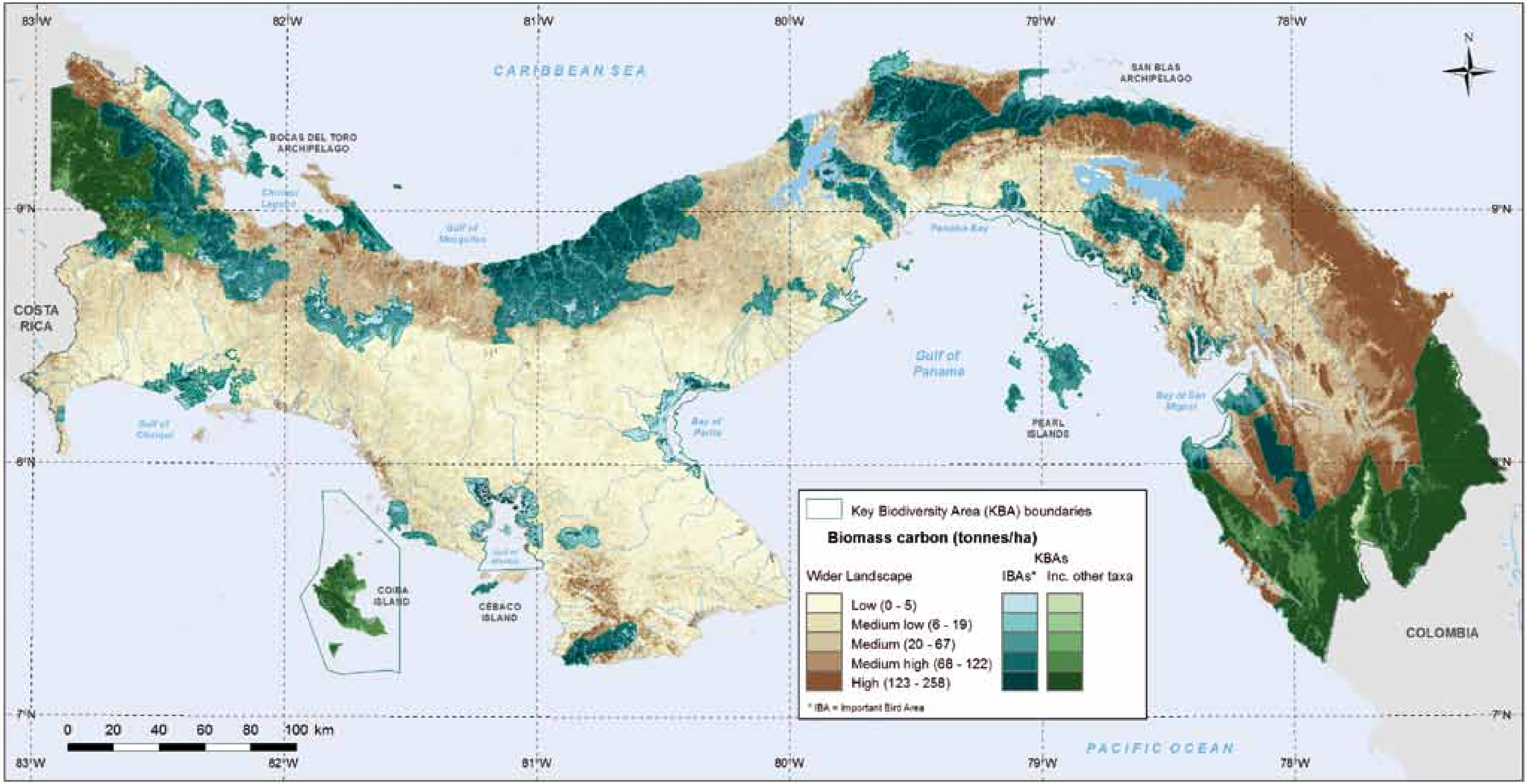
Deforestation is a serious threat to ecosystems in the Panama Canal watershed, which covers an area of 3 313 km^2 (Moreno 1993; Ibanez et al. 2002). In 1952 an estimated 85% of the basin was forested; however, this figure had dropped to 30% by 1983 (Moreno 1993). Deforestation has led to both floods and unreliability of the water supplies needed to maintain the functioning of the Canal and its locks. It also increases soil erosion, with soil particles carried by runoff contributing to higher sediment loads in streams and rivers (Moreno 1993). This resulting build up of silt can damage downstream infrastructure, such as hydroelectric and other dams, and is a major problem for the functioning of the Panama Canal itself. At an estimated cost of US$20 per ton of sediment, dredging to keep open the shipping channels is a major expense in the Canal's operation (Miguel 2010; Jaen and Shirota 2011). It can also limit supplies and increase the costs of providing clean drinking water.

2 There are important regional variations in rainfall related to Panama's geography. The mountains intercept storms from the Caribbean, so that Panama's wettest areas are on mountainsides, where annual precipitation is often over 3 000 mm; the Pacific slopes, on the other hand, are generally drier, often with 1 000 to 3 000 mm of rain per year (and sometimes less than 1 000 mm of annual precipitation) (Condit et al. 2011).

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

Map 6. Key Biodiversity Areas (KBAs) in relation to biomass carbon

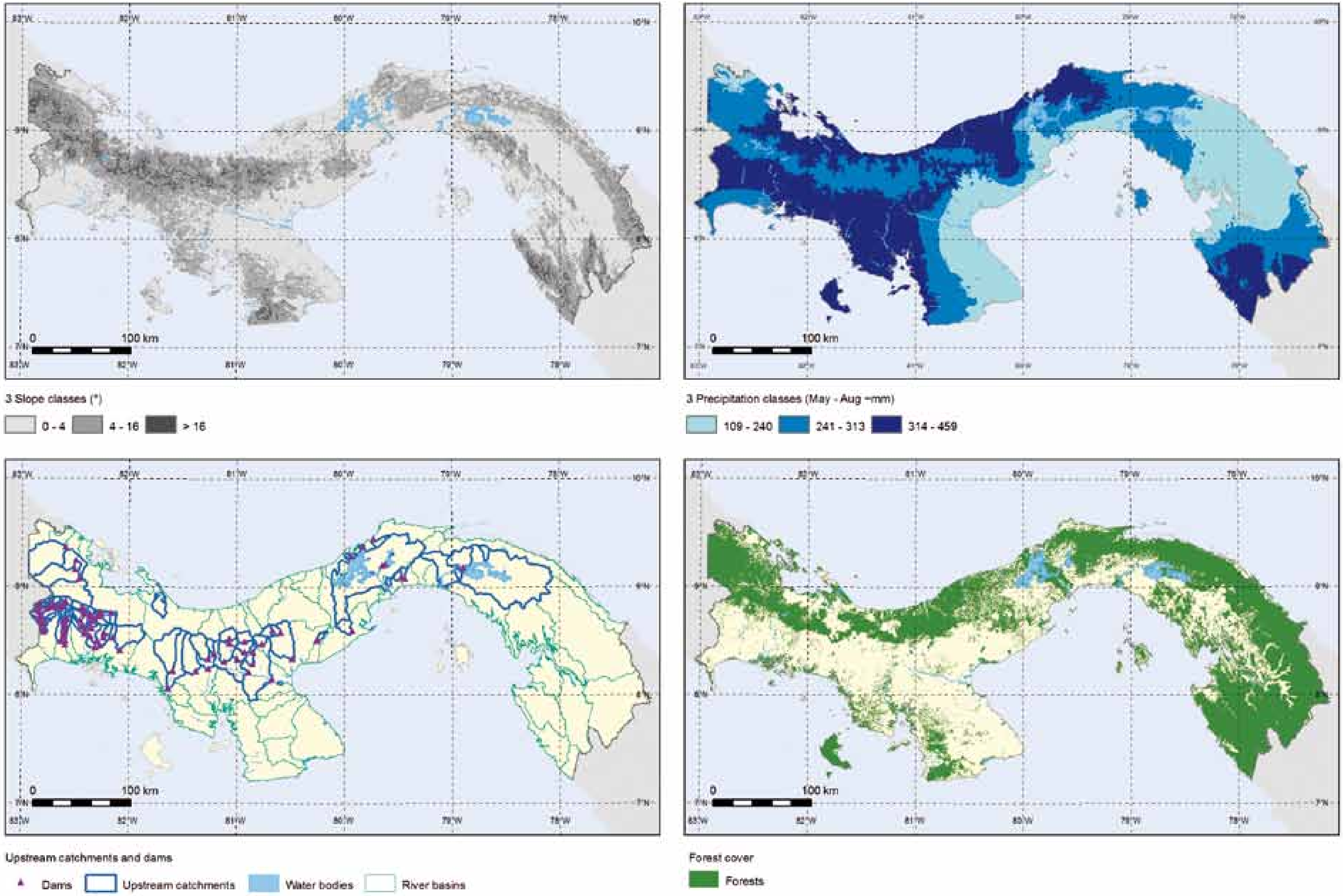
Key Biodiversity Areas (KBAs) are identified nationally according to internationally agreed criteria relating to the vulnerability of the species that occur within them, and the irreplaceability of the site in relation to conservation of individual species. The logic applied in Map 5 applies here: REDD+ actions in KBAs (areas of importance for biodiversity conservation) where carbon stocks are high may generate substantial benefits for biodiversity conservation as well as for climate change mitigation (darkest blue and green). These, along with KBAs in areas with low carbon stock (paler blues and greens), may be important foci for identifying risks and monitoring REDD+ impacts.



Methods and data sources:
Biomass Carbon: Asner, G., Mascaro, J., Anderson, C., Knapp, D., Martin, R., Kennedy-Bowdoin, T., van Breugel, M., Davies, S., Hall, J., Muller-Landau, H., Potvin, C., Sousa, W., Wright, J., and Bermingham, E. (2013) High-fidelity national carbon mapping for resource management and REDD+. Carbon Balance and Management 8:7. http://www.cbmjournal.com/content/8/1/7. Ecosystem-specific conversion factors (IPCC 2006) were used to add below-ground carbon to this map.
Biodiversity: Key Biodiversity Areas (KBAs) of the world including Important Bird Areas (IBAs) and Alliance for Zero Extinction sites (AZEs) compiled by BirdLife International and Conservation International, October 2012. For further information, please contact mapping@birdlife.org.

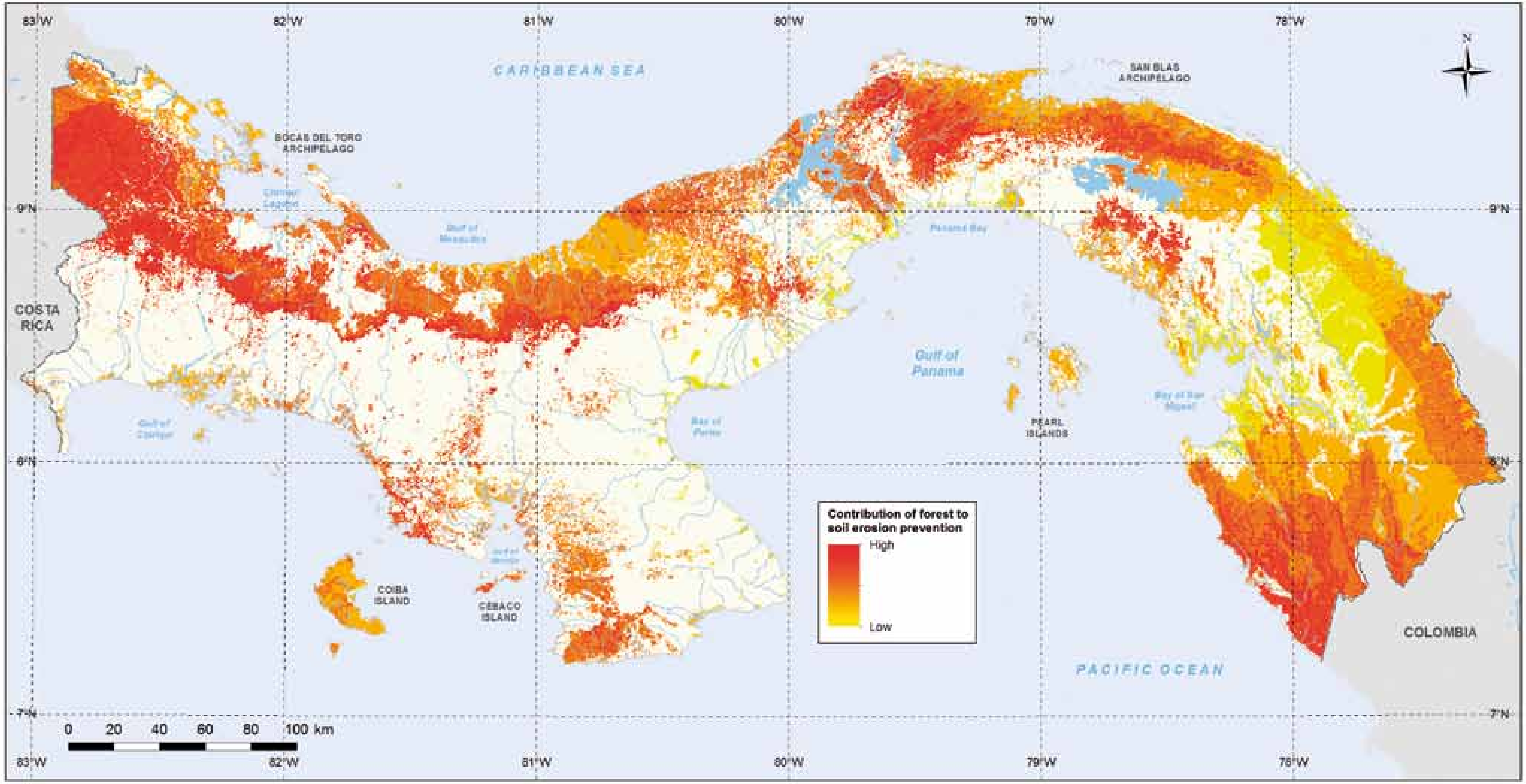
Map 7. Importance of forest for limiting soil erosion – methodology

The role of forest in limiting erosion and sedimentation is most critical where erosion risk is high. Areas with high slope (upper left) and high precipitation (upper right), and within catchments above dams and lakes (lower left) are combined with forest area (lower right) to assess forest importance for erosion control (Map 8).



Map 8. Importance of forest for limiting soil erosion

Targeting REDD+ actions in areas of most value for soil erosion control (see Map 7 for component criteria) may help to provide additional benefits of REDD+ in Panama.



Methods and data sources:
The relative importance of forest has been evaluated as a function of slope, rainfall and the presence of something important downstream that could be adversely affected by soil erosion (dams and lakes). This method uses an overlay approach, where data on precipitation is combined with data generated for slope, and upstream catchments of dams and lakes. This is then combined with forest data.
Elevation: Lehner, B., Verdin, K., Jarvis, A. (2008): New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU, 89(10): 93-94. See http://hydrosheds.cr.usgs.gov/
Precipitation: Wet season average May - August (mm). Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. See http://www.worldclim.org/
Dams: Lehner, B., R-Liermann, C., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P. et al.: High resolution mapping of the world's reservoirs and dams for sustainable river flow management. Frontiers in Ecology and the Environment. Source: GWSP Digital Water Atlas (2008). Map 81: GRanD Database (V1.0). Available online at http://atlas.gwsp.org. This was combined with national data on hydroelectric and other dams from Autoridad de los Servicios Públicos (ASEP) and Autoridad Nacional del Ambiente de Panamá (ANAM) 2012.
Forest Cover: National dataset of 2008 land cover (CATHALAC 2011).

Excess sediment regularly needs to be dredged to ensure proper functioning of the Panama Canal.

The importance of Panama's forests for stabilizing soils and limiting soil erosion has been evaluated in this report by developing an index which combines three criteria: slope, wet season precipitation and the presence of downstream features with the potential to be adversely affected by sedimentation (lakes, hydroelectric and other dams). A simple classification for each criterion (low, medium, high or presence/absence) was applied; the datasets were then combined and overlaid with forest cover data for Panama (Map 7; Annex II provides a more detailed methodology).

The role of forest in limiting erosion and sedimentation is most critical where high rainfall combines with steep slopes to increase erosion risk within catchments above dams and lakes (Map 8). Careful design and targeting of REDD+ actions in areas of most value for soil erosion control may help ensure they provide additional benefits for Panama. Further analyses of areas that have lost forest in important catchments where erosion risk is high may be useful in identifying potential locations for reforestation or forest restoration.

2.6 Tourism

In addition to storing and sequestering carbon, hosting biodiversity and controlling soil erosion, forests also play a key socio-economic role in supporting and enhancing some types of tourism in Panama. The process of consultations with stakeholder groups also identified as key the cultural and recreational services that forests provide. These can also become important sources of income for forest dependent people. The experience of countries like Costa Rica shows that the aggregate importance of these services can be of major significance not only at the micro but at the macroeconomic level as well. Locating REDD+ actions in areas of value for tourism may help to ensure that REDD+ provides benefits for this important sector.

Panama is a popular tourist destination in Central America, offering both political and economic stability and many natural resources and attractions. The tourism industry, including associated lodging, transportation, activities and services, contributed 4.6% to Panama's GDP in 2007 (Instituto Panameño de Turismo 2008). Panama's national development strategy recognises tourism's contribution to economic development, and Panama's *Master Plan for Sustainable Tourism* (2007–2020) similarly stresses the importance of tourism in generating economic and social resources and investment for Panama (Instituto Panameño de Turismo 2008).

In addition to socio-economic benefits, there are potential environmental benefits from tourism. In order to ensure continued interest of tourists in Panama's natural world, it is imperative to maintain the environmental quality of tourist sites. The conservation of biodiversity, the sustainable use of natural resources and the protection of areas of ecological value can help to ensure continued nature tourism in Panama (Instituto Panameño de Turismo 2008).

The *Master Plan for Sustainable Tourism* divides tourism into twelve different types of "products"; of these, three types were deemed relevant for forests in Panama. Eco-tourism is seen to offer the opportunity to visit unexploited areas in the country, with a focus on promoting the sustainable use of natural resources, causing minimal environmental impact and providing jobs and economic opportunities to local populations. Active/adventure tourism enables visitors to see natural spaces like mountains, rivers, and volcanoes without damaging them. Scientific tourism takes advantage of land and marine areas with endemic species. Panama is home to the Smithsonian Tropical Research Institute (STRI), which offers unique opportunities for scientific tourism (Instituto Panameño de Turismo 2008). Map 9 shows forest in areas of importance for eco, active/adventure, and scientific tourism in Panama. In these areas REDD+ actions that preserve forest may have the added benefit of supporting continued or enhanced tourism. Other areas apart from those mentioned in the Master Plan, for example protected areas, may also be important for tourism.

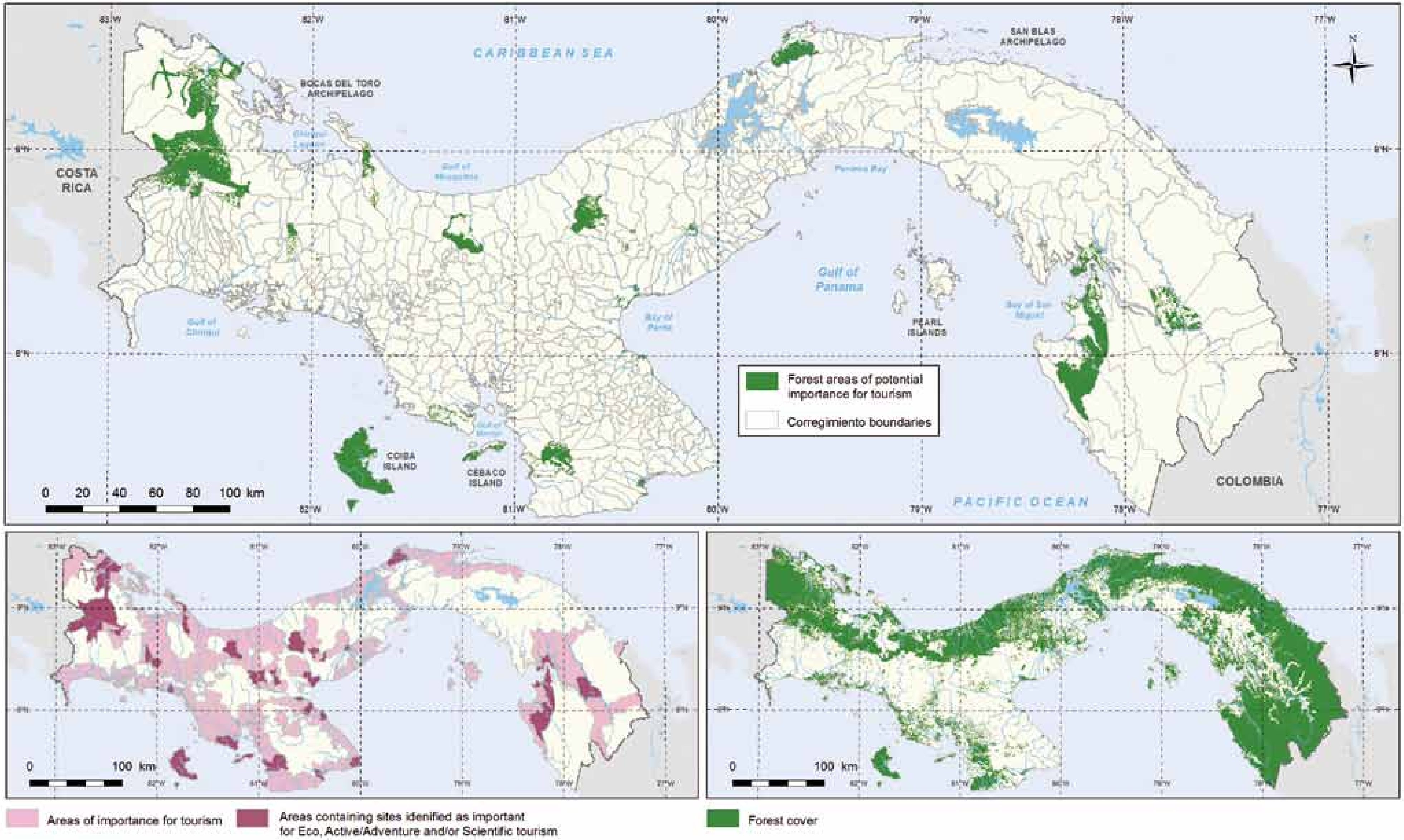
3. Areas that are potentially important for more than one benefit

The previous sections identified different environmental and social benefits from forests and areas where REDD+ actions could potentially deliver individual specific benefits in addition to the climate mitigation benefits of REDD+. However, all else being

REDD+ actions that preserve forest may have the added benefit of supporting tourism.

Map 9. Forest in areas of importance for eco, active/adventure and scientific tourism (as identified by Panama's Master Plan for Sustainable Tourism 2007–2020)

In these areas REDD+ actions to preserve forest may have the added benefit of supporting continued or enhanced tourism related to forests.



Methods and data sources:
Tourism destinations and types: Atlas Ambiental de la República de Panamá (Primera Versión 2010). ANAM 2011. Tourism destinations generated for the Tourism Master Plan 2007-2020. Destinations have been divided into 5 zones with 26 tourist destinations, which in many cases used administrative political divisions.
Forest Cover: National dataset of 2008 land cover (CATHALAC 2011).

equal, the greatest priority for REDD+ might be to focus on areas where action to retain or restore forests can potentially provide multiple benefits. Accordingly, the separate results can be combined to identify forest areas of potential importance for a larger number of benefits from REDD+.

Drawing on the maps of above- and below-ground biomass carbon (Map 3), Key Biodiversity Areas (Map 6), the importance of forest for limiting soil erosion (Map 8) and forest in areas of importance for eco, active/adventure and scientific tourism (Map 9), it is possible to identify areas of high importance for various combinations of potential benefits (Map 10) (Annex III provides more detailed methodology). If these areas are at risk of deforestation or degradation, they may be of particularly high priority for REDD+ actions to reduce deforestation or forest degradation, even if there are challenges related to cost or feasibility.

4. Prioritizing areas for REDD+ action based on potential for multiple benefits and deforestation risk

Successful REDD+ efforts that focus on preserving forests at high risk of deforestation are likely to have the greatest climate change mitigation impacts. The UN-REDD Programme in Panama has engaged in a comprehensive plan to identify forest areas at risk. A joint team composed of staff at CATIE, ANAM and UNEP produced detailed work on scenario-based modeling of deforestation in Panama. A local team in Panama prepared data layers that included land cover and land use from 1992–2000–2008, infrastructure, road networks and other socio-economic and environmental characteristics. In addition, it undertook a survey of opinions and several rounds of consultations with key stakeholder groups to assess perceptions on the likelihood of different development paths for Panama. This information was then used by CATIE to calibrate and validate several models that estimate land-use transitions and assesses the probability that a given pixel will make a transition to another form of use. The best-performing models were then used to project the distribution of future deforestation (to 2016 and 2028) under different scenarios of future socio-economic development (CATIE 2013).

Map 11 displays areas at risk of deforestation by 2028 under a low impact scenario (SCNBI) that accounts for new developments in terms of roads, hydroelectric projects and metal mining, based on identifying those projects that had been approved or were under construction in 2013. Future road development associated with hydroelectric projects and mines was projected through a simple model of potential road construction, based on slope and distance from established roads (CATIE 2013).

In addition to the risk of deforestation, the climate change mitigation effect of preserving forests depends on the carbon stocks of the forests in question. To identify areas where forests with high biomass carbon are at risk from deforestation, Map 12 combines modelling results in terms of the spatial variation in probability of future deforestation with the data on biomass carbon from Map 3. Areas where high carbon stocks are subject to high risk (dark brown in Map 12) may be high priorities for REDD+ actions designed to reduce local deforestation risk. The extent and location of areas highlighted by such an analysis depend on both the model and the scenario used (in this case DINAMICA-EGO and the low impact development scenario, SCNBI; CATIE 2013), as well as the quality and currency of the carbon data, so careful consideration of the range of results is needed to support effective decisions making.

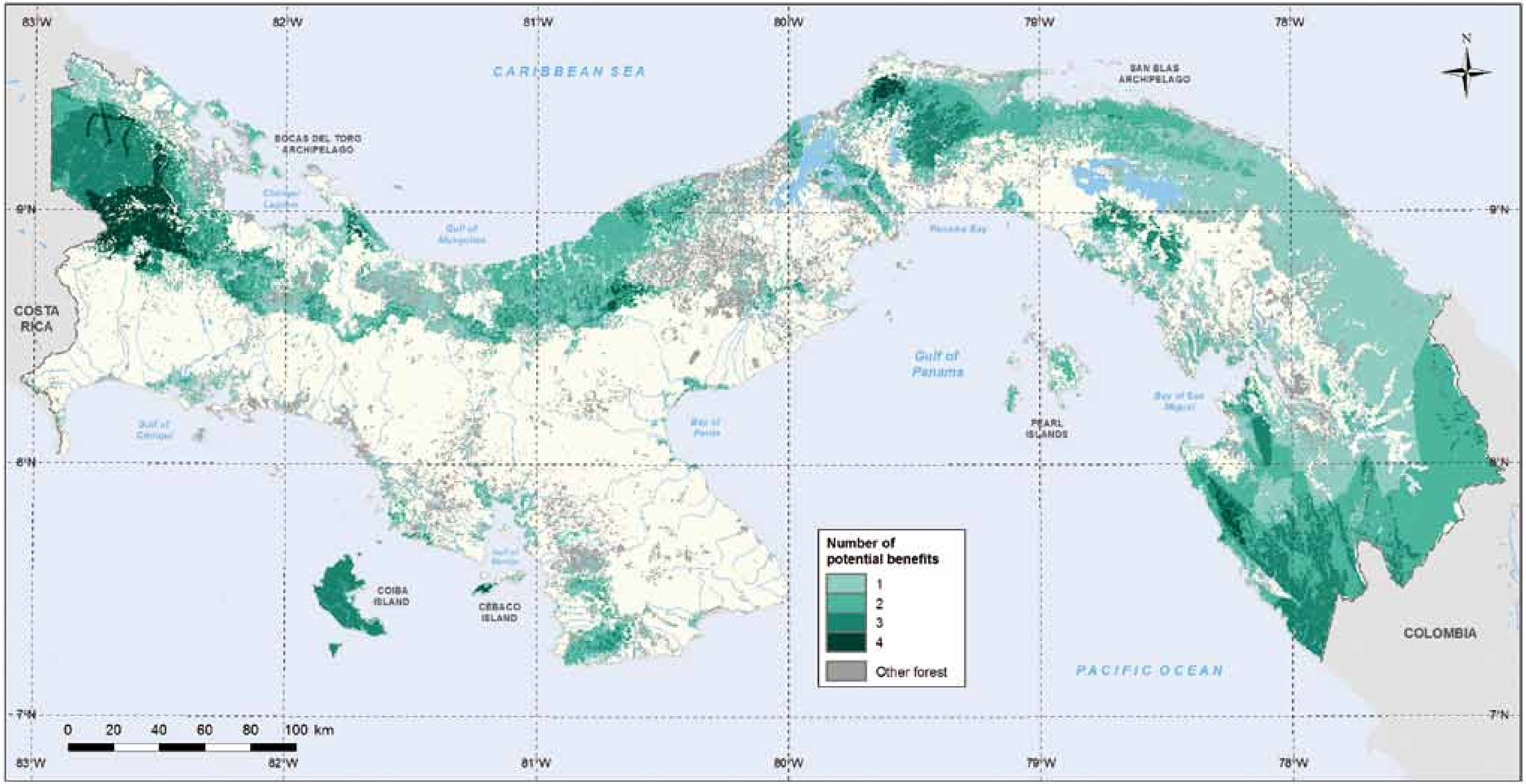
Areas of even greater priority for REDD+ action would be locations where both deforestation risk and the potential for multiple social and environmental benefits are high. Map 13 provides an example of this type of analysis, which could be used to support decisions on prioritising REDD+ actions to reduce deforestation. In the areas with the greatest potential for benefits that are also at risk, REDD+ action would deliver important mitigation benefits and would also potentially yield important benefits for biodiversity conservation, soil erosion control and/or tourism, as indicated in Map 10.

Different modelling approaches are associated with different degrees of uncertainty. Further, they may project future deforestation in different locations, which may alter priorities for REDD+ actions. To minimise uncertainty and provide a conservative view of which forest areas are most at risk, Map 14a displays the areas where two models agree that deforestation will occur if current rates of deforestation continue under the low impact scenario (SCNBI; CATIE 2013). The DINAMICA-EGO model (used in maps 11 to 13), and the Econometrica model both estimate land-use transitions, but employ different techniques to assess the probability that a given pixel will make a transition to another form of use (CATIE 2013).

As Map 14a displays only those areas likely to be deforested according to both models, it is likely to

Map 10. Forest areas of potential importance for multiple benefits of REDD+

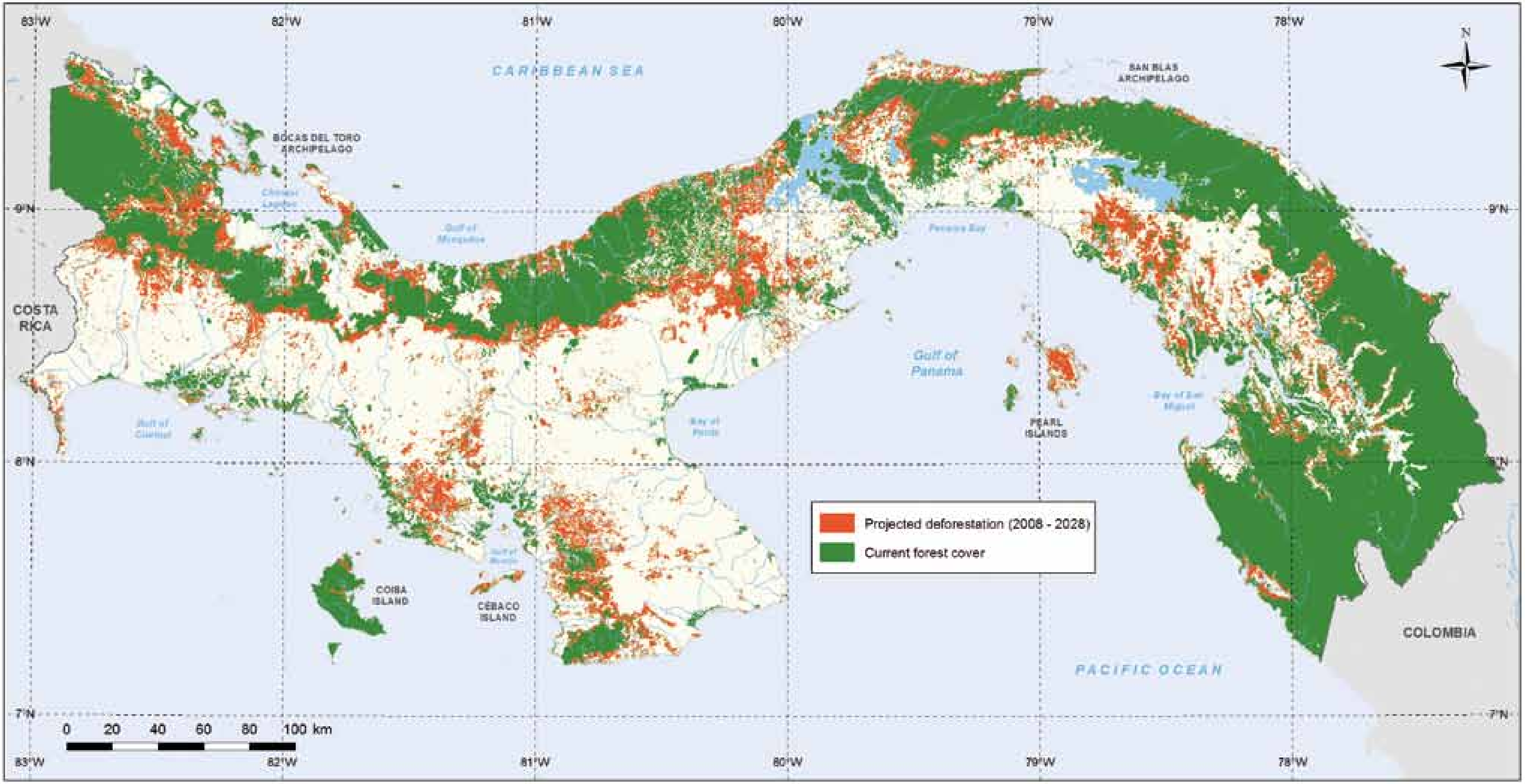
Drawing on Maps 3, 6, 8 and 9, it is possible to identify forest areas potentially important for several benefits at once. Darker shading indicates areas important for a higher number of these benefits (maximum four). The benefits included are: a) climate change mitigation (areas with high (68–258 tonnes/ha) biomass carbon stocks); b) biodiversity conservation (Key Biodiversity Areas); c) soil erosion control (areas identified as having high importance for soil erosion control); and d) supporting tourism (located within areas containing sites important for eco, active/adventure and scientific tourism).



Methods and data sources:
Biomass Carbon: Asner, G., Mascaro, J., Anderson, C., Knapp, D., Martin, R., Kennedy-Bowdoin, T., van Breugel, M., Davies, S., Hall, J., Muller-Landau, H., Potvin, C., Sousa, W., Wright, J., and Bermingham, E. (2013) High-fidelity national carbon mapping for resource management and REDD+. Carbon Balance and Management 8:7. http://www.cbmjournal.com/content/8/1/7. Ecosystem-specific conversion factors (IPCC 2006) were used to add below-ground carbon to this map. The top two classes of biomass carbon "medium high" and "high" (see map 3) were used to represent areas of highest importance for carbon in this map. **Tourism:** Atlas Ambiental de la República de Panamá (Primera Versión 2010). ANAM 2011. Tourism destinations generated for the Tourism Master Plan 2007-2020. Destinations have been divided into 8 zones with 26 tourist destinations, which in many cases used administrative political divisions. These were then clipped to forest area (see map 9). **Biodiversity:** Key Biodiversity Areas (KBAs) of the world including Important Bird Areas (IBAs) and Alliance for Zero Extinction sites (AZEs) compiled by BirdLife International and Conservation International, October 2012. For further information, please contact mapping@birdlife.org (see map 6). **Soil erosion:** The relative importance of forest has been evaluated as a function of slope, rainfall and the presence of something important downstream that could be adversely affected by soil erosion (dams and lakes). The top three classes from map 8 have been used to identify areas of greatest importance here. Elevation: Lehner, B., Verdin, K., Jarvis, A. (2008): New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU, 89(10): 93-94. Precipitation: Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. Dams Lehner, B., R-Liermann, C., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P. et al.: High resolution mapping of the world's reservoirs and dams for sustainable river flow management. Frontiers in Ecology and the Environment. Source: GWSP Digital Water Atlas (2008). Map 81: GRanD Database (V1.0). Available online at http://atlas.gwsp.org. This was combined with national data on hydroelectric and other dams from Autoridad de los Servicios Públicos (ASEP) and Autoridad Nacional del Ambiente de Panamá (ANAM) 2012. **Forest:** National dataset of 2008 land cover (CATHALAC 2011).

Map 11. Modelled future deforestation

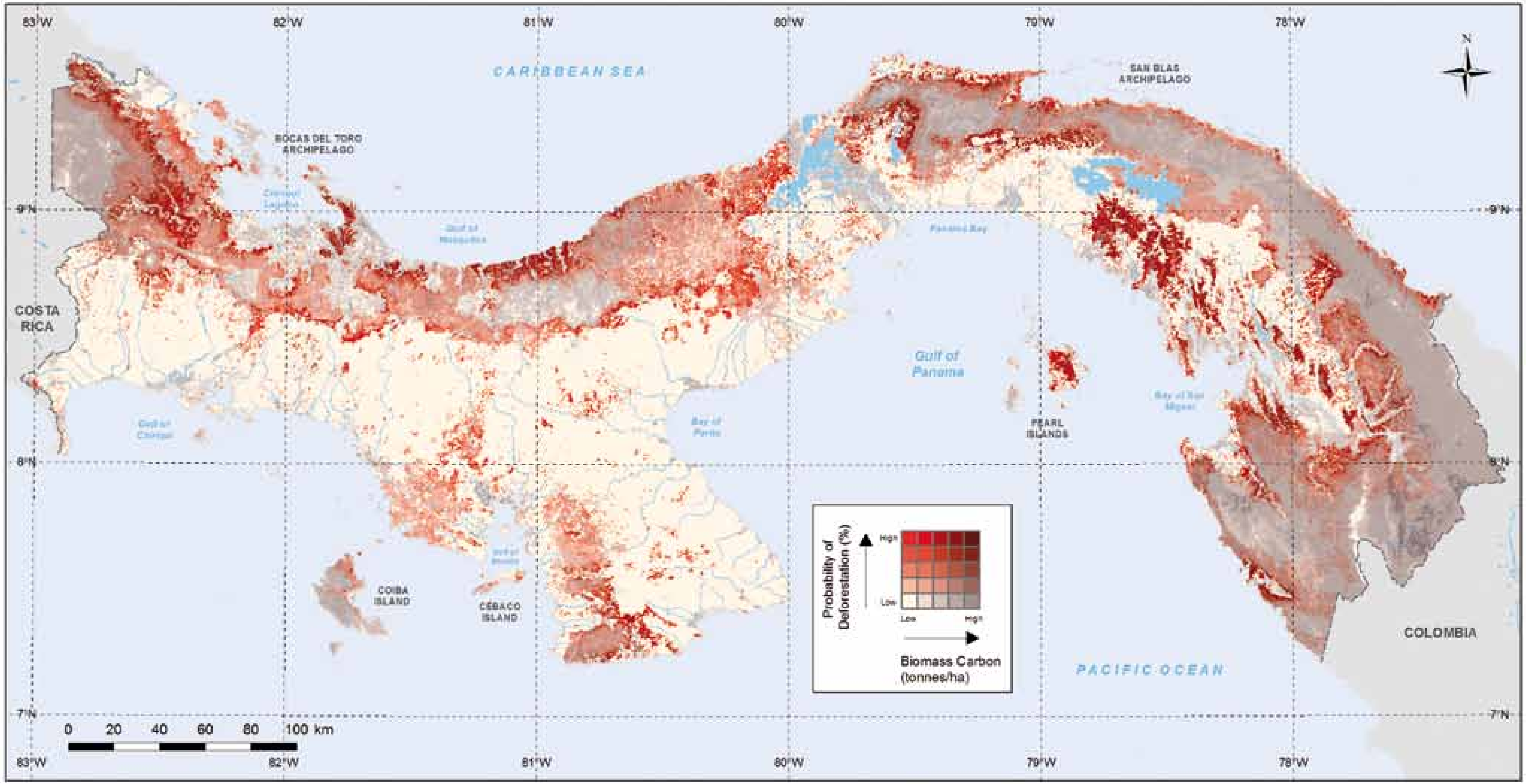
Based on historic deforestation rates and land use modelling approaches, CATIE (2013) has mapped where deforestation is likely to occur under different scenarios. This map presents the results of the modeled low impact scenario (SCNBI) output from the DINAMICA-EGO model, which accounts for projected infrastructure development likely to change the spatial distribution (but not total amount) of deforestation. (This map is the basis for Map 15b, and the probabilities underlying it are used in maps 12 and 13.)



Methods and data sources:
Forest: National dataset of 2008 land cover (CATHALAC 2011).
Projected Deforestation 2008 - 2028: CATIE (2013). Análisis de cambio de uso de la tierra (1992 – 2008) y formulación de escenarios de deforestación futura de los bosques de Panamá. Turrialba, Costa Rica: Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). This map displays the results of the modelled "Low Impact, SCNBI" scenario output from the DINAMICA-EGO model, where historic deforestation rates are extrapolated into the future, and a conservative estimate of likely development of infrastructure is accounted for (based on national plans).

Map 12. Biomass carbon at risk

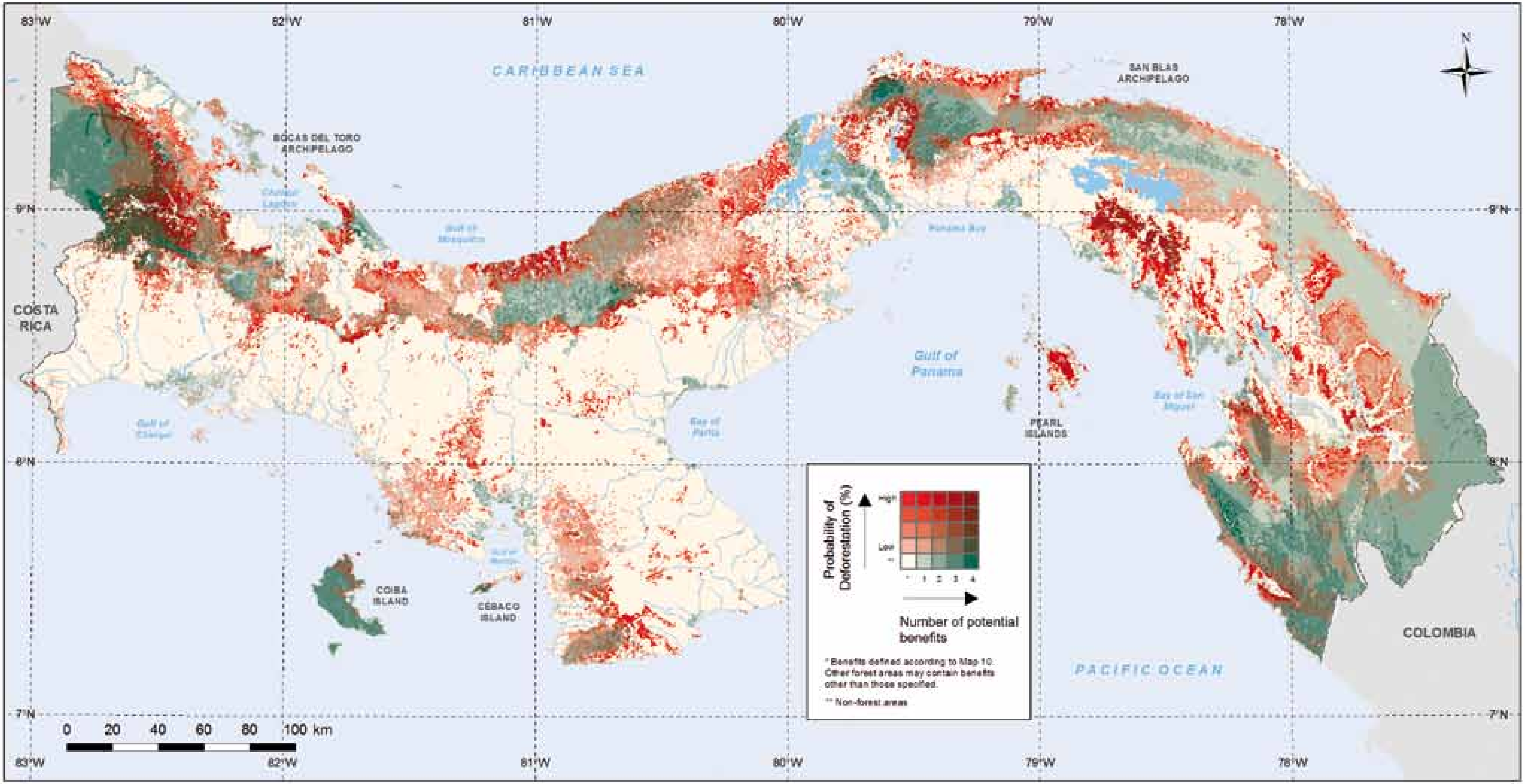
The climate mitigation effect of preserving forests at risk also depends on their carbon stocks. This map shows where carbon stocks may be at risk by combining biomass carbon (Map 3) with the probability of future deforestation, derived from the DINAMICA-EGO model that incorporates the impact of projected infrastructure (SCNBI; CATIE 2013). Areas of high biomass carbon that are also potentially at a high risk of deforestation are shown in dark brown. Areas at high risk of deforestation but which contain low carbon stock are shown in bright red. Areas of high carbon stocks with a low risk of deforestation are light brown.



Methods and data sources:
Biomass Carbon: Asner, G., Mascaro, J., Anderson, C., Knapp, D., Martin, R., Kennedy-Bowdoin, T., van Breugel, M., Davies, S., Hall, J., Muller-Landau, H., Potvin, C., Sousa, W., Wright, J., and Bermingham, E. (2013) High-fidelity national carbon mapping for resource management and REDD+. Carbon Balance and Management 8:7. http://www.cbmjournal.com/content/8/1/7. Ecosystem-specific conversion factors (IPCC 2006) were used to add below-ground carbon to this map.
Probability of Deforestation (2008 – 2028): CATIE (2013). Análisis de cambio de uso de la tierra (1992 – 2008) y formulación de escenarios de deforestación futura de los bosques de Panamá. Turrialba, Costa Rica: Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). This map features the probability of deforestation outputs from the DINAMICA-EGO model of future deforestation low impact scenario (SCNBI), which have been divided using a quantile classification scheme and combined with biomass carbon.

Map 13. Risk to forest areas of potential importance for multiple benefits of REDD+

Using the projected probabilities of deforestation underlying Map 11, based on the DINAMICA-EGO model, areas of forest important for various combinations of potential benefits (Map 10) that are potentially at risk can be highlighted. Areas that are of potential importance for multiple benefits, but that are also at high risk of future deforestation, are shown in dark red. These areas could be priority locations for REDD+ actions to reduce deforestation.



Methods and data sources:
Probability of Deforestation (2008 – 2028): CATIE (2013). Análisis de cambio de uso de la tierra (1992 – 2008) y formulación de escenarios de deforestación futura de los bosques de Panamá. Turrialba, Costa Rica: Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). This map features the probability of deforestation outputs from the DINAMICA-EGO model of future deforestation low impact scenario (SCNBI), which has been divided using a quantile classification scheme and combined with the multiple benefits layer presented in Map 10.
Multiple benefits: Biomass Carbon: Asner, G., Mascaro, J., Anderson, C., Knapp, D., Martin, R., Kennedy-Bowdoin, T., van Breugel, M., Davies, S., Hall, J., Muller-Landau, H., Potvin, C., Sousa, W., Wright, J., and Bermingham, E. (2013) High-fidelity national carbon mapping for resource management and REDD+. Carbon Balance and Management 8:7. http://www.cbmjournal.com/content/8/1/7. Ecosystem-specific conversion factors (IPCC 2006) were used to add below-ground carbon to this map. The top two classes of biomass carbon "medium high" and "high" (see map 3) were used to represent areas of highest importance for carbon in this map. **Tourism:** Atlas Ambiental de la República de Panamá (Primera Versión 2010). ANAM 2011. Tourism destinations generated for the Tourism Master Plan 2007-2020. Destinations have been divided into 8 zones with 26 tourist destinations, which in many cases used administrative political divisions and then clipped to forest area (see map 9). **Biodiversity:** Key Biodiversity Areas (KBAs) of the world including Important Bird Areas (IBAs) and Alliance for Zero Extinction sites (AZEs) compiled by BirdLife International and Conservation International, October 2012. For further information, please contact mappingbirdlife.org. (see map 6). **Soil erosion:** The relative importance of forest has been evaluated as a function of slope, rainfall and the presence of something important downstream that could be adversely affected by soil erosion (dams and lakes).The top three classes from map 8 have been used to identify areas of greatest importance here. Elevation: Lehner, B., Verdin, K., Jarvis, A. (2008): New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU, 89(10): 93-94. Precipitation: Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. Dams Lehner, B., R-Liermann, C., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P. et al. High resolution mapping of the world's reservoirs and dams for sustainable river flow management. Frontiers in Ecology and the Environment. Source: GWSP Digital Water Atlas (2008). Map 81: GRanD Database (V1.0). Available online at http://atlas.gwsp.org. This was combined with national data on hydroelectric and other dams from Autoridad de los Servicios Públicos (ASEP) and Autoridad Nacional del Ambiente de Panamá (ANAM) 2012. **Forest:** National dataset of 2008 land cover (CATHALAC 2011).

represent an underestimate of future deforestation risk. Map 14b uses the conservative forecast of deforestation from Map 14a to highlight areas of forest important for various combinations of potential benefits (Map 10) that are potentially at risk. Areas that are of potential importance for three or four benefits, but that are also at high risk of future deforestation, are shown in red. These areas could be priority locations for REDD+ actions to reduce deforestation.

5. Poverty, income generation and sustainable forest use

There is a growing consensus that decisions on conservation and sustainable use of forests cannot be divorced from issues of basic needs, poverty and inequality. REDD+ will significantly increase its chances of success if it becomes a key income source for communities and forest dependent people. Spatial analysis can help to identify places where REDD+ activities could be designed to contribute to reducing poverty and inequality. REDD+ efforts in areas of high poverty need to be designed with particular care and attention to the needs of the poor and the potential for both benefits and risks to local livelihoods.

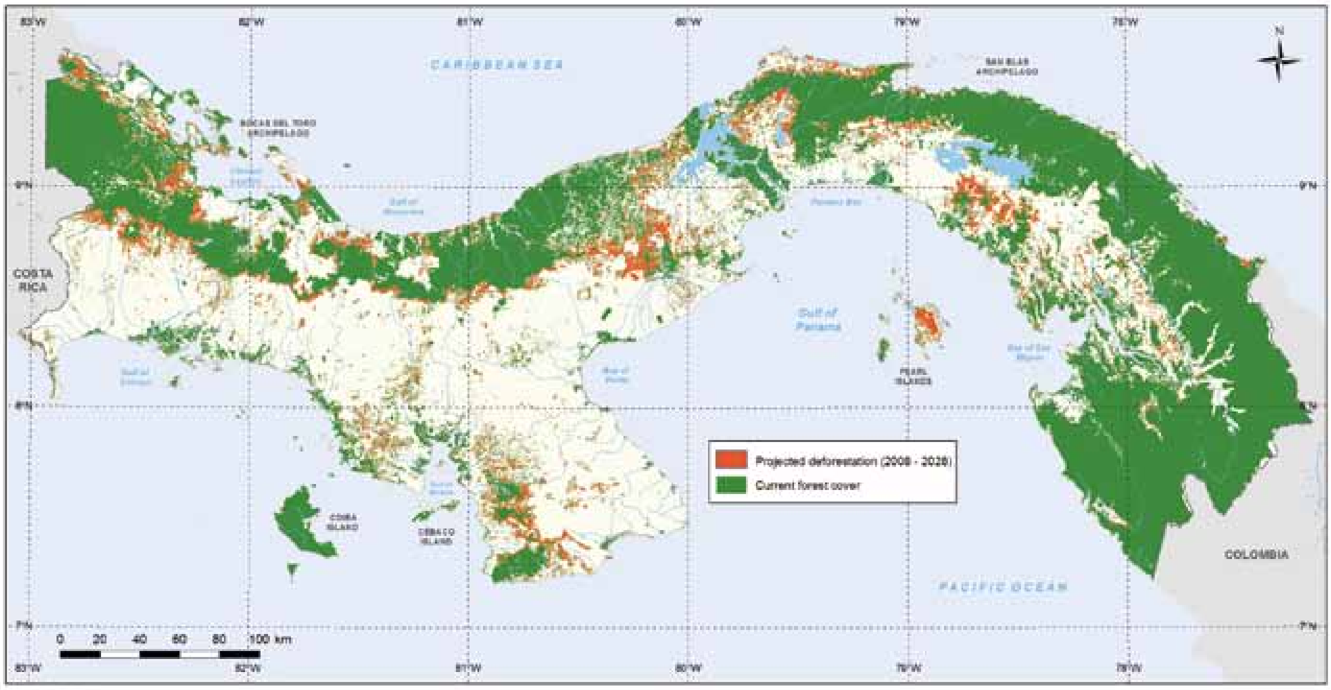
Over the past few decades, Panama has achieved a high level of human development, with improvements in health and life expectancy, education and per capita income. However, it is estimated that 37.3% of the total national population lives below the poverty line, two-thirds of whom are involved in rural economies (World Bank 2009). In particular, 95% of residents of indigenous areas live below the poverty line, with 86% in extreme poverty (World Bank 2009). There is often a spatial correspondence between areas of high carbon stocks, typically located in natural forests and in remote rural areas, and poverty. These areas may suffer from low market access, weak infrastructure and few opportunities for agricultural production, which together create “poverty traps”, from which it is difficult to escape (Lawlor et al. 2013). In areas of high forest cover and high poverty, there is also a relatively high dependence on forests for livelihoods, especially in times of hardship; the rural poor are the most likely to be reliant on ecosystem services, and are therefore the most vulnerable to changes in those services (MEA 2005; Sunderlin et al. 2008). The loss of forests through deforestation or forest degradation may therefore pose threats to the income and employment, food security and the health of the world’s poor.

REDD+ actions can benefit local livelihoods by helping to clarify and strengthen land tenure rights, enhancing community capacity for forest management and

In some remote rural areas, there may be a relatively high dependence on forests for local livelihoods. REDD+ actions in such areas need to be planned to take account of this dependence.

Map 14a. Most likely areas of future deforestation according to combined results from two models

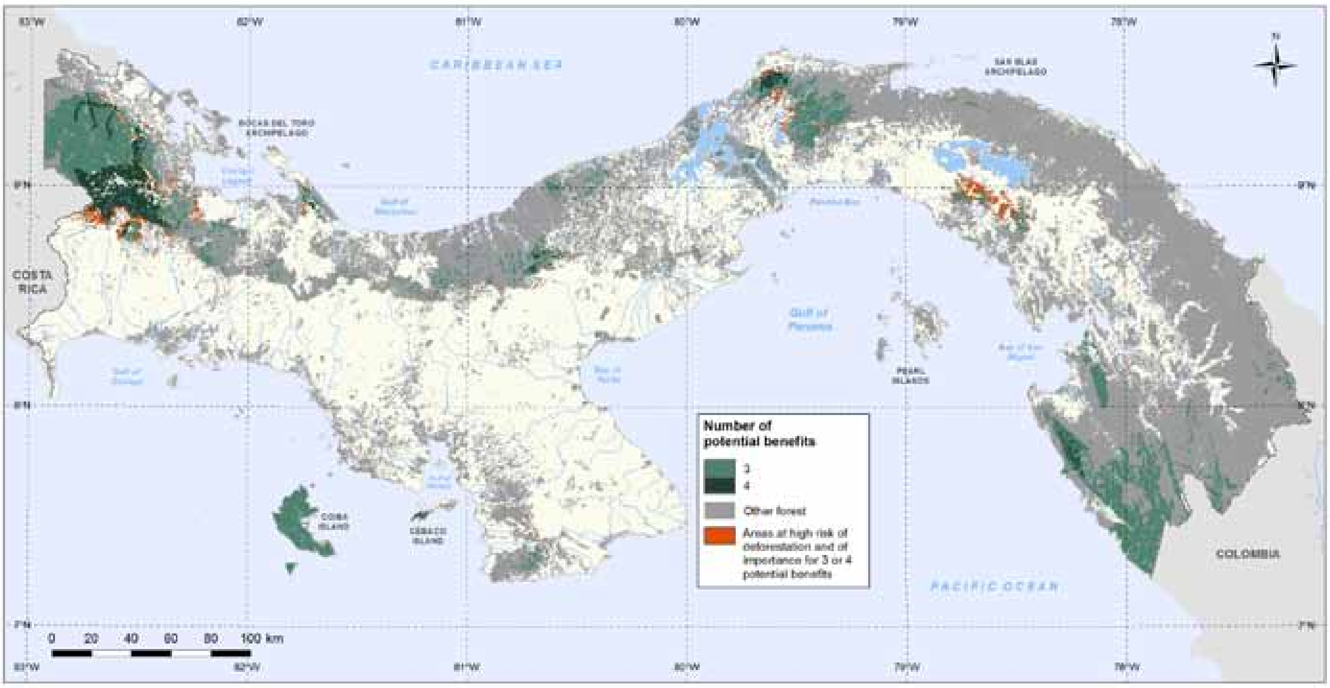
This map presents a conservative forecast of future deforestation; it shows only those areas where both the DINAMICA-EGO and Econometrica models predict deforestation will occur under a low impact scenario (SCNBI) that accounts for projected infrastructure development likely to change the spatial distribution (but not total amount) of deforestation.



Methods and data sources:
Forest: National dataset of 2008 land cover (CATHALAC 2011).
Projected Deforestation 2008 - 2028: CATIE (2013). Análisis de cambio de uso de la tierra (1992 – 2008) y formulación de escenarios de deforestación futura de los bosques de Panamá. Turrialba, Costa Rica. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). The results of two modelling approaches for analysing future trends of deforestation and forest degradation (DINAMICA-EGO and econometric models) are presented here. This map combines the modelled "Low Impact, SCNBI" scenario outputs from both the DINAMICA-EGO and econometric models, where historic deforestation rates are extrapolated into the future, and a conservative estimate of likely development of infrastructure is accounted for (based on national plans). Only those areas likely to be deforested according to both models are presented here, providing a 'conservative forecast' of future deforestation.

Map 14b. Projected deforestation (combined results) in areas of potential importance for multiple benefits of REDD+

The conservative forecast of deforestation presented in Map 14a is used to highlight (in red) areas of forest important for three or four potential benefits (Map 10) that are potentially at risk of future deforestation. These areas could be high priority locations for REDD+ actions.



Methods and data sources:

collective action and sustaining ecosystem services important for food security and adaptation to climate change (Lawlor et al. 2013). However, REDD+ actions could also cause livelihood risks for forest-dependent communities. The Cancun safeguards were agreed by Parties to the UNFCCC with the aim of ensuring that REDD+ avoids potential social or environmental risks, and delivers "additional social and environmental benefits".

A "pro-poor" REDD+ would provide sufficient access to ecosystem services and other livelihood benefits for forest-dependent individuals and communities. This may involve: developing alternative income-generating opportunities and sources of forest products that reduce pressures on forests; improving agricultural productivity on non-forest lands to avoid the possibility of displacing cultivation to forested areas; creating disincentives for illegal logging or unsustainable forest management; and providing more secure tenure via formal legal recognition of rights to forest or forest products (Springate-Baginski and Wollenberg 2010).

Map 15a shows how the distribution of biomass carbon relates to poverty. It is possible go one step further in identifying priority areas of social interest by combining the results of the deforestation modelling exercise with biomass carbon and poverty (Map 15b). For example, retention of forests may be of critical importance for poor rural communities where food security depends to a great extent on non-timber forest products. Further, avoiding deforestation and land invasions may help to secure land rights and access to resources for communities at the bottom of the income ladder.

Note that both maps show the proportion of the population in poverty as a percentage of the total population per province, rather than the number of people that are poor. These maps can be used to identify areas where REDD+ actions to address carbon at risk could be designed to have local livelihoods benefits, based on local needs.

6. Conclusions and outlook

Planning for REDD+ in Panama, as elsewhere, depends on recognising and reconciling different demands for land use, as well as considering the potential benefits and risks of different options for REDD+ action. These factors all vary from place to place in different ways. The spatial analyses and resulting maps presented in this report show how different types of spatial data and analyses can be used to support informed decisions on the design of REDD+ in the country. These and related analyses can be used in national planning, including in the development of Panama's a National REDD+ Strategy.

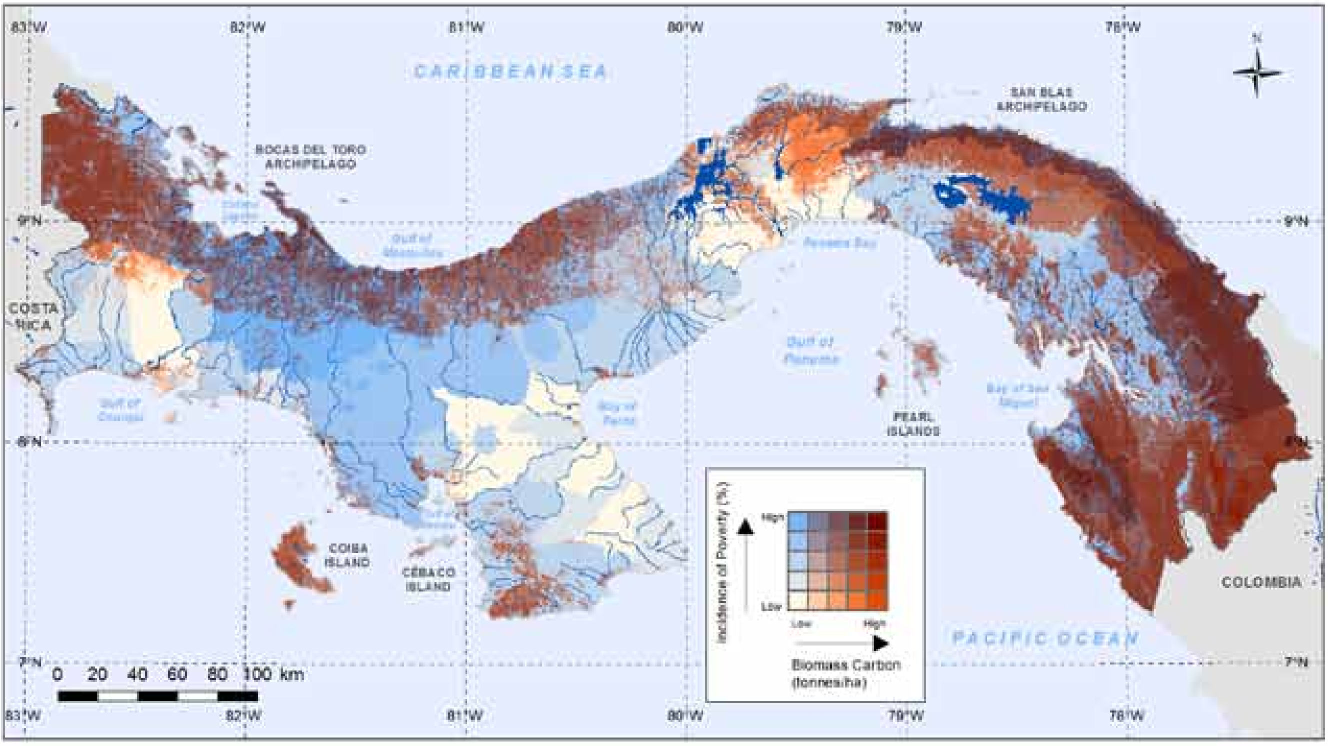
The maps presented in this report are a way of making available to planners information on locations where the potential for multiple social and environmental benefits may make reducing deforestation a priority for REDD+ action. Similar analytical approaches can also be used to identify areas that might be priorities for forest restoration in the context of REDD+. In combination with information on costs of implementation, such information can help to assess more thoroughly the potential gains from REDD+ action in relation to the costs of REDD+. Indeed, in addition to multiple benefits and risks, an important criterion in REDD+ planning will be the relative costs of different actions (see, for example, World Bank 2011). Related work on opportunity costs in Panama has sought to provide the information necessary for an overview of the value of forest multiple benefits in three regions in Panama.

Both the results presented in this report and the results of a cost assessment of REDD+ in Panama form the basis of a spatial decision support tool that is currently in development for Panama. The deforestation model results can be used to identify areas where biomass carbon is at risk under various scenarios. Together with the cost data and an estimate of the potential monetary benefits of REDD+ based on possible carbon-related income, it should be possible to assess where REDD+ might be viable in purely monetary terms, and place these in the context of the social and environmental benefits that might result. It should then be possible to use areas identified as of high importance for biodiversity and ecosystem services as a basis for determining the costs, if any, of attaining additional benefits.

As more and better data becomes available, the spatial analyses for Panama presented here should be updated and extended accordingly to provide better support for planning, including at sub-national scale. Additional data are needed to assess the potential for other REDD+ activities (i.e. reducing degradation, sustainable management of forests and forest carbon stock enhancement). For example, it would be useful to have data on areas where forest has been or is being degraded, and more detailed data on land use. Both historical forest cover and current land use can be used to assess realistic potential for forest restoration. Spatial data on areas of importance for additional ecosystem services, such as the provision of non-timber forest products, as well as data on their perceived value to people, would help to extend the analysis of forest values. Finally, maps addressing similar questions could be

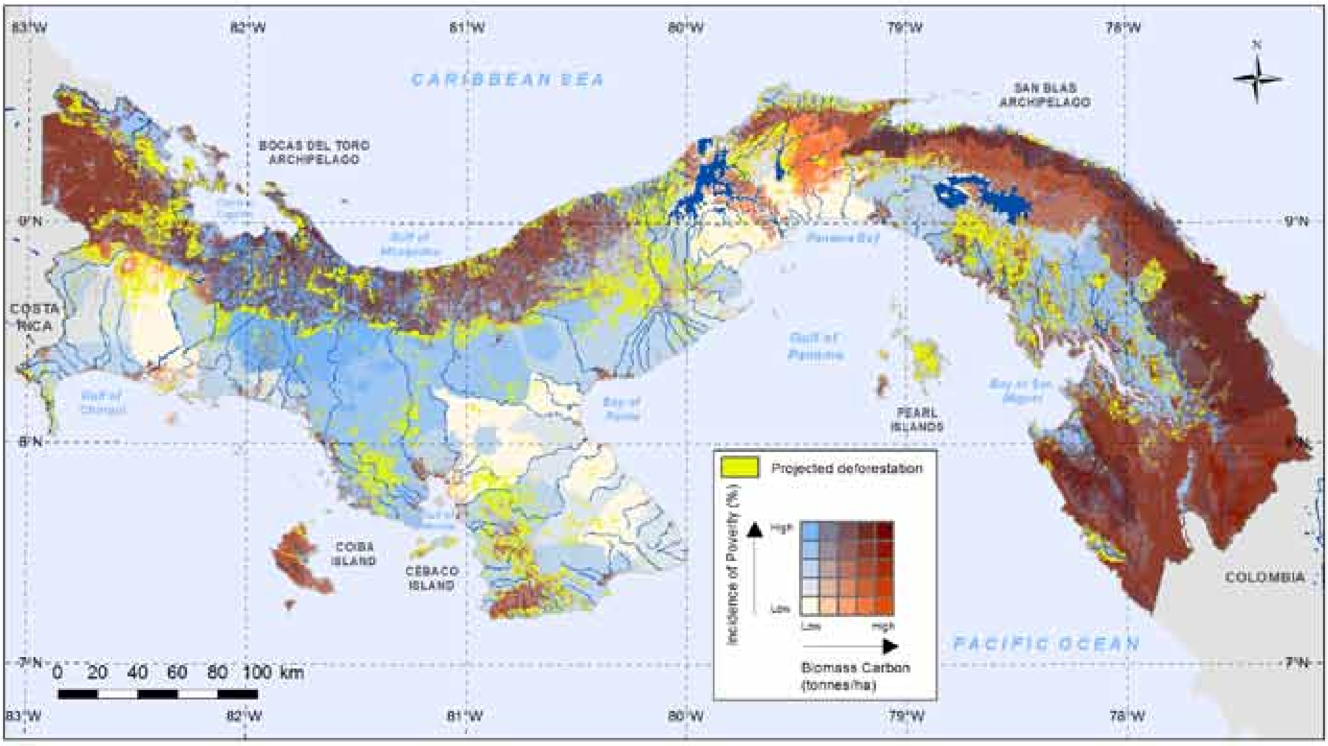
Map 15a. Incidence of poverty in relation to biomass carbon

REDD+ efforts in areas of high poverty need to be designed with particular care and attention to the needs of the poor, and the potential benefits and risks to local livelihoods. Dark brown areas on the map highlight areas high in biomass carbon that are also areas of high poverty, while areas low in biomass carbon but with a high incidence of poverty are light blue. Areas high in biomass carbon but low in poverty are orange.



Map 15b. Incidence of poverty in relation to biomass carbon and modelled deforestation risk

Here, areas of high deforestation risk (in yellow, from Map 11) have been overlaid on the previous map, 15a. Together, these maps can identify areas where reducing deforestation may be a priority.



Methods and data sources:
Biomass Carbon: Asner, G., Mascaro, J., Anderson, C., Knapp, D., Martin, R., Kennedy-Bowdoin, T., van Breugel, M., Davies, S., Hall, J., Muller-Landau, H., Potvin, C., Sousa, W., Wright, J., and Bermingham, E. (2013) High-fidelity national carbon mapping for resource management and REDD+. Carbon Balance and Management 8:7. http://www.cbmjournal.com/content/8/1/7. Ecosystem-specific conversion factors (IPCC 2006) were used to add below-ground carbon to this map.
Poverty: Incidence of poverty in Panama per province (%). Dirección de Administración de Sistemas de Información Ambiental de la Autoridad Nacional del Ambiente (ANAM) y Ministerio de Economía y Finanzas (MEF) (2008).
Projected Deforestation (2008 – 2028): See Map 11 for method description. CATIE (2013). Análisis de cambio de uso de la tierra (1992 – 2008) y formulación de escenarios de deforestación futura de los bosques de Panamá. Turrialba, Costa Rica: Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). This map features the probability of deforestation outputs from the DINAMICA-

developed for sub-national planning, depending on the availability of appropriate data.

Decision support tools that combine spatial analyses identifying areas important for multiple benefits with cost assessments of REDD+ under varying scenarios can help decision-makers to target REDD+ actions in Panama in a cost-effective way that ensures multiple environmental and socioeconomic benefits, while avoiding potential risks.

Annex I. Generation of the biomass carbon map for Panama

Asner et al. (2013) used extensive airborne LiDAR (Light Detection and Ranging) surveys combined with field verification to produce the most detailed map to date of above-ground biomass carbon stocks in Panama. Their study focused exclusively on above-ground biomass carbon density of standing trees ≥10 cm in diameter, excluding below-ground carbon, necromass, lianas and small woody plants. Top-of-canopy height (TCH) LiDAR data measured at a 1.1 m spatial resolution was calibrated with field-based above-ground carbon density estimates in 228 field plots ranging in size from 0.1–0.36 ha, across a range of vegetation types. Airborne LiDAR sampling transects were selected to match the planned national forest inventory plot network, to be installed in the coming years by the United Nations Food and Agricultural Organization (FAO).

For the purposes of this study, below-ground biomass carbon was added to the Asner et al. (2013) map by applying root-to-shoot ratios to the above-ground carbon values as recommended by the Intergovernmental Panel on Climate Change (IPCC 2006). The national land cover map (CATHALAC 2011) was used as a basis for identifying the ecosystem-specific ratios, which were applied to generate a map of total biomass carbon that includes both above-ground and below-ground stocks. The data presented in Map 3 has been divided using a "quantile" classification scheme, where each class contains the same number of features, covering a similar proportion of the area of the map.

Annex II. Evaluation of the importance of forest for soil stabilization

To evaluate the importance of forests for soil stabilization and limiting soil erosion, the analysis presented here evaluates the relative importance of forest as a function of slope, rainfall and the presence of a feature downstream used by humans, that could be adversely affected by soil erosion, such as a dam or water body.

This method uses an overlay approach, where data on mean precipitation (Panama wet season average mm May to August), is combined with data generated for slope and upstream catchments of dams and lakes. This is then combined with forest cover data. This process involves the generation of single layers with three classes (low, medium and high) for mean precipitation (109–240 mm; 241–313 mm; 314–459 mm, natural breaks classification) and for slope steepness (0–4°; 4–16° and >16°, manual classification). A binary layer is generated for the presence or absence of a dam and/or lake catchment. These are then combined additively. Since there are three classes for slope (1–3), three classes for mean precipitation (1–3) and two for the presence or absence of a dam catchment (0–1), the resulting output has a maximum value of 8, and a minimum value of 2, and therefore seven classes. These classes represent a low to high potential importance of forests for soil stabilization and limiting soil erosion. Highest values represent higher erosion impact in the absence or degradation of forests. No weighting is used in this approach; the relative importance of high precipitation is the same as that for steep slopes.

Annex III. Forest areas of potential importance for multiple benefits of REDD+

Drawing on Maps 3, 6, 8 and 9, it is possible to identify areas important for various combinations of potential benefits; darker shading indicates areas important for a higher number of these benefits (maximum four).

The benefits are: the conservation of (a) areas containing high biomass carbon; (b) Key Biodiversity Areas; (c) forest areas identified as having high importance for soil erosion control; and (d) forest within areas containing sites of importance for eco, active/adventure or scientific tourism. To create this map, the following elements were combined:

- **Carbon:** The top two classes of biomass carbon, "medium high" and "high" (≥68 tonnes/ha, see Map 3), were used to represent areas of highest importance for carbon.
- **Biodiversity:** Key Biodiversity Areas (KBAs) of the world were used to create a binary layer of presence or absence of a KBA.
- **Soil erosion:** The relative importance of forest has been evaluated as a function of slope, rainfall and the presence of something important downstream that could be adversely affected by soil erosion (dams and lakes). The top three classes from

Map 8 have been used to identify areas of greatest importance here.

- **Tourism:** Destinations highlighted as containing sites important for eco, active/adventure and scientific tourism as generated by Panama's Tourism Master Plan (2007–2020) were used to create a binary layer of importance.

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

References

ANAM 2011a. A*tlas Ambiental de la República de Panamá. Panamá City: Autoridad Nacional del Ambiente*. Web. http://www.somaspa.org/noticias/Atlas_Ambiental.pdf

ANAM 2011b. *Panamá: Segunda Comunicación Nacional ante la Convención de las Naciones Unidas sobre el Cambio Climático*. Panamá City: Autoridad Nacional del Ambiente. Web. 5 Nov. 2013. <http://unfccc.int/resource/docs/natc/pannc2.pdf>.

Arias García, M. 2004. *Forests, indigenous peoples, and forestry policy in Panama: an assessment of national implementation of international standards and commitments on traditional forest related knowledge and forest related issues*. Fundación para la Promoción del Conocimiento Indígena de Panamá. Web. 6 Nov. 2013. <http://binal.ac.pa/panal/downloads/fipdoc.pdf>.

Asner, G.P., Mascaro, J., Anderson, C., Knapp, D.E., Martin, R.E., Kennedy-Bowdoin, T., van Breugel, M., Davies, S., Hall, J.S., Muller-Landau, H.C., Potvin, C., Sousa, W., Wright, J. and Bermingham, E. 2013. High-fidelity national carbon mapping for resource management and REDD+. *Carbon Balance and Management* 8.1: 1–14.

Baccini, A., Goetz, S.J., Walker, W.S., Laporte, N.T., Sun, M., Sulla-Menashe, D. , Hackler, J., Beck, P.S.A., Dubayah, R., Friedl, M.A., Samanta, S. and Houghton, R.A. 2012. Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change* 2: 182–185. Web. <http://dx.doi.org/10.1038/NCLIMATE1354>.

BirdLife International. 2008. What are Key Biodiversity Areas? Presented as part of the BirdLife State of the world's birds website. Web. 11 Nov. 2013. <http://www.birdlife.org/datazone/sowb/casestudy/88>.

Blyth, S., Ravilious, C., Purwanto, J., Epple, C., Kapos, V., Barus, H., Afkar, H., Setyawan, A. and Bodin, B. 2012. *Using spatial information to promote multiple benefits from REDD+ in Indonesia. A compendium of maps for Central Sulawesi Province*. Cambridge, UK: UNEP-WCMC. Web. 12 Nov. 2013. <http://www.un-redd.org/MultipleBenefitsPublications/tabid/5954/Default.aspx>.

CATIE. 2013. Análisis de cambio de uso de la tierra (1992 – 2008) y formulación de escenarios de deforestación futura de los bosques de Panamá. Turrialba, Costa Rica: Centro Agronómico Tropical de Investigación y Enseñanza.

CATHALAC (The Water Centre of the Humid Tropics of Latin America and the Caribbean). 2011. National dataset of 2008 land cover based on Landsat data. http://www.cathalac.org/en/

Condit, R., Robinson, W.D., Ibáñez, R., Aguilar, S., Sanjur, A., Martínez, R., Stallard, R.F., García, T., Angehr, G.R., Petit, L., Wright, S.J., Robinson, T.R. and Heckadon, S. 2001. The status of the Panama Canal Watershed and its biodiversity at the beginning of the 21st Century. *BioScience* 51.5: 389–398.

Condit, R., Pérez, R. and Daguerre, N. 2011. *Trees of Panama and Costa Rica*. Princeton, NJ: Princeton University Press.

Correa, M. D., Galdames, C. and de Stapf, M. S. 2004. *Catálogo de las Plantas Vasculares de Panamá*. Smithsonian Tropical Research Institute, Panama.

Eken, G., Bennun, L., Brooks, T.M., Darwall, W., Fishpool, L.D.C., Foster, M., Knox, D., Langhammer, P., Matiku, P., Radford, E., Salaman, P., Sechrest, W., Smith, M.L., Spector, S. and Tordoff, A. 2004. Key biodiversity areas as site conservation targets. *BioScience* 54: 1110–1118.

Falla, A. 1978. Plan de desarrollo forestal Parte III: Política y proyectos propuestos para el desarrollo forestal. Rome: FAO.

FAO. 2010. *Evaluación de los recursos forestales mundiales 2010: Informe nacional Panamá*. FAO Forest Department. Web. 15 Nov. 2013. <http://www.fao.org/docrep/013/al595S/al595s.pdf>.

Gamfeldt, L., Snäll, T., Bagchi, R., Jonsson, M., Gustafsson, L., Kjellander, P., Ruiz-Jaen, M.C., Fröberg, M., Stendahl, J., Philipson, C.D., Mikusinksi, G., Andersson, E., Westerlund, B., Andrén, H., Moberg, F., Moen, J. and Bengtsson, J. 2013. Higher levels of multiple ecosystem services are found in forests with more tree species. *Nature Communications*. 4: 1340.

Web. 12 Nov. 2013. <http://www.nature.com/ncomms/journal/v4/n1/abs/ncomms2328.html>.

Garver, R. D. 1947. *National survey of the forest resources of the Republic of Panama*. Washington, DC: State Department.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., Townshend, J.R.G. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* 342.6160 (2013): 850–853.

Holdridge, L.R., Grenke, W.C., Hatheway, W.H., Liang, T. and Tosi, J.A. *Forest environments in tropical life zones: a pilot study*. New York: Pergamon.

Ibanez, R., Condit, R., Angehr, G., Aguilar, S., Garcia, T., Martinez, R., Sanjur, A., Stallard, R., Wright, S.J., Stanley, Rand, A.S., Heckadon, S. 2002. An ecosystem report on the Panama Canal: Monitoring the status of the forest communities and the watershed. *Environmental Monitoring and Assessment* 80: 65–95.

Instituto Panameño de Turismo. 2008. *Sustainable Tourism Master Plan of Panama 2007–2020.* Panama City: Instituto Panameño de Turismo.

IPCC. 2006. *IPCC Guidelines for National Greenhouse Gas Inventories.* National Greenhouse Gas Inventories Programme. Japan: Institute for Global Environmental Strategies.

IPCC. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IUCN. 2013. Red List overview. The IUCN Red List of Threatened Species. Last accessed 10 November 2013. Web. <http://www.iucnredlist.org/about/red-list-overview>.

Jaén, E. and Shirota, R. 2011. Valoración económica del servicio ambiental de reducción de sedimentos de los bosques de la cuenca hidrográfica del Canal de Panamá. Unpublished. http://www.fao.org/fileadmin/user_upload/training_material/docs/EJN%20-%20VE%20Bosques%20Canal%20de%20Panam%C3%A1.pdf

Lawlor, K., Myers Madeira, E., Blockhus, J. and Ganz, D.J. 2013. Community Participation and Benefits in REDD+: A Review of Initial Outcomes and Lessons. *Forests* 4.2: 296–318.

Miguel, P. 2010. *Informe del Programa de Sedimentos Suspendidos Periodo 1998–2007.* Autoridad del Canal de Panama, Departamento de Ambiente, Agua y Energía, División de Agua Sección de Recursos Hídricos Unidad de Hidrología Operativa.

Millennium Ecosystem Assessment (MEA). 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis*. Washington, DC: World Resources Institute.

Moreno, S.H. 1993. Impact of Development on the Panama Canal Environment. *Journal of Interamerican Studies and World Affairs* 35.3: 129–149.

Ruesch, A. and Gibbs, H. 2008. *New IPCC Tier-1 Global Biomass Carbon Map for the Year 2000.* Carbon Dioxide Information Analysis Center Oak Ridge, Tennessee: Oak Ridge National Laboratory. Web. 5 Nov. 2013. <http://cdiac.ornl.gov>.

Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T., Salas, W., Zutta, B.R., Buermann, W., Lewis, S.L., Hagen, S., Petrova, S., White, L., Silman, M. and Morel, A. 2011. Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences* 108.24: 9899–9904.

Springate-Baginski, O. and Wollenberg, E. 2010. *REDD, forest governance and rural livelihoods: the emerging agenda*. Bogor, Indonesia: CIFOR.

Sunderlin, W.D., Dewi, S., Puntodewo, A., Müller, D., Angelsen, A. and Epprecht, M. 2008. Why Forests Are Important for Global Poverty Alleviation: a Spatial Explanation. *Ecology and Society* 13.2: 24. Web. 12 Nov. 2013. <http://www.ecologyandsociety.org/vol13/iss2/art24/>.

Trumper, K., Bertzky, M., Dickson, B., van der Heijden, G., Jenkins, M. and Manning, P. 2009. *The Natural Fix? The role of ecosystems in climate mitigation. A UNEP rapid response assessment.* United Nations Environment Programme. Cambridge, UK: UNEP-WCMC.

Walker, W., Baccini, A., Nepstad, M., Horning, N., Knight, D., Braun, E. and Bausch, A. 2011. *Field Guide for Forest Biomass and Carbon Estimation. Version 1.0.* Falmouth, MA: Woods Hole Research Center.

World Bank. 2009. Panama: Country Note on Climate Change Aspects in Agriculture. December 2009. Web. <www.worldbank.org/lacagccnotes>.

World Bank. 2011. *Estimating the opportunity costs of REDD+: A training manual.* Version 1.3. Washington, DC: World Bank.