Using spatial analysis to support REDD+ land-use planning in Papua New Guinea

Strengthening benefits for biodiversity, ecosystem services and livelihoods

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

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DISCLAIMER

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Using spatial analysis to support REDD+ land-use planning in Papua New Guinea

Strengthening benefits for biodiversity, ecosystem services and livelihoods

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Contents

Key messages

Papua New Guinea's forests are under threat

Papua New Guinea (PNG) is one of the most densely forested countries in the world. These forests provide vital ecosystem goods and services for the more than 85% of the population based in rural areas. However, there is a considerable threat of deforestation and forest degradation. Trends of deforestation and forest degradation are likely to continue in the future, unless underlying drivers are addressed as part of PNG's approach to REDD+.

REDD+ can provide benefits beyond carbon

While the main purpose of REDD+ is to contribute to climate change mitigation, it can also deliver additional benefits by protecting forest livelihoods, biodiversity and ecosystem services. Recognizing this, PNG aims to strengthen the conservation of biodiversity and ecosystem services while ensuring forests are used in a sustainable and equitable manner. This will also contribute to progress towards other policy goals, including the UN Sustainable Development Goals.

Maps can support the consideration of these benefits in REDD+ decision making

Different forests have different values to people: for example, the most important forests for wildlife conservation may not be the most important for water regulation. Mapped information can help to understand better this heterogeneity to inform land-use planning. However, the availability of this type of information is often limited. This report presents maps that can help understand the distribution of forest values such as climate change mitigation, biodiversity conservation, soil erosion control, nature-based tourism and landslide risk reduction. By combining these maps, it is possible to highlight areas where REDD+ activities could bring about the greatest benefits.

The forests of PNG offer a high potential for the provision of those benefits

The maps produced in this report show that forests in PNG are vast carbon sinks. Analyses identify areas of high biodiversity value in the central montane areas and the islands of New Britain, Bougainville and Manus. Some of these areas may provide opportunities for the promotion of nature-based tourism as well. The analyses also assessed the role of forests in controlling soil erosion and reducing landslide risk, identifying key areas for the provision of those benefits in the central cordillera, Morobe and New Britain. Future deforestation or forest degradation in those areas due to logging, or conversion to palm oil plantations may pose a significant risk to community livelihoods. These results could serve as a useful guide for targeting priority areas for REDD+ implementation.

This project contributed to raise national technical capacity in spatial analysis and planning

Some of the analyses presented here were developed by national technicians in joint working sessions. This contributed to building national capacity in spatial analysis, access to relevant datasets and the use of decision support tools. As more and better data becomes available, the analyses presented here could be updated to provide better support for planning, including at sub-national scale. We encourage follow-up work to build on the analyses presented here and to capitalize on the enhanced in country capacity for spatial analysis for evidence-based decision-making.

1. Introduction

Papua New Guinea (PNG) hosts one of the largest areas of intact tropical forest in the world. The extremely wide rainfall and altitudinal gradients present in the country ensure a continuous yet heterogeneous forest cover from the lowlands to its natural limits at about 3,700 m. As a result of this extent and diversity, PNG's forests are globally renowned for their high levels of biodiversity and endemism (Laurence et al. 2012). Along with Western New Guinea, it is estimated that it hosts more than 6% of the world's known land species, around half of which are endemic (Papua New Guinea Department of Conservation, 2014).

With over 85% of the human population based in rural areas and in close relationship with forests, PNG's forests also provide ecosystem services critical for people's livelihoods, including regulating hydrological flows, supplying clean water, protecting soils, providing food, medicine and forests products, and serving cultural and spiritual purposes. As a major carbon store and sink for carbon dioxide from the atmosphere, forests also play a crucial role in climate regulation (IPCC, 2013). However, ongoing drivers of deforestation and forest degradation, linked to rapid economic growth in PNG in recent years, have caused an increase in greenhouse gas (GHG) emissions and threaten the future provision of ecosystem services. This loss of forests and their services can limit the capacity of local communities to adapt to the negative impacts of climate change.

In order to reverse this trend, PNG has committed to a low-carbon sustainable development pathway (Department of National Planning and Monitoring, 2014), aiming to achieve stronger long-term economic growth while ensuring that natural resources are managed in a sustainable and equitable manner for future generations. The global initiative on Reduced Emissions from Deforestation, forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+) under the UN Framework Convention on Climate Change (UNFCCC), represents an opportunity to address forest loss while supporting the transition towards a more sustainable, low-carbon development pathway (Figure 1). PNG's National REDD+ Strategy, which was endorsed by the Government on 5th May 2017, provides a strategic direction for this opportunity, within the broader context of PNG's national development objectives and goals.

While the main purpose of REDD+ is to contribute to climate change mitigation, it is widely recognised that it also has the potential to deliver additional social and environmental benefits, such as conservation of biodiversity and ecosystem services and/or promoting local livelihoods. Recognizing this, PNG's vision for REDD+ states that it aims to strengthen "*long term economic growth and community livelihoods and the effective conservation of biodiversity and ecosystem services while ensuring*

Figure 1: REDD+ activities under UNFCCC

REDD+ =

Reducing Emissions from Deforestation and forest Degradation

+

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

that Papua New Guinea's forest resources are used in a sustainable and equitable manner for the benefit of current and future generations" (Government of Papua New Guinea, 2017a). The National REDD+ Strategy also recognizes the potential of REDD+ to contribute to progress towards other existing goals, such as the UN Sustainable Development Goals (particularly, SDG13 and SDG15).

However, REDD+ also carries potential risks. For example, pressures on forests may be merely displaced from one area to another, or local communities' access rights to forests may be reduced as part of REDD+ implementation. The UNFCCC asks countries to promote and support the Cancun safeguards (Decision 1/CP16, Appendix 1)[1] which have been specifically developed to encourage benefits and address potential risks of REDD+. A REDD+ implementation that delivers social and environmental benefits and avoids social and environmental risks can, therefore, contribute to a range of policy goals beyond climate change mitigation, making REDD+ efforts more sustainable in the long-term.

Among other measures, PNG's National REDD+ Strategy aims to strengthen national and sub-national land-use planning through the zoning of lands according to their environmental and development priorities, in a way that is "*both consistent with and able to promote the concepts of the National Strategy for Responsible Sustainable Development for Papua New Guinea*" (StaRS) (Government of Papua New Guinea, 2017a).

This report shows how spatial analyses can be used as a tool to support this objective. The maps included here are designed to help support the explicit consideration of social and environmental benefits in REDD+ decision making in PNG, with a focus on three provinces prioritized for pilot REDD+ implementation: Madang, East New Britain and West New Britain. The aim is to contribute to an analysis of REDD+ potential that takes into account the conservation of natural forest, biodiversity and the multiple functions of forest, especially with regard to PNG's priorities for benefits from REDD+. The analyses presented here may contribute to the planning and implementation of REDD+ pilot activities and harmonization of REDD+ policies with other national development policies and plans.

This report first presents maps that can be used to understand the potential distribution of individual environmental and social benefits of REDD+ in PNG, including through examining the role of forests in mitigating climate change, supporting biodiversity conservation, soil erosion control, nature-based tourism and reducing natural hazards, such as landslide risk. These data layers are then combined to identify areas where action to conserve forests could deliver the greatest potential benefits overall. Further analyses demonstrate how spatial analysis can be used to support the development of more sustainable commercial agriculture, focusing on oil palm expansion. These maps aim to inform REDD+ implementation in PNG and can also serve as a basis for future more detailed analysis with improved datasets, or similar analyses in different parts of PNG.

2. Forests in Papua New Guinea

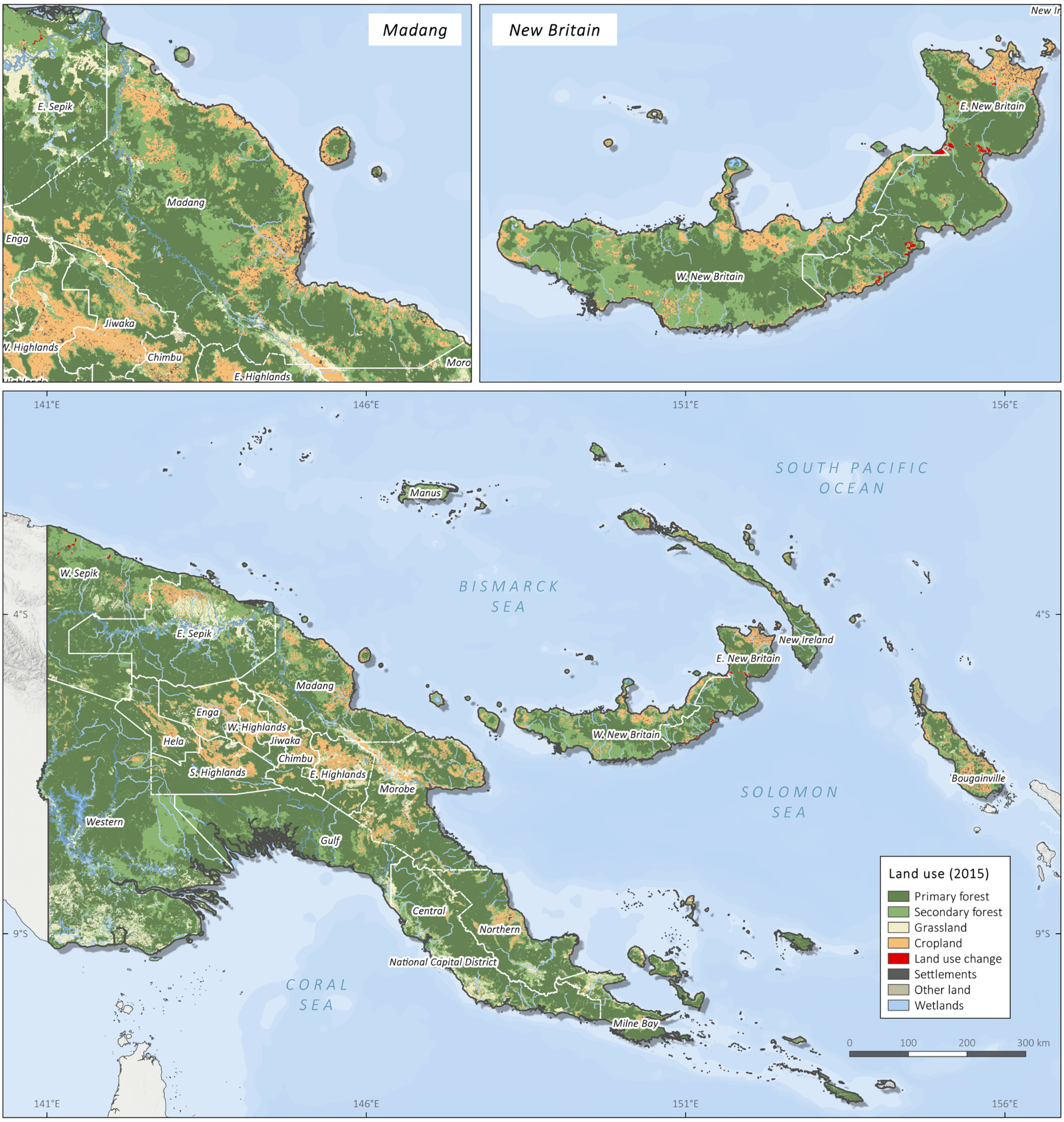
With an estimated forest cover of approximately 78% of the country's 46.9m ha of land, PNG is one of the most densely forested countries in the world (Government of Papua New Guinea, 2017a). As a consequence of rugged topography, with a number of peaks reaching at least 4,000 m altitude, PNG forests are highly diverse, ranging from different types of rainforests, mangroves, swamp forests and dry evergreen forests (Bryan and Shearman, 2015). This diversity in forest types both reflects and is a factor in determining PNG's significant plant diversity.

Primary rainforest is the most widespread ecosystem in the country (Map 1). It is mostly found among the mainland coastal provinces, and to a lesser degree, the highland and island provinces (Bryan and Shearman, 2015). Rainforests can be classified, based on their altitude range, into: lowland forests (below 1,000 m altitude), lower montane forests (1,000 to 2,800 m altitude) and montane forests (above 2,800 m altitude) (Shearman et al. 2008). Secondary forests, which are disturbed rainforests that have experienced commercial logging and/or low intensity burning, are mostly found in the lowlands, which are more accessible to people. Swamp forests occur in PNG's lowland and coastal areas, close to water courses in flat areas that are permanently or seasonally flooded in East and West Sepik and Western and Gulf provinces. Dry evergreen forests are located almost exclusively in the Western province, to the south-west of the lower Fly river (Shearman et al. 2008). Mangrove forests are widely distributed in all coastal provinces, with the most extensive areas located in the Gulf and Western provinces (Shearman et al. 2008). Much of the remaining land area has been converted to cropland, used for settlements or infrastructure.

[1] *https://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf*

All these forests play a key role in the country's ecology and economy, providing vital ecosystem services such as watershed protection, water filtration, soil stability and fertility, suitable agricultural land, protection against flash flooding and landslides, and carbon sequestration (Government of Papua New Guinea, 2017a; Sherman et al. 2008). Furthermore, forests provide cultural services and vital resources to local populations such as food and building materials (Sherman et al. 2008). More than 500 wild plant species are used for food, and if bush meat consumption were replaced with farmed meat, the estimated cost to the consumer would be $26 million (Government of Papua New Guinea, 2017a). The diversity of tree species and variety of services provided by forests not only heighten the importance of actions to conserve these areas, but also the importance of reducing any unintended impacts of REDD+ interventions on ecosystem services and biodiversity conservation.

Map 1: How are land uses and land covers distributed in Papua New Guinea?



Data sources:

CCDA (2015). *TerraPNG landuse and landcover base map.* Climate Change and Development Authority. Government of Papua New Guinea. Port Moresby. Papua New Guinea.

Over 90% of PNG's territory is under customary land ownership (Government of Papua New Guinea, 2017a). Customary land is held by tribes, clans and other communal groups, and its ownership is dictated by local customs and traditional values, and protected by the country's national constitution (Karigawa et al. 2016). This may represent a hurdle for logging and other extractive industries operating in PNG, as permission from traditional landowners is required prior to any commercial exploitation (Fingleton, 2004). In addition, considerable parts of the country are judged to be physically inaccessible to many large-scale resource exploitation activities (Laurence et al. 2012). As a consequence, it is estimated that over 60% of existing forest remains relatively intact (Government of Papua New Guinea, 2017b).

While large areas of forest remain, considerable threats from deforestation and forest degradation exist (Government of Papua New Guinea, 2017a). This pressure varies amongst the different forest types, with the more accessible lowland areas being amongst the most deforested and threatened (Bryan and Shearman, 2015). Some of the main drivers of deforestation and forest degradation include expansion of industrial logging and conversion of forested area to smallholder or large-scale agriculture (Government of Papua New Guinea, 2017a). It is estimated that a total of 261,528 ha of forest (0.7%) was lost between 2000 and 2015, contributing to average emissions of 5 $MtCO_2e$ per annum (Government of Papua New Guinea, 2017a). Agricultural expansion accounts approximately for 87% of this loss. Of this, subsistence shifting agriculture, the main form of farming in the country, is responsible for 63%, while oil palm cultivation accounts for 30% of the deforested land (Government of Papua New Guinea, 2017b). Forest degradation, on the other hand, is primarily driven by commercial logging, with an estimated total of about 2.5 M ha of forest (6.7%) being degraded between 2000 and 2015, contributing to an average emissions of over 25 $MtCO_2e$ per annum (Government of Papua New Guinea, 2017a). These trends are likely to continue in the future, unless underlying drivers of deforestation and forest degradation are addressed as part of PNG's approach to REDD+ (Government of Papua New Guinea, 2017a).

3. Spatial analysis of potential social and environmental benefits of REDD+

The maps included in this section provide examples on how spatial analysis can support planning of strategy options to enhance benefits such as the effective conservation of biodiversity and ecosystem services, by identifying areas where the provision of such benefits is high. The results of this exercise could serve as a useful guide for targeting priority areas for a REDD+ implementation that delivers benefits beyond carbon storage and sequestration.

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3.1 Climate change mitigation

Forests, in particular tropical forests, are vast carbon stores and sinks (Trumper et al. 2009), immobilizing carbon in their biomass both aboveground (in leaves, branches and stems) and belowground (in roots) (Walker et al. 2011). The tropical forests of PNG are estimated to store around 3% of total global forest carbon (Peck et al. 2017). Furthermore, recent research suggests that intact old-growth tropical forests such as those in PNG may be capturing and storing more carbon than previously thought (Qie et al. 2017).

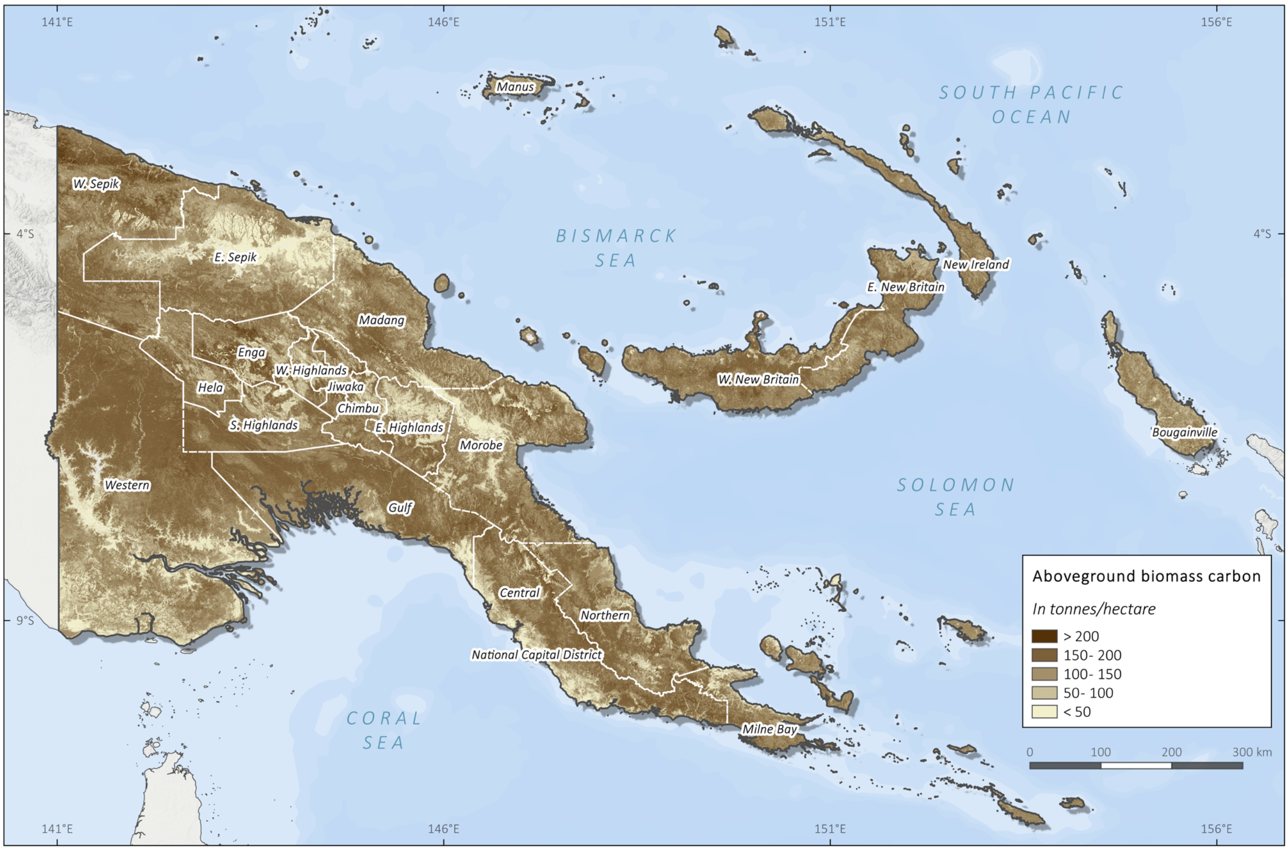
When making decisions on where to focus efforts to reduce the threat of deforestation and forest degradation, it is useful to consider information on where biomass carbon stocks are located and what land-cover change pressures are anticipated over the period of REDD+ implementation. Highly threatened, high carbon forests are likely to be of high priority for REDD+ intervention, especially if the potential provision of other benefits is also high.

Despite multiple studies on PNG forest carbon stocks (Bryan et al. 2010, Fox et al. 2010, Peck et al. 2017, Vincent et al. 2015), estimates have varied. To address this, PNG is currently finalizing its first Multipurpose National Forest Inventory, a major objective of which is the collection of carbon stocks data to accurately estimate GHG emissions from forests and land use changes (Government of Papua New Guinea, 2017b). Until this information becomes available, an initial understanding of the distribution of carbon stocks can be obtained from global and regional maps based on field data and/or remote sensing. Several global and regional scale maps of carbon stocks based on different data sources and methods are available.

Map 2a shows the estimated spatial distribution of aboveground live woody biomass density in PNG for the year 2000 (Baccini et al. 2015). In addition to aboveground biomass, there are other carbon pools, like soil, that store significant amounts of carbon. In PNG, soils could account for up to 50% of the total forest carbon stocks (McIntosh et al. 2016). Map 2b shows organic soil carbon stocks for the first 30 cm soil depth (FAO and ITPS, 2018). In addition, vast amounts of carbon are stored up to several metres deep in the country's peatlands. Having been identified as the most carbon-dense terrestrial ecosystem in the world (Joosten and Couwenberg, 2008; Urák et al. 2017), climate change mitigation potential from peatlands is huge. In New Guinea, peat is found across all altitudes, from mangroves to swamp forests in the lowlands, to montane peat forests and subalpine fens and bogs in montane areas (Hope and Prentice, 2016). Information on peatland distribution and status in PNG is still insufficient and poor, however, preliminary estimates suggest that the island of New Guinea hosts around 10.2 M ha of peatland, containing approximately 9 Gt of carbon (Hope and Prentice, 2016). The maps presented here are intended as a useful interim dataset for decision making until PNG finalizes a nationally validated map of carbon stocks.

Map 2: What is the distribution of biomass carbon and topsoil organic carbon?

Map 2a (top) shows aboveground biomass carbon density at 30 m resolution, based on a pantropical remote sensing-based study by Baccini et al. (2015). Map 2b (below) shows soil organic carbon stocks to a depth of 30 cm, and is based on a global soil organic carbon map developed by the Food and Agriculture Organization of the United Nations (FAO) and the Intergovernmental Technical Panel of Soils (ITPS) (2018).



Data sources:

Aboveground biomass carbon (above): Baccini A., W. Walker, L. Carvahlo, M. Farina, D. Sulla-Menashe, R. Houghton (2017). Tropical forests are a net carbon source based on new measurements of gain and loss. *Science*. Accessed through Global Forest Watch Climate on January 2018. climate.globalforestwatch.org

Topsoil organic carbon (below): FAO and ITPS (2018). Global Soil Organic Carbon Map - GSOCmap. Version 1.2.0. FAO, Rome, Italy. Accessed through http://54.229.242.119/apps/GSOCmap.html on January 2018.

3.2 Biodiversity

Considered as one of the 17 mega-diverse countries of the world (Mittermeier et al. 1997), it is estimated that PNG accounts for more than 6% of the world's species diversity with less than 1% of the world's total landmass (Papua New Guinea Department of Conservation, 2014). PNG is home to approximately 813 species of birds, 298 species of mammals, 352 species of amphibians and 335 species of reptiles, around half of which are endemic (Papua New Guinea Department of Conservation, 2014). PNG is also one of the most diverse countries in terms of flora, with over 11,000 species of vascular plants, including 15% of the world's fern species and 11% of the world's total orchid species (Papua New Guinea Department of Conservation, 2014). Nevertheless, there is a general consensus that the true extent of PNG's biological diversity is still poorly known. Species new to science are frequently discovered: between 1998 and 2008, more than 1,000 species were discovered from the forests, wetlands and waters of the island of New Guinea, including 218 plants, 580 invertebrates, 71 fishes, 132 amphibians, 43 reptiles, 2 birds and 12 mammals (WWF, 2011).

These extraordinary levels of biodiversity are recognised in PNG at many different levels. The national constitution, for instance, declares the conservation and sustainable use of the country's natural resources and environment as one of its four national goals, and calls for "*all necessary steps to be taken to give adequate protection to our valued birds, animals, fish, insects, plants and trees*". In line with this, PNG ratified the UN Convention on Biological Diversity in 1993 and, more recently, the National Strategy on Responsible and Sustainable Development (StaRS) recognised forests and biodiversity as one of seven national key strategic assets (Department of National Planning and Monitoring, 2014). Finally, the National REDD+ Strategy recognises the conservation of biodiversity as one of main REDD+ benefits and considers it as an asset to contribute to progress towards the UN Sustainable Development Goals (SDGs) (Government of Papua New Guinea, 2017a).

However, as a consequence of the land-use change connected to PNG's rapid economic growth in recent years, this wealth of biodiversity faces a growing threat (Papua New Guinea Department of Conservation, 2014). Major threats to biodiversity in the country include logging, clearing and degradation of land for agriculture and mining, environmental pollution, as well as invasive species (Adams et al. 2017). As a consequence, it is estimated that PNG's rate of biodiversity loss is one of the highest in the world (Waldron et al. 2017).

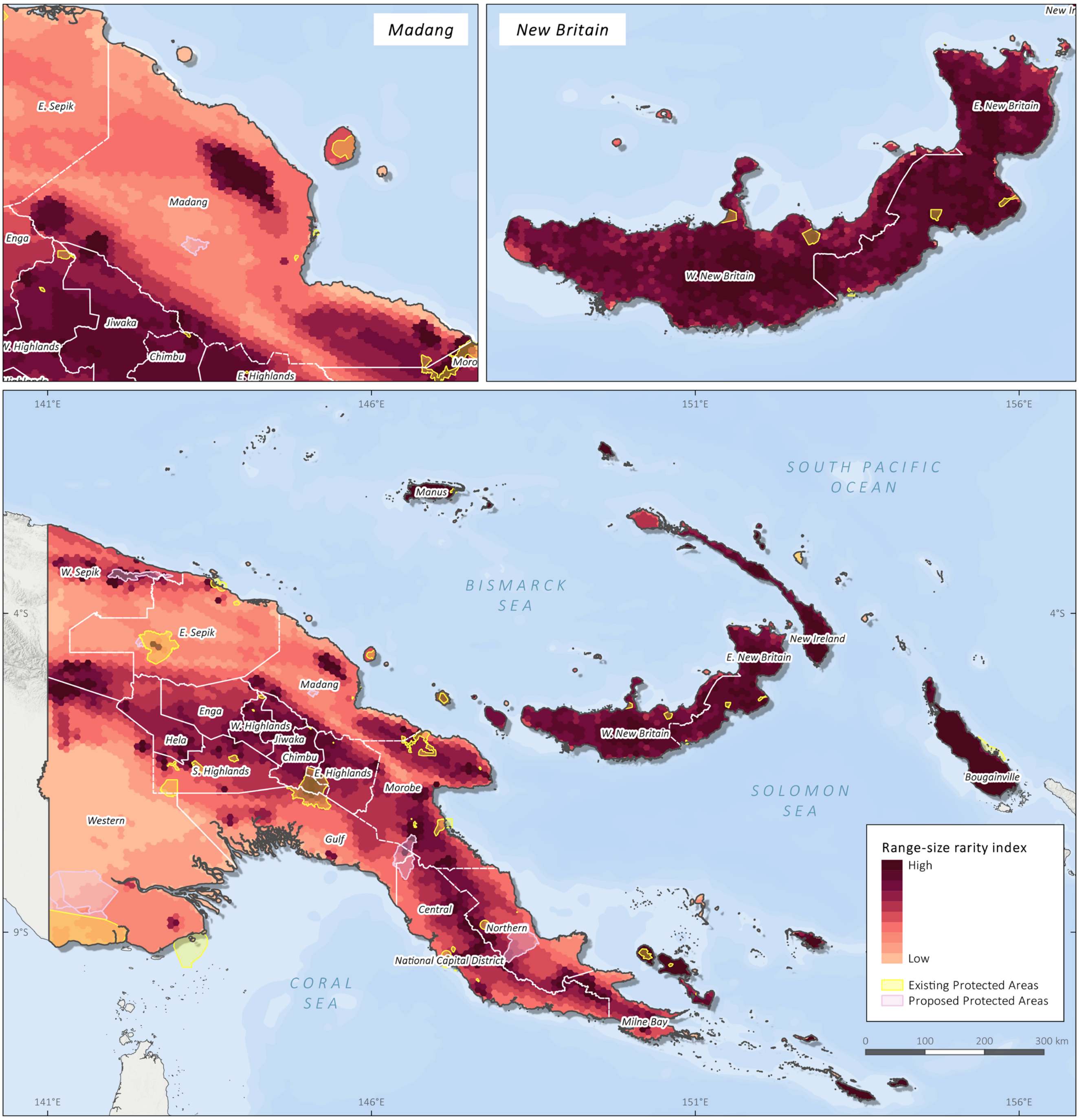
REDD+ actions can provide additional benefits for biodiversity conservation, if efforts to maintain natural forest are prioritized in areas of high biodiversity value and/or in their surroundings, where such efforts can contribute to creating buffer zones or maintaining connectivity with other forests. Restoration of degraded forests in these areas using appropriate methods (such as 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.

By its very nature, the diversity of living things is difficult to capture in a single indicator or map. 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 areas that have been protected for their biodiversity value, particular ecosystems, overall measures of species richness or species of conservation concern. Species endemism is considered an important indicator of the biological value of a specific area, as endemic species are by definition found nowhere else. Determining patterns of endemism combined with species richness can therefore be a useful indicator of the conservation value of an area (Kier and Barthlott, 2001). Given the abundance of range-restricted species and thus high level of endemism in PNG, it is particularly important to consider not only species richness but also endemism values.

Map 3 provides an initial basis for identifying priority areas for providing biodiversity benefits from REDD+ implementation, by showing areas of importance for vertebrate diversity conservation using the range-size rarity index (Kier and Barthlott, 2001). This index was calculated by combining species richness and endemism at a 1 km^2 resolution. For each grid cell, the inverse range sizes of all species occurring in that grid cell was summed. High index values show an area holds a large number of threatened species and/or that the average distribution ranges of the threatened species present in the area are small. The map could, therefore, be suitable for identifying areas where reducing the risks of adverse impacts of deforestation and forest degradation through REDD+ could deliver the greatest biodiversity benefits. It could also be useful for wider conservation planning efforts, such as for further developing the national network of protected areas.

Map 3: Where are the forests with the highest value for conserving vertebrate diversity?

This map shows the range-size rarity index using a regular grid of hexagons of 100 km² size for the national-scale map and 25 km² size for Madang and New Britain. This index combines species richness and endemism based on the distribution of all 1184 forest-based mammals, birds, reptiles and amphibian species native to PNG, as defined by the IUCN Red List of Threatened Species (2017). The areas of the highest conservation value appear to be located in the country's montane areas and in the islands of New Britain, Bougainville and Manus, among others.



Data sources:

Range-size rarity index: Based on the spatial distribution of forest-based mammal, bird, reptile and amphibian species native to PNG classified as threat status 'Critically Endangered', 'Endangered', 'Vulnerable', 'Near Threatened' and 'Least Concern' by the IUCN Red List of Threatened Species (2017). Version 2016.3. http://www.iucnredlist.org. Downloaded in March 2017.

Protected areas: Conservation and Environment Protection Authority (CEPA). Government of Papua New Guinea.

3.3 Soil conservation

Forests, particularly those on slopes, are a major factor in controlling soil erosion because they reduce the impact of raindrops falling on soil as well as the speed of water flowing over the land. Deforestation and forest degradation may diminish the capacity of land to store water, and cause greater surface runoff after heavy rains, with attendant erosion and sedimentation, increasing downstream flood risk and leading to water shortages at other times of the year.

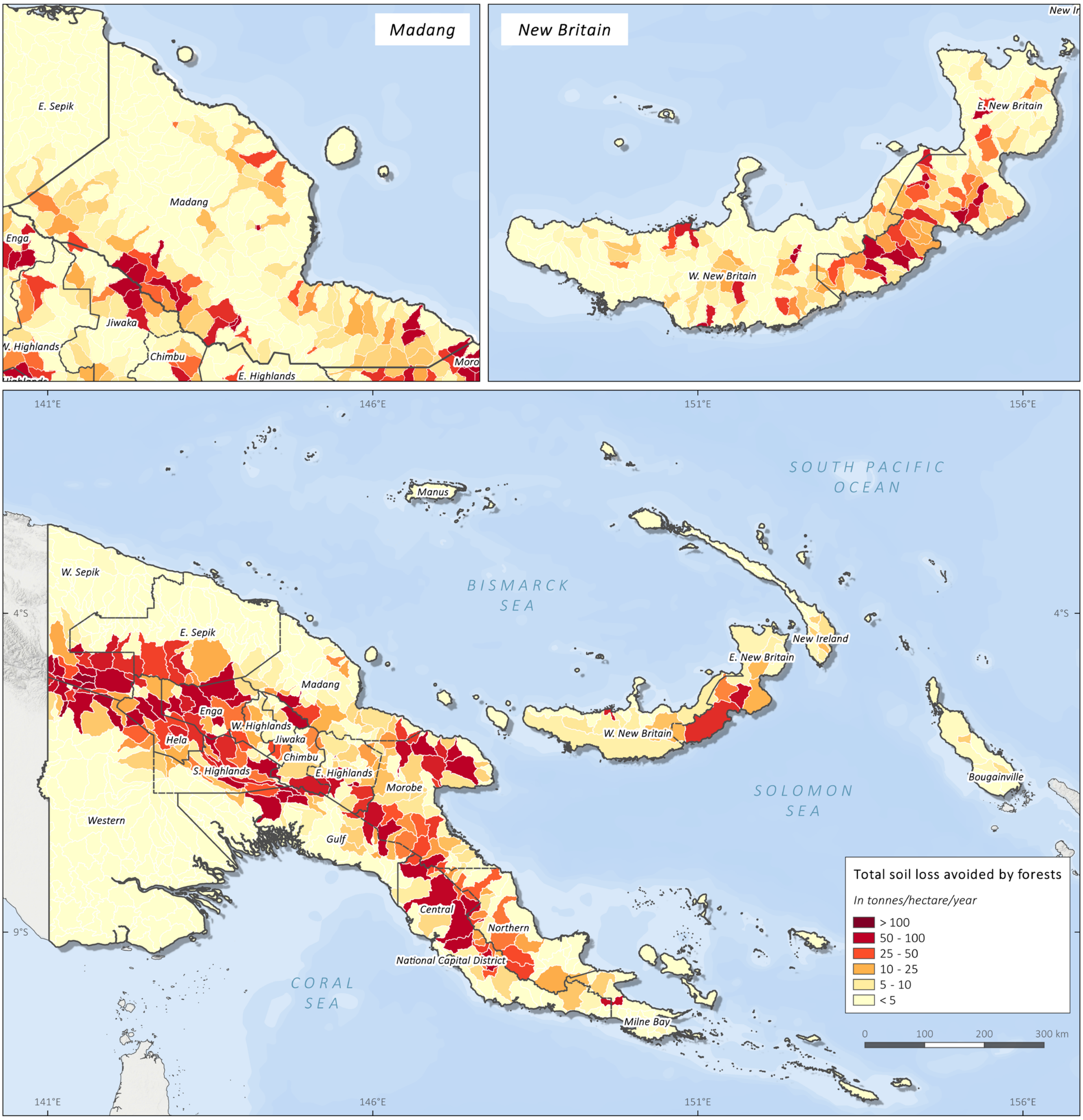
Deforestation and land use change are a serious threat to PNG's soil conservation. The country's landscape is abundant in forested river catchments fed by heavy rainfall. When these areas lose forest cover due to land use change, they become more vulnerable to rainfall, high winds, landslides and floods, leading to soil erosion and changes in soil hydrology (Shearman et al. 2008). Increased soil erosion results in soil particles being carried downstream, contributing also to higher sedimentation in streams and rivers. Sedimentation can impact the local ecosystem as well as limit water supply to local communities.

For this report, the role of PNG's forest in stabilizing soil and limiting soil erosion was modelled using WaterWorld, an open-access, web-based, eco-hydrological modelling tool (Mulligan, 2013).

Map 4 shows the estimated total soil loss avoided because of forests, averaged by water basin. The role of forest in limiting erosion and sedimentation is most critical where high rainfall combines with steep slopes, particularly in the central cordillera. Carefully designed and targeted REDD+ actions may help contribute to soil erosion control in these areas. Further analyses of areas that have lost forest, or that have degraded forest, in catchments where erosion risk is high may help to identify potential locations for forest restoration with additional benefits for the stabilization of soils.

Map 4: Where are the forests with the highest value for controlling soil erosion?

The role of forests in controlling soil erosion in PNG is illustrated here based on the estimated total soil loss avoided because of forest cover. These values were obtained by comparing estimated soil erosion under current forest cover (using land cover data from the MODIS Vegetation Continuous Fields (DiMiceli et al. 2011)) and in the absence of trees. Soil erosion was calculated at 1 km^2 resolution using Thornes (1990) erosion equation. The changes in soil erosion (in mm) were then converted to t/ha, using an average soil bulk density of 1,200 Kg/m^3 and averaged for each river basin. River basins were derived from the Hydrobasins dataset (Lehner and Grill, 2013) using Pfafstetter's level 7 subdivision of basin area (Verdin and Verdin, 1999) for the national-scale map, and level 12 for the maps of Madang and New Britain island.



Data sources:
Modelled in the WaterWorld modelling system (Mulligan, 2013) and aggregated per river basin. River basins were derived from the Hydrobasins dataset (Lehner & Grill, 2013) using Pfafstetter's level 7 subdivision of basin area (Verdin & Verdin, 1999) for the national-scale map, and level 12 for the maps of Madang and New Britain island.

3.4 Landslide risk reduction

Similar to other Pacific nations, PNG is highly vulnerable to natural disasters such earthquakes, volcanic eruptions, tsunamis, floods, coastal erosion and landslides. Landslide hazard, in particular, described as the risk of downward movement of soil material, rock mass or debris under the influence of gravity on favourable slope conditions (Nayak, 2010), is extremely high in the country due to its heavy rainfall, terrain ruggedness and tectonic instability (Greenbaum et al. 1995, GFDRR, 2016). This frequently results in the loss of human lives, economic losses and environmental damage. Although no official statistics are kept, estimates from the Geological Survey of Papua New Guinea suggest that approximately one hundred people are killed annually by landslides in PNG (Greenbaum et al. 1995).

Landslides can be triggered by several factors such as earthquakes, rainfall, deforestation and human induced vibrations; all these factors can interact to initiate the movement, transport and deposit of materials (Michael and Samanta, 2016). In PNG, most landslides are triggered by rainfall events or seismic activity (Robins et al. 2013). Topography characteristics such as slope gradient and curvature are important factors in determining susceptibility to landslides, and vegetation cover can then reduce landslide risk. The complex root systems of trees and shrubs not only stabilize the soil but also help to reduce its water content through transpiration, thus minimizing landslide risk. When landslides happen, forests can also act as a physical barrier against the flow of debris or rocks (Forbes and Broadhead, 2013). Consequently, deforestation can increase both the intensity and frequency of landslides (Forbes and Broadhead, 2013).

Landslide vulnerability analyses can help identify vulnerable areas as well as the potential contribution of forests in mitigating landslides occurrence. Landslide vulnerability maps have traditionally been developed using landslide inventories (old landslide areas are more prone to reactivate) and geotechnical ground survey techniques. This can be challenging in many countries because of the remoteness of many areas where landslides occur (e.g., in PNG, there are no landslide records for more than 80% of the country (Michael and Samanta, 2016)) and because of limited resources and expertise. The use of spatial analysis can help to overcome these issues. The application of GIS and remote sensing methods for the development of landslide vulnerability maps have been tested in Papua New Guinea by Greenbaum et al. (1995), using the Kaiapit landslide (1998) as a case study. These methods have been utilized worldwide to generate landslide susceptibility and other natural hazards maps (Akgün and Bulut, 2007; Yalcin, 2008; Shahabi et al., 2014; Pourghasemi et al., 2014).

For the present report, these techniques were applied to assess the relative importance of forest in reducing landslide risk in PNG, based on factors such as rainfall, elevation, slope, earthquake hazard, landforms, lithology and presence of roads and rivers (Map 5). Drawing on this information, planners and policy makers can make more informed decisions on infrastructure development and wider land-use planning. REDD+ actions that conserve or restore forests in areas with high landslide risk (shown in dark green in the map) may have the added benefit of enhancing slope stability, in addition to carbon storage and sequestration.

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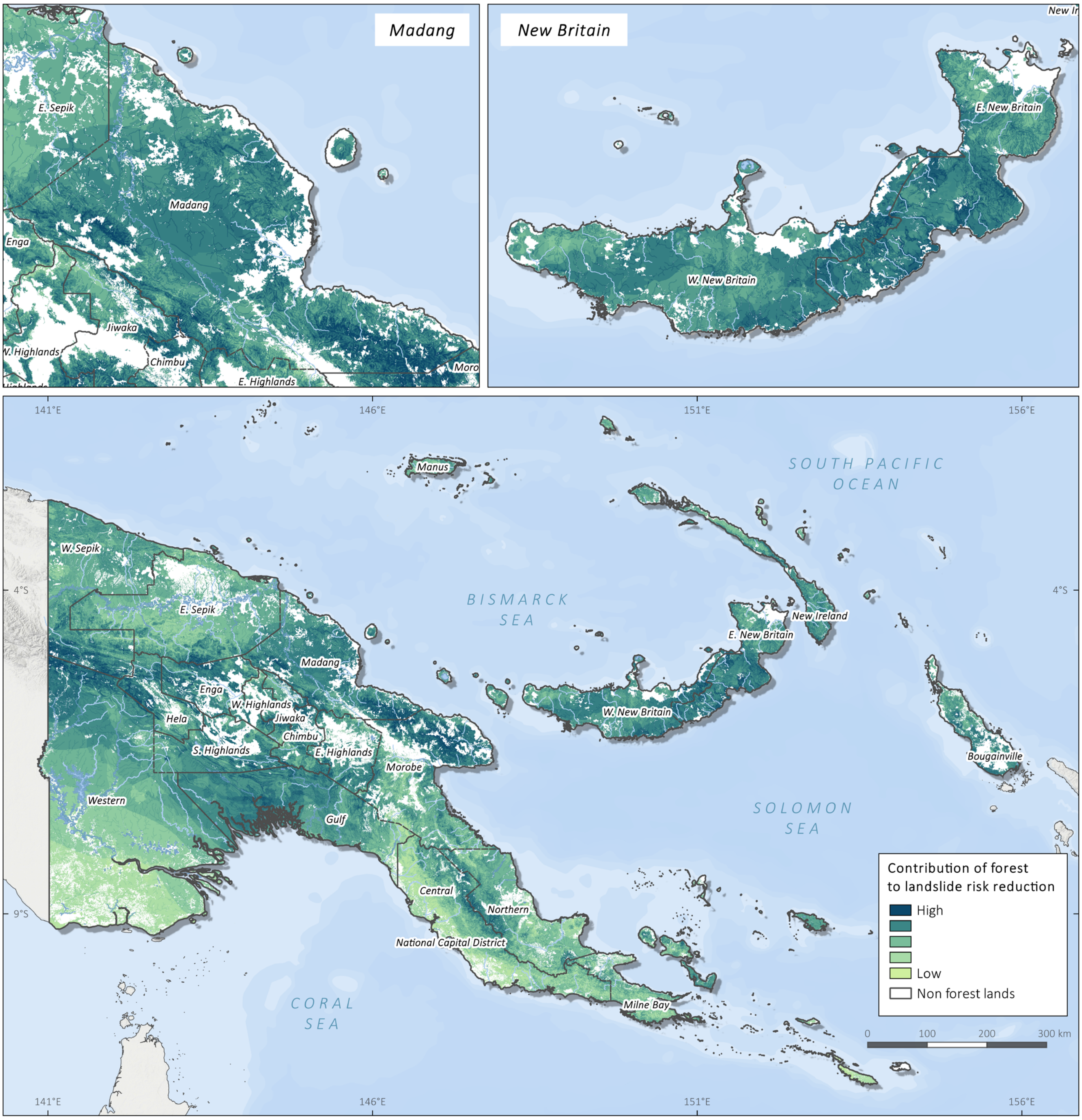
Map 5: Where are the forests with the highest value for reducing landslide risk?

This map shows the relative importance of forests in controlling landslide risk in PNG. Landslide risk was evaluated applying a Weighted Linear Combination Method (WLC), which involved establishing the relational importance and degree of influence of eight parameters known to have an influence on landslide occurrence in PNG. These were: rainfall, elevation, slope, earthquake hazard, landforms, lithology and presence of roads and rivers, with slope, rainfall and earthquake hazard being most influential. The choice of the parameters, as well as ranking and weights, were based on Michael and Samanta (2016).



Data sources:

Rainfall, Roads and Rivers: University of Papua New Guinea (2008) The Papua New Guinea Resource Information System - PNGRIS.

Elevation: Lehner, B., Verdin, K., Jarvis, A. (2006): HydroSHEDS Technical Documentation. World Wildlife Fund US, Washington, DC. Available at http://hydrosheds.cr.usgs.gov.

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3.5 Nature-based tourism

Besides storing carbon, hosting biodiversity and regulating soil erosion, forests provide key cultural and recreational services that can play an important socio-economic role in supporting and enhancing tourism activities. PNG's scenic beauty and rich indigenous cultural heritage makes the country a potentially relevant destination for nature-based tourism. Recognising this, PNG's Tourism Master Plan (PNG Tourism Promotion Authority, 2006) states that "*the core products* [of PNG tourism] *are essentially based around nature and culture; these include diving, culture and village based tourism, special interest flora and fauna including bird watching, trekking, sport fishing, surfing and WWII history*". Similarly, eco-tourism is recognised by the StaRS, emphasising that "*the intact environment also provides the basis for a future economy based on our strategic assets of tourism*" (Department of National Planning and Monitoring, 2014).

In addition to the important source of income that this activity could represent for forest-dependent communities, there are also potential environmental benefits from tourism; as it would be imperative to maintain the environmental quality of tourist sites in order to secure continued interest in PNG's natural forests. This can be achieved by ensuring the conservation of biodiversity, the sustainable use of natural resources and the protection of areas of ecological value. Locating REDD+ actions in areas of value for tourism may therefore help to ensure that REDD+ provides benefits for this sector.

Nonetheless, tourism activity in PNG is still relatively low, mainly due to high costs of air travel and accommodation around the country (Papua New Guinea Department of Conservation, 2014), as well as the low accessibility of certain areas. Indeed, much of PNG's interior remains remote, and the country's complex topography strongly hinders accessibility to many areas. As a consequence, current tourism activities are mainly limited to trekking and expeditions on vessels along coastal areas and the Sepik River. Informal travellers and birding groups can also be found seeking out endemic and other interesting species in more accessible forest areas (Papua New Guinea Department of Conservation, 2014).

Spatial analysis can help support nature-based tourism planning by, for example, identifying and prioritizing potential nature-based tourism areas, taking into account factors like attractiveness or constraints, like accessibility. Map 6 shows estimated accessibility of PNG's intact forests to international tourism based on estimated travel time from major PNG airports.

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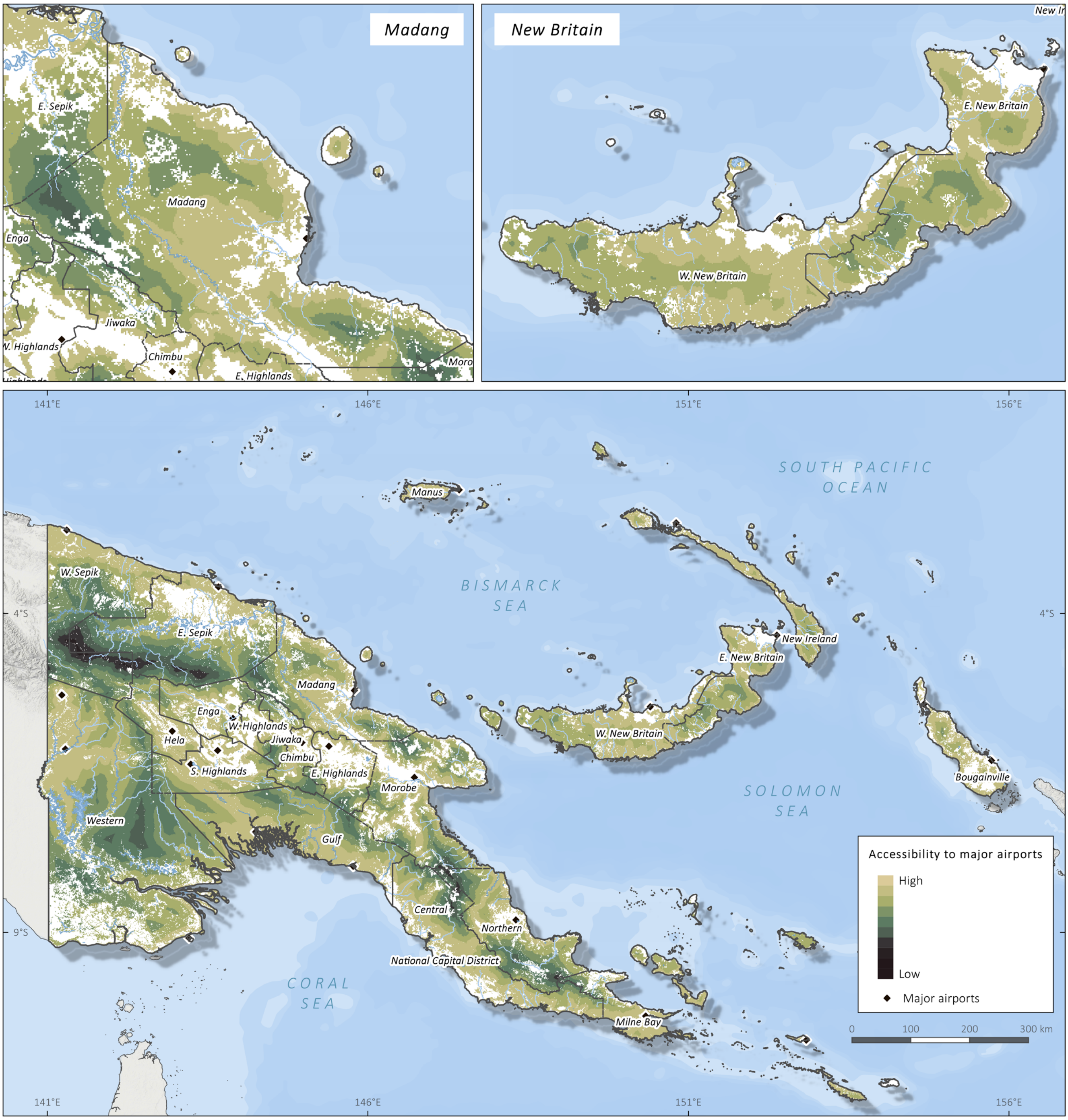
Map 6: Where are the forests most accessible to international tourists located?

Accessibility of intact forests to tourists was measured by estimating travel time from major PNG airports via surface transport. Travel time from major airports was estimated by adapting data and methods developed by Weiss et al. (2018), and using Google Earth Engine (Gorelick et al. 2017). Intact forest areas were identified by extracting all areas categorized as 'forest' in the TerraPNG land-cover/land-use assessment (Map 1) with less than 5% forest loss in the period 2000-2016 years according to Hansen et al. (2013). Those REDD+ actions that conserve accessible intact forest areas (symbolised as pale beige in the map) may provide the added benefit of supporting continued or enhanced nature-based tourism.



Data sources:
Accessibility: D.J. Weiss, A. Nelson, H.S. Gibson, W. Temperley, S. Peedell, A. Lieber, M. Hancher, E. Poyart, S. Belchior, N. Fullman, B. Mappin, U. Dalrymple, J. Rozier, T.C.D. Lucas, R.E. Howes, L.S. Tusting, S.Y. Kang, E. Cameron, D. Bisanzio, K.E. Battle, S. Bhatt, and P.W. Gething. A global map of travel time to cities to assess inequalities in accessibility in 2015. (2018). Nature. doi:10.1038/nature25181.
Major airports: Climate Change and Development Auhority. Government of Papua New Guinea.
Roads and tracks: National Statistics Office. Government of Papua New Guinea.

Spatial information regarding physical accessibly of forests, like the one shown in Map 6, can be combined with indicators of other factors relevant to nature-based tourism, such as landscape beauty, to identify forest areas that are both accessible and attractive for this type of tourism. Map 7 shows one such analysis, which uses Bird-of-Paradise species richness as a simple proxy indicator of attractiveness for one of the core tourism products highlighted in PNG's Tourism Master Plan: birdwatching.

Birdwatching is indeed a growing industry in PNG, with several thousand 'high-end' birdwatchers (spending more than USD 10,000 per trip) visiting the country each year (Newsome, 2015). This provides income for a significant number of people, from landowners that set up lodges where bird watchers can stay, to local guides that provide guiding services to tourists (Newsome, 2015). Among the list of species of interest for birdwatchers who travel to PNG, Birds-of-Paradise are particularly popular because of their spectacular courtship displays. Areas with high diversity of Birds-of-Paradise are therefore key locations for birding tours. Map 7a shows estimated distribution of richness of the 30 Bird-of-Paradise species present in PNG, according to IUCN Red List geographic range data (IUCN, 2017). Map 7b illustrates the relationship between this information and the results of the accessibility analysis shown in Map 6, allowing identification of areas that are both attractive and accessible for bird watchers (in dark red).

As with any proxy indicator, Birds-of-Paradise species richness has limitations - for example, other groups of birds could have been considered and yielded different results. For these reasons, this index may underestimate the birdwatching potential of well-known tourist areas such as New Britain or New Ireland. In addition, there are other factors that would be required to take into account to measure nature-based tourism attractiveness, such as scenic beauty, suitable diving locations or trekking routes. Moreover, there may be other constraints in addition to accessibility, such as occurrence of violent conflicts. The purpose of these maps is to illustrate how spatial analysis can be used to identify areas where forest conservation could enable nature-based tourism, and thus where REDD+ actions may provide additional socio-economic benefits. We encourage the updating of these maps as further data becomes available.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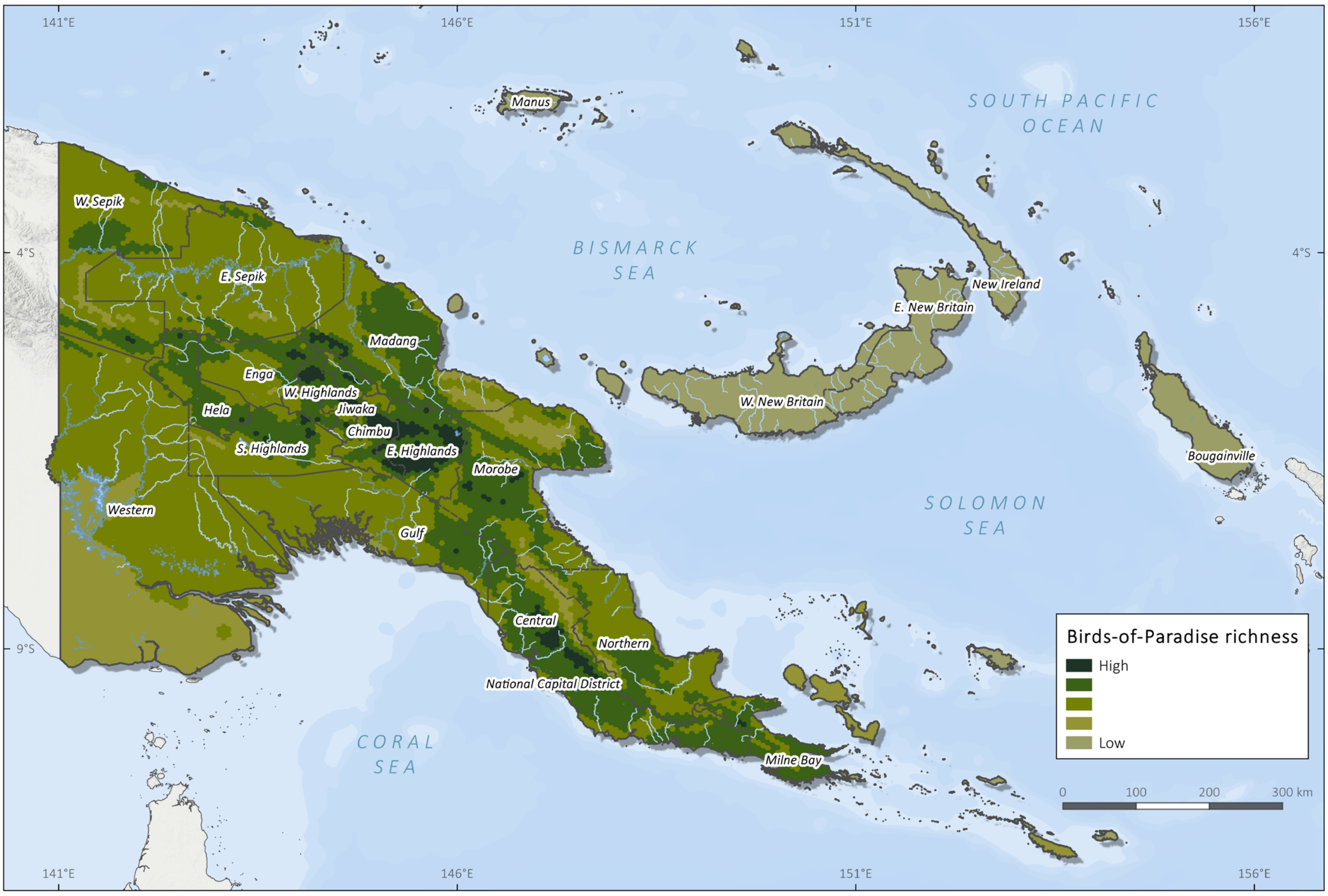
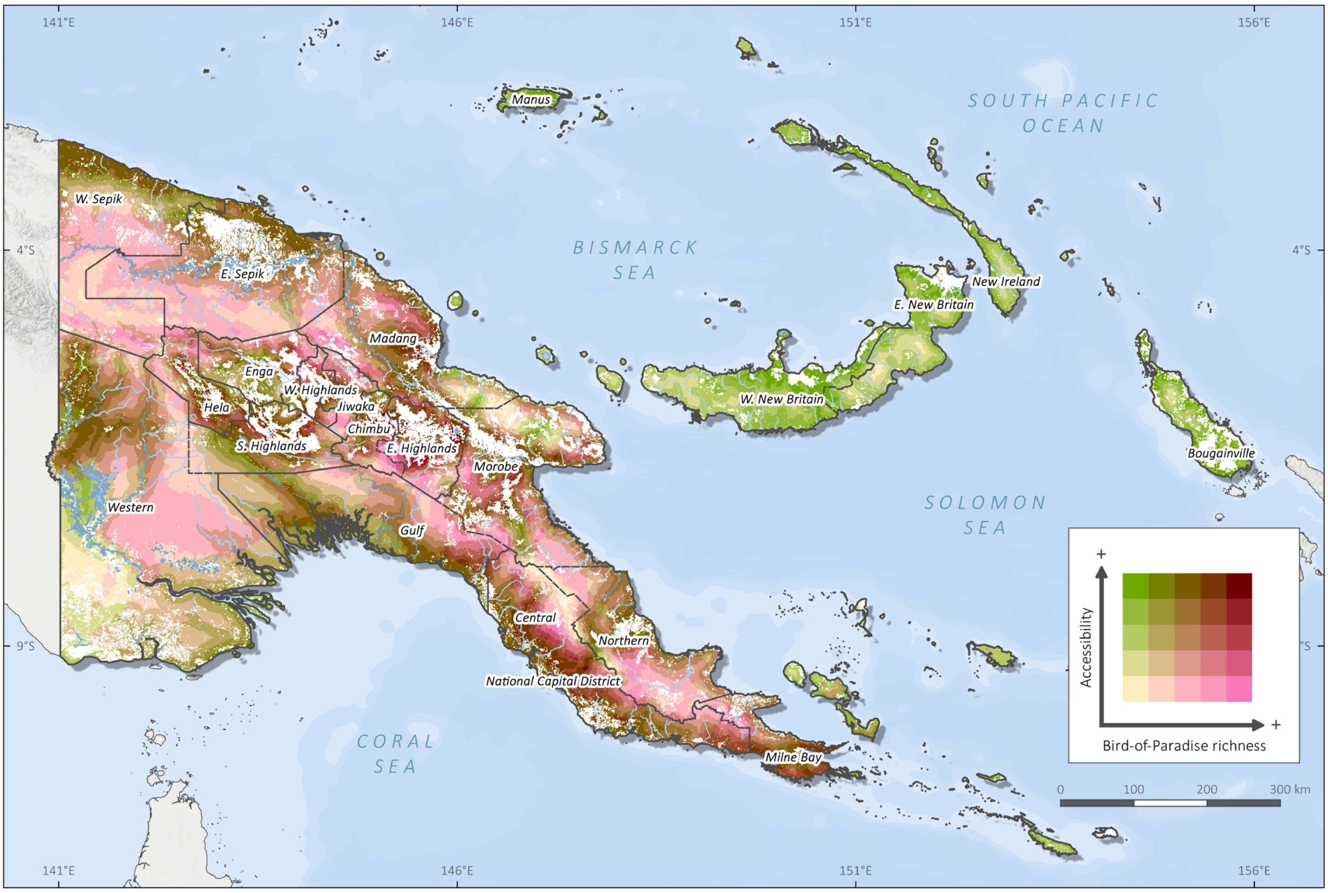
Map 7: Where are the most attractive areas for birdwatchers, and how accessible are they?

The top map (7a) shows estimated Bird-of-Paradise richness using a regular grid of 25 km^2 size hexagons, based on the spatial distribution of all 30 species belonging to the Paradisaeidae family according to the IUCN Red List of Threatened Species (2017). Map 7b (below) shows the relationship between Bird-of-Paradise richness and forest accessibility (Map 6).





Data sources:
Birds-of-Paradise richness: Based on the spatial distribution of 30 bird species belonging to the family *Paradisaeidae* of the order *Passeriformes* present in PNG according to the IUCN Red List of Threatened Species (2017). Version 2016.3. http://www.iucn.redlist.org. Downloaded in March 2017.
See Map 6 data sources

4. Prioritizing areas for REDD+ actions

The previous sections identified a variety of 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 equal, the greatest priority for REDD+ implementation in PNG might be to focus on areas where action to retain or restore forests can potentially provide multiple benefits. Accordingly, the separate results presented above can be combined in a single map that allows us to examine where REDD+ actions could deliver the highest provision of multiple benefits.

Among the different spatial analysis techniques available to achieve this, Multi-Criteria Evaluation (MCE), defined as the identification of priority areas to achieve a specific objective on the basis of a variety of attributes that the selected areas should possess, is a particularly suitable method to support decision-making processes (Eastman, 1999). This technique takes into account the intrinsic spatial heterogeneity in the provision of social and environmental benefits (here called criteria) that could be derived from retaining forests, in order to achieve a specific objective (in this case, the highest provision of benefits) through the implementation of actions in specific areas (identified based on their attributes, in this case, the degree of spatial congruence in the provision of benefits).

Drawing on the maps of aboveground biomass carbon and topsoil organic carbon (Maps 2a and 2b), biodiversity conservation (Map 3), soil erosion control (Map 4), landslide risk reduction (Map 5) and accessibility of intact forests (Map 6), it is possible to identify areas of overall high importance for biodiversity and ecosystem services. Map 8 combines these different values of forest, with the areas with the overall highest values shown in dark green. Medium values may still be high for individual layers, even if low in others (for example, an area high in biodiversity but low in other criteria mapped would show up in the middle of the scale). If areas high for multiple values are at risk of deforestation or degradation, they may be of particularly high priority for REDD+ actions, even if there are challenges related to cost or feasibility.

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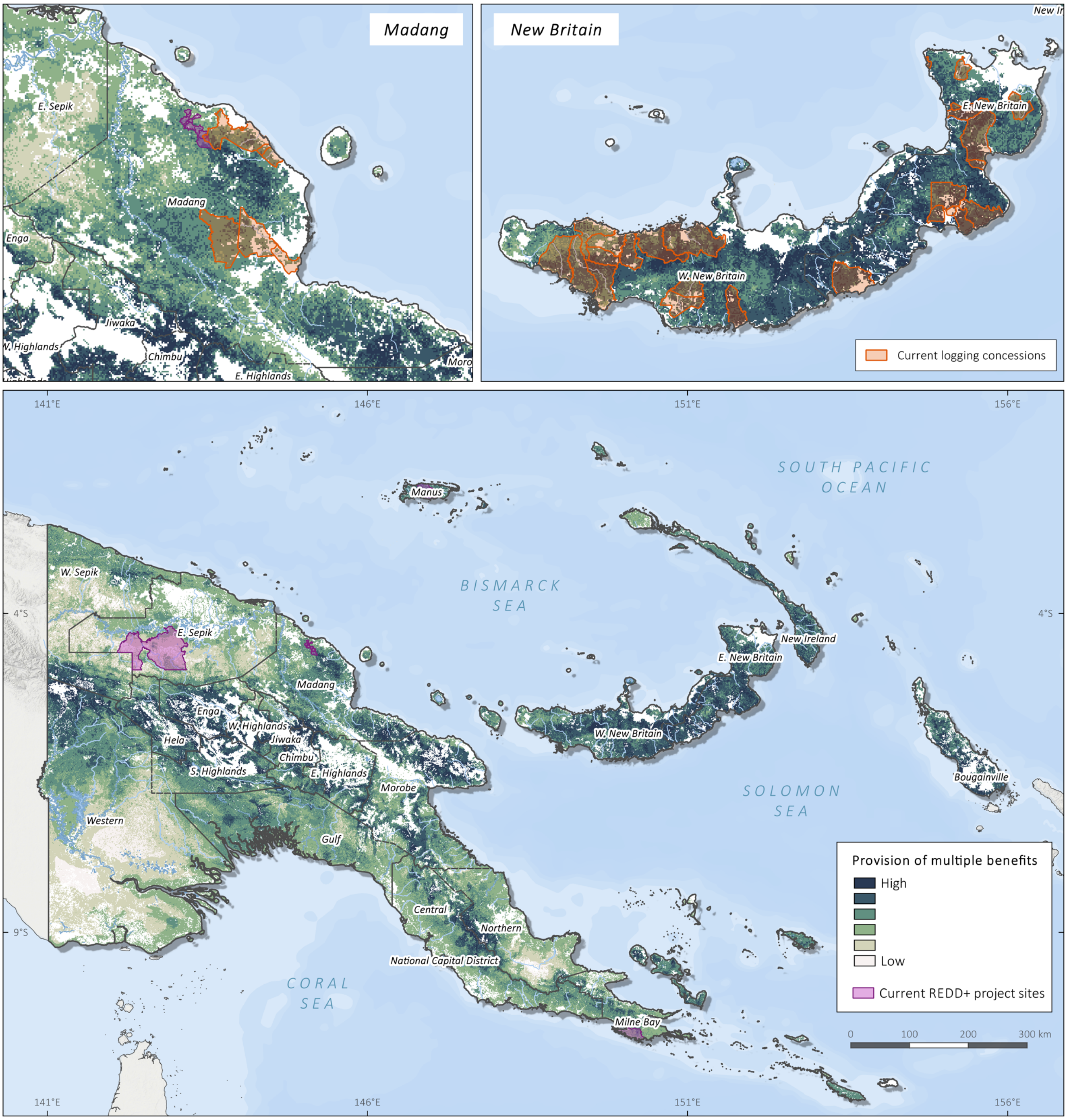
Map 8: Where could retaining or restoring natural forests offer most social and environmental benefits?

The combination of the individual benefit layers described in section 3 allows identification of areas of spatial congruence amongst them, as well as forest areas that do not hold these values. This map was produced by first standardising the values of the individual benefit layers (0 to 100, by means of equally-weighted linear combination), and then creating a composite layer with the same numeric range as the standardized factors. Darker shading indicates areas with high provision of the benefits considered. The map shows that forest values are more highly concentrated in the montane areas, the islands of New Britain and Bougainville, and Eastern part of Morobe, among others.



Data sources:
REDD+ project sites: Climate Change and Development Authority. Government of Papua New Guinea. Port Moresby. Papua New Guinea.
Logging concessionss: PNG Forest Authority. Government of Papua New Guinea. Port Moresby. Papua New Guinea.

5. How spatial planning can support decision-making to reduce the impact of commercial agriculture on PNG's forests?

Palm oil is the biggest agricultural export of PNG, providing an estimated annual revenue of Kina 1 Billion (about USD 313 million) and jobs for tens of thousands of people in rural areas (Government of Papua New Guinea, 2017a). To help meet growing international demand, the government of PNG has ambitious plans to increase palm oil production by increasing both productivity and the area of land under cultivation, targeting a ten-fold increase in palm oil production area in the next 15 years (PNG REDD+ National Programme, 2016).

These targets may not be in line with current sustainability standards applied in the country and may also represent a potential significant threat to PNG's forests and the services they provide (PNG REDD+ National Programme, 2016). Indeed, if not planned carefully, oil palm cultivation may result in significant negative impacts to biodiversity (Koh and Wilcove, 2008) and human health, with associated fires in Indonesia hugely increasing air pollution (Petrenko et al. 2016). Oil palm cultivation may also result in major GHG emissions, especially if it involves drainage of peatland areas, as has happened in Indonesia and Malaysia (Crump, 2017).

PNG aims to avoid these problems, engaging with increasing international demand while being at the forefront of environmentally sustainable production (Government of Papua New Guinea, 2017a). In order to achieve this, the country aims to develop a National Policy for Sustainable Palm Oil, with the goal of increasing productivity and developing the agricultural sector while strengthening forest protection, biodiversity conservation and mitigate GHG emissions, as well as empowering local communities (Bito and Petit, 2016).

Managing the demand for new commercial agricultural areas will be undeniably important in achieving REDD+ goals. Spatial analysis tools can support this by assessing not only which areas could be more physically suitable for oil palm cultivation but also where such expansion could cause the greatest negative impact on biodiversity and ecosystem services. This is usually referred to as 'land use optimization' (Chapter 10 of Agenda 21)[2].

In PNG, interviews undertaken in the palm oil sector suggest that palm oil producers would welcome "*help from government mapping work on identifying good areas for expansion that would not be environmentally damaging or impact high conservation areas*" (Bito and Petit, 2016). Map 9 provides a simple example of this type of analysis by combining the results of the analyses included in section 4 with the results of a study carried out by Raschio et al. (2016) for the provinces of Madang and the island of New Britain. This map illustrates areas with high provision of social and environmental benefits that may be at risk from deforestation due to high suitability for oil palm. Areas where both provision of benefits and land suitability is high (shown in blue tones in the map) may be priorities for REDD+ actions designed to reduce local deforestation risk and minimise the environmental impacts of oil palm expansion.

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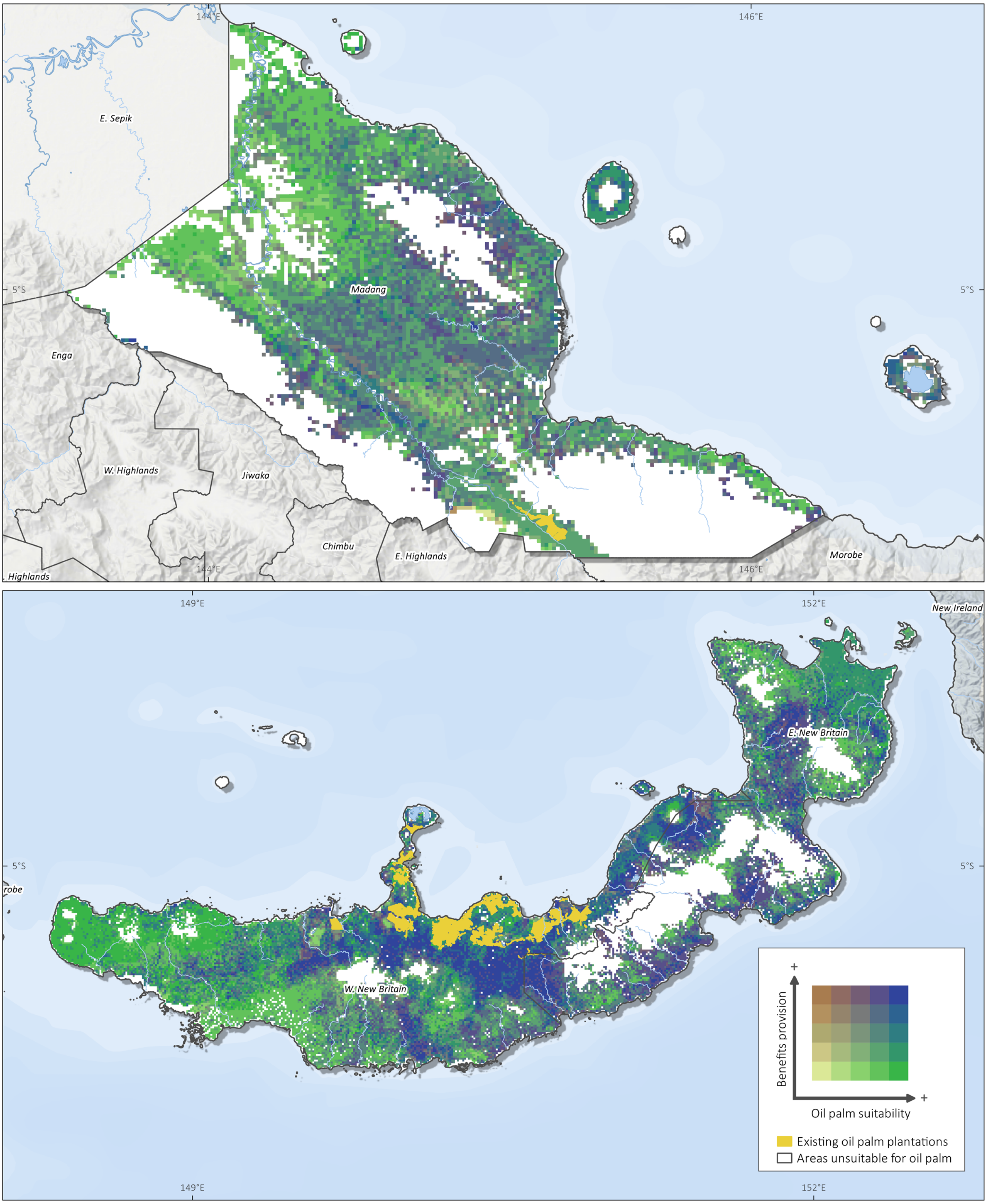
[2] *https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf*

Map 9: In which areas of Madang and New Britain could the expansion of palm oil cause the greatest loss of forest biodiversity and ecosystem services as assessed in this report?

This map combines data on provision of multiple benefits shown in Map 8 with the results of a palm oil land suitability analysis from Raschio et al. (2016). Raschio et al. developed an oil palm suitability model based on a set of nine climatic and physical variables, including elevation, slope, minimum temperature, precipitation, soil erodibility, soil depth, soil drainage and soil texture. Forest areas where both oil palm suitability and provision of multiple benefits is high are shown in dark blue. Areas where the provision of multiple benefits is high but oil palm suitability is low are shown in brown. Finally, areas where palm oil suitability is high but the relative provision of multiple benefits is low are shown in green. Successful REDD+ efforts that focus on conserving forests where both oil palm suitability and the multiple values of forest are high, are likely to deliver the greatest benefits. Please note that peat carbon stock maps were not available to use in this analysis.



Data sources:
Oil palm suitability: Raschio, G., Alei, F. and Alkam, F. (2016). *Future Deforestation Modelling and Land Suitability Assessment for Oil Palm. Agricultural Mapping Assessment in Papua New Guinea.* UNDP. FCPF.
Oil palm plantations: Palm Oil Council/New Britain Palm Oil Ltd.

6. Conclusions

Implementing REDD+ in PNG, as elsewhere, will depend on reconciling different demands for land, as well as considering the different benefits and risks that could result from PNG's REDD+ strategy options. Integrating forest benefits beyond climate change mitigation into REDD+ planning will be key to increasing the positive impact of future REDD+ implementation in PNG, making it more sustainable in the long term.

The maps presented in this report show where the social and environmental benefits of REDD+ could help achieve the objectives stated in PNG's national vision for REDD+, with particular attention to the three prioritized provinces: East New Britain, West New Britain and Madang. The maps may also be useful for the development of PNG's national REDD+ safeguards approach.

As more and better data become available, such as those that will be derived from the Multipurpose National Forest Inventory, the spatial analyses presented here could be updated and extended accordingly to provide better support for planning, including at sub-national scale. Additional local-scale information may also be necessary for suitable assessments of REDD+ strategy options in different country locations; and for feasibility studies to understand current land uses and land tenure, and final spatial plans for REDD+ implementation. The maps in this report can help to identify areas for such further, more detailed study. Finally, for spatial land use planning to be sustainable, the participatory and collaborative nature of the process is just as important as the quality of the analyses and the input data.

We hope that the analyses presented here can provide valuable information to support decision-makers to explicitly consider potential environmental and social co-benefits in REDD+ implementation, can feed into participatory consultations and decision-making processes, and can help PNG to achieve the objectives stated into its national vision for REDD+.

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REDD+ can contribute to more policy goals than to climate change mitigation alone. Recognizing this, Papua New Guinea's vision for REDD+ states that it aims to strengthen long term economic growth and community livelihoods and the effective conservation of biodiversity and ecosystem services while ensuring that Papua New Guinea's forest resources are used in a sustainable and equitable manner for the benefit of current and future generations.

The Government of Papua New Guinea has also identified a need to strengthen land-use national and sub-national planning through the zoning of lands according to their environmental and development priorities, in a way that is both consistent and able with the concepts of the National Strategy for Responsible Sustainable Development for Papua New Guinea. This report shows how spatial analyses can be used as a tool to support this objective.

The purpose of this study is to support the explicit consideration of social and environmental benefits in REDD+ decision making in Papua New Guinea, with a focus on three provinces prioritized for pilot REDD+ implementation: Madang, East New Britain and West New Britain. The aim is to contribute to an analysis of REDD+ potential that takes into account the conservation of natural forest, biodiversity and the multiple functions of forest, especially with regard to Papua New Guinea's priorities for benefits from REDD+. The analyses here presented may contribute to the planning and implementation of REDD+ pilot activities and harmonization of REDD+ policies with other national development policies and plans.

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