



Using spatial analysis to support REDD+ land-use planning in Liberia



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environment





UN Environment World Conservation Monitoring Centre
219 Huntingdon Road
Cambridge, CB3 0DL
United Kingdom
Tel: +44 (0) 1223 277314
Fax: +44 (0) 1223 277136
E-mail: info@unep-wcmc.org
Website: www.unep-wcmc.org

Forestry Development Authority
Whein Town
Mount Barclay
Liberia
E-mail: iinfo@fda.gov.lr
Website: <http://www.fda.gov.lr/>

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Contents

1	Introduction	1
2	Forests in Liberia.....	2
2.1	Forest carbon stocks	4
3	Legal and institutional framework	6
3.1	The Protected Area Network	7
4	Biodiversity and ecosystem services	10
4.1	Biodiversity	10
4.2	Ecosystem services	13
5	Drivers of deforestation and forest degradation.....	16
6	Maps to support planning for REDD+ strategy options.....	20
6.1	Maps for decision makers	20
6.2	Combining benefits to prioritize areas for REDD+ actions	21
6.3	Spatial workflows for REDD+ planning	25
7	Conclusions and recommendations.....	28
8	References	30





1 Introduction

Liberia has approximately 4.3 million hectares of lowland tropical forest, which constitutes 43% of the remaining Upper Guinean Forests of West Africa (CEPF, 2003). Liberia has four main topographical regions, which run in parallel to the coast and reflect the increase in elevation: from the Coastal Plain along the sea, passing through the Mountain Ranges and Plateaux and the Rolling Hills to the Northern Highlands featuring the highest mountain in the country, Mount Wutivi (1,440 m) (Government of Liberia, 2017).

Liberia's forests have high levels of biodiversity, falling within the richest 5% of land area for threatened amphibians, birds and mammals (Tweh *et al.*, 2013; Jenkins *et al.*, 2013). These include many endemic species, which occur nowhere else on Earth. The forests provide a wide range of ecosystem services to local communities, 67% of which live below the poverty line. The services include opportunities for ecotourism and sustainable agriculture, soil conservation, provision of water resources and non-timber forest products.

As a result of shifting cultivation, logging, human settlements and road development, Liberia's once continuous forest is now fragmented into two main blocks, one in the south-east and the other one in the north-west. These two blocks are separated by a central zone of disturbed forest vegetation, which goes from Monrovia to Nimba County (UNDP, 2006).

This last extensive forest of West Africa is threatened by poverty and commercial land contracts for palm oil, mining and forestry (World Bank, 2015).

Liberia recognizes the importance of its forests and the need for their sustainable management in its policies and laws and it is a signatory to international agreements on conserving biodiversity and tackling climate change. The global initiative under the UN Framework Convention on Climate Change (UNFCCC), 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+), represents an opportunity to address forest loss while supporting the transition towards a more sustainable, low carbon development pathway (Figure 1).

Liberia is party to the UNFCCC and has started engaging in the REDD+ process in 2007, with funds

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 under UNFCCC

from the Forest Carbon Partnership Facility (FCPF). In October 2016, the National REDD+ Strategy of Liberia was officially released. The strategy identifies five priorities aiming to tackle the main drivers of deforestation and forest degradation, provide better protection to biodiversity through the further expansion of the protected areas network and ensure the equitable benefits sharing from REDD+ among all stakeholders.

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

Liberia with the aim of limiting these risks developed a comprehensive Strategic Environmental and Social Assessment (SESA) concurrently and in support to the development of the National REDD+ Strategy. The SESA identifies the potential social and environmental impacts of the strategy and addresses the applicable World Bank safeguards.

The National REDD+ Strategy is considered a living and adaptable document that can be refined as Liberia moves through the different phases of REDD+. The maps and approaches described in this report aim to help Liberia in the effective implementation of its REDD+ strategy.



2 Forests in Liberia

Liberia's forest covers more than 60% of the country (Geoville, 2016; Map 1). A national forest definition was agreed during the National Forest Definition Conference in Voinjama (Lofa County) in January 2016. Based on the resulting definition forest are areas with "a 30% minimum forest cover, a 5 meter minimum height and 1 ha minimum areas. Importantly, Liberia recognizes the contribution of industrial agricultural plantations to national economy but chooses to exclude them from its forest definition" (Geoville, 2016). This definition was confirmed during a technical validation workshop in February 2018.

Liberia's forests are characterised by high rainfall as well as high diversity and abundance of animal and plant species. Rain forests are the predominant type of forest; mangroves are also present, but cover approximately just 0.5% of the country (Brandolini and Tigani, 2006). Two main types of rain forest are present, evergreen lowland forest, characterized by dense vegetation and found mostly in the southeast of the country, and moist semi-deciduous forest, found in the northwest (Voorhoeve, 1965; Government of Liberia, 2017). These two threatened forest blocks constitute probably the largest remaining area of Upper Guinean Forest of West Africa.

From 1990 to 2015 the annual deforestation rate was estimated at 0.7% (FRA, 2015). The results of one of

the first major surveys of forest resources in Liberia were published in 1951 by Karl R. Mayer and were based on aerial photography from 1945–46 and on field surveys carried out between 1947 and 1949. This study estimated that high forest (forest with a complete closed canopy and greater than 5,000 board feet per acre) and broken bush (forest with a broken canopy and containing at least one merchantable 16 feet log), covered approximately 58% of the total land area, of which 38% by high forest alone. Mayer also estimated that 20,000 hectares of high forest and broken forest were destroyed annually. A second major survey was conducted from 1960 and 1967 by The German Forest Mission and focused on identifying high forest exploitable and un-exploitable for timber. The results showed that approximately 25% of total land area was covered by high forest, but this survey didn't cover the entire country (Sachtler, 1968). This figure was used and updated by the Tropical forest resources assessment, which estimated about 20% of closed broadleaf forest area (Hammermaster, 1985). In 1985 the FDA/FAO forest resources survey found that high forest, defined as forests of a primary or old secondary nature occurring on dryer sites with a closed or almost closed canopy exceeding 30 meters in height, covered about 50% of the total land (Hammermaster, 1985). The forest estimates described above show how critical is the definition of forest used. The first forest inventories used a



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Map 1: Land cover map of Liberia

The most recent forest cover dataset for Liberia was released in 2015. The production of this land cover/forest cover map was commissioned by the Forestry Development Authority (FDA) from Joint Venture Metria AB and Geoville GmbH as part of REDD+ readiness activities. The forest areas were classified based on canopy density: tree cover <80%, 30–80% and <30%.



Data sources and methods:

Land cover: The map was produced using satellite images acquired over Liberia in the years 2013–2015 at 5–30 m resolution. Source: JV Metria/Geoville and Forestry Development Authority, 2016. Liberia Land Cover and Forest Mapping 2015. Monrovia, Liberia.



definition of forest focused on the commercial use of timber, but starting from the 80s more importance was given to the ecology. This new approach is also reflected in the new definition agreed in 2016.

Currently a new National Forest Inventory is being conducted by the Forestry Development Authority (FDA), with funding from FCPF of the World Bank, and technical support of FAO. This effort is part of Liberia's REDD+ readiness work and will provide a baseline for Monitoring, Reporting and Verification activities, but will also be critical for the development of more detailed spatial analyses on benefits beyond carbon.

2.1 Forest carbon stocks

Tropical forests are essential for mitigating global climate change, being important carbon stores and sinks. Any REDD+ readiness activity, from Measuring, Reporting and Verifying emissions reductions (MRV) to the identification of priority areas where to implement REDD+ projects, requires the knowledge of the spatial distribution of carbon stocks.

In their REDD+ readiness phase, under the UNFCCC's Warsaw Framework, countries are requested to develop a system for measuring, reporting and verifying changes in forest carbon stocks, which is likely to involve both national forest inventory work

and remote sensing analyses. Liberia's national carbon stock estimates are not available yet, but according to global data it is among the countries with the highest density of above ground biomass carbon in the world (Avitabile *et al.*, 2016; Conservation International, 2017). Conserving Liberia's forests is therefore critical for achieving national and global climate targets.

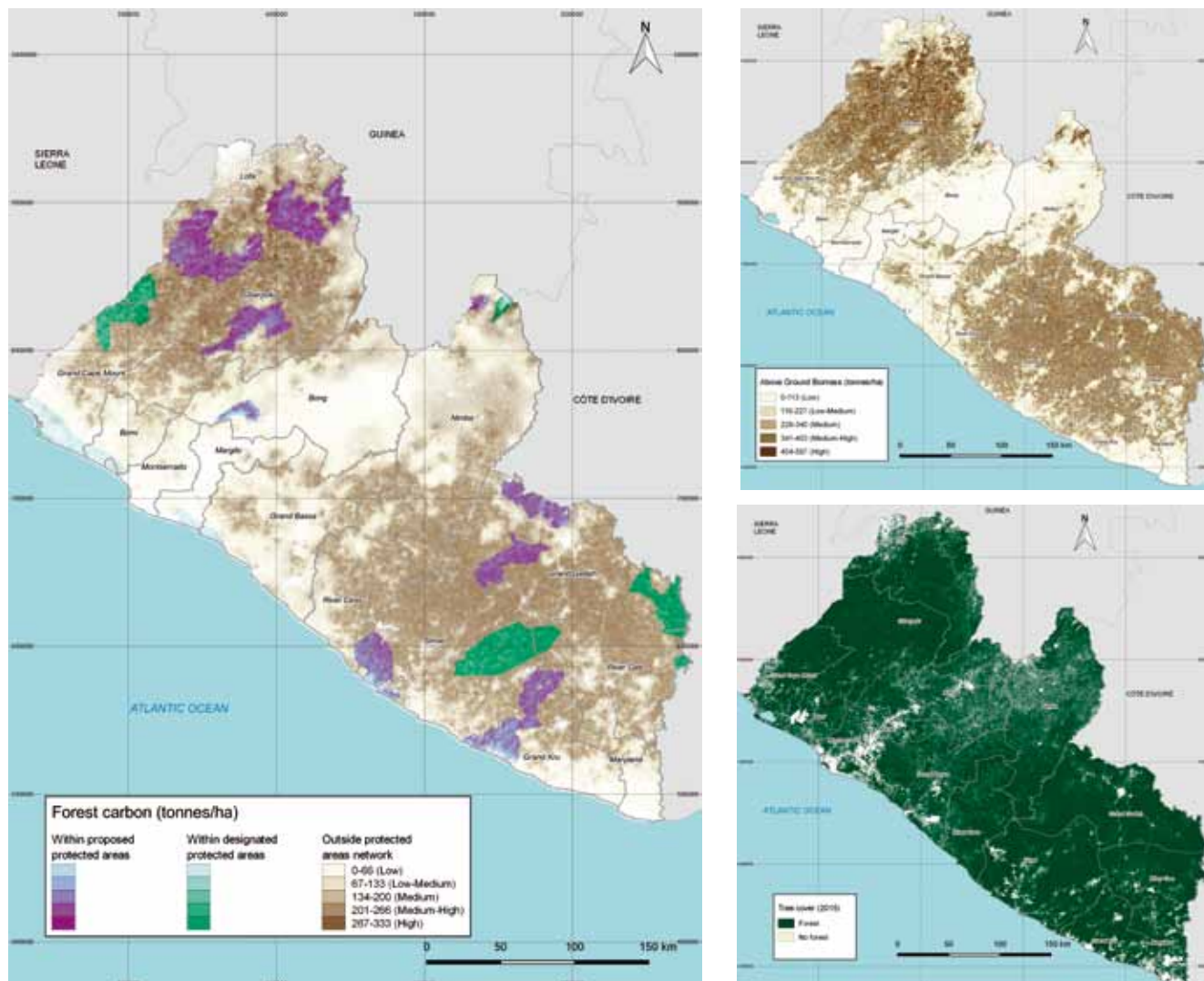
The global above-ground biomass map (Avitabile *et al.*, 2016) and the 2015 national land cover map (JV Metria/Geoville and Forestry Development Authority, 2016) were combined by Conservation International to provide a map of forest carbon stocks in Liberia calibrated to national data (Map 2). The two areas highest in forest carbon stocks are, as expected, the two remaining large blocks of forest, in the north-west and south-east. Most of the areas with high and medium-high carbon content, defined as areas including more than 200 tonnes C/ha, fall outside the formal protected area network. The current designated protected areas include just 7% of the high and medium-high forest carbon area.

The National Forest Inventory that is currently underway will provide national carbon data. Coupled with data on suitable areas for different REDD+ actions, and the other benefits that forests provide, this can support the development of integrated land use plans aiming to identify suitable areas where to implement REDD+ projects that reduce net emissions and deliver non-carbon benefits.



Map 2: Forest carbon

The **left-hand map** shows the above-ground and below ground biomass developed by Conservation International (2017). It is based on the 2015 land-cover map of Liberia (JV/Metria Geoville and Forestry Development Authority, 2016) and the Global above-ground biomass map by Avitabile et al. (2016). The below ground biomass has been calculated from the above-ground biomass using the equation from Mokany et al. (2006). This map shows also the distribution of forest carbon inside and outside protected areas and highlights that the most of the areas with high carbon content follow outside protected areas.



Data sources and method

Forest carbon map (left): This map was developed by Conservation International (2017) using the 900m resolution global above-ground biomass (AGB) map (Avitabile et al. 2016). The biomass was resampled at 30m resolution, and just the forest biomass density was included, by identifying the pixels occupied more than 95% by forest. The output was then clipped to the 2015 forest cover map (JV Metria/GeoVill and FDA, 2015). Below-ground biomass (BGB) was added to the above-ground biomass, using the equation from Mokany et al. (2006). Source: Conservation International (2017). Liberia: Mapping Natural Capital.

Above-ground Biomass (top right): Avitabile, V., et al. (2016). An integrated pan-tropical biomass map using multiple reference datasets. *Global Change Biology*, 22, 1406–1420.

Forest cover map (bottom right): JV Metria/GeoVill and Forestry Development Authority (2016). *Liberia Land Cover and Forest Mapping – 2015*

Proposed & designated protected areas: Dataset provided by the Liberia Institute of Statistics & Geo-Information Services (LISGIS) during the working session held in Monrovia in February 2018.



3 Legal and institutional framework

In the last 15 years, Liberia has developed and updated its legislative framework that addresses and aims to protect its forests and their biodiversity:

- The **Environment Protection and Management Law** (2002–2003) established the Environmental Protection Agency (EPA) and appointed it as the focal institution for several multilateral environmental agreements, such as the Convention on Biological Diversity, the UNFCCC and its Kyoto Protocol.
- The **Act for the Establishment of a Protected Forest Areas Network** (2003) committed the government to establish “a biologically representative network of protected areas covering at least 30% of the existing forest area”. The Forestry Development

- Authority (FDA) was made responsible for proposing the appropriate protected forest area category for each new area to be included in the Network. The act provided a comprehensive set of definitions that remain in use today and are reflected in other legislative provisions (Box 1). These include definitions of National Parks, Game Reserves, Nature Reserves, Multiple Sustainable Use Reserves and Strict Nature Reserves.
- The **National Forestry Reform Law** (2006) amended the National Forestry Law (2000) and provided the foundation for a revised process for forest concession definition (Box 2), allocation and management, as well as restructuring the FDA. This law embraced the new “3C’s” management approach giving equal balance to community,

Box 1: Definitions of Forest Protected Area types as per the Act for the Establishment of a Protected Forest Areas Network (2003) and the National Forestry Reform Law (2006)

Buffer Zone in the context of Protected Forest Area, means a transitional zone (such as Communal Forest, Game Reserve, Multiple Sustainable Use Reserve) surrounding a more strictly protected zone, intended for low-impact sustained human use to reduce the impact of outside human disturbance, to protect the boundaries from encroachment, and to preserve the natural state of the more strictly protected zone it surrounds.

Communal Forest means an area set aside legally or temporarily by regulation for the sustainable use of non-timber forest products by local communities on a non-commercial basis.

Cultural Site means an area set-aside by regulation for the preservation and enjoyment of features with a local or national cultural significance.

Conservation Corridor means the use of a Game Reserve, Multiple Sustainable Use Reserve or any other protected area category to ensure large blocks of the Protected Forest Area Network remain contiguous for the purpose of maximum genetic exchange between blocks.

Game Reserve means an area set aside by regulation for a fixed period, to immediately protect and important feature or to allow the recovery or growth of natural species.

National Forest means an area legally set aside for sustainable regulated commercial forest product extraction, hunting and the preservation of essential environmental functions performed by the forest.

National Park means an area of sufficient size to form a complete ecological unit, legally set-aside for the preservation and enjoyment of features that have outstanding natural beauty, cultural or biological significance.

Nature Reserve means an area that does not represent a complete ecological unit, legally set aside for the preservation and enjoyment of features that have outstanding natural beauty, cultural or biological significance, which may require some management intervention.

Multiple Sustainable Use Reserve means an area set aside by regulation for a fixed period, to allow sustainable use of forest products including subsistence, and potentially, licensed and community forestry schemes.

Strict Nature Reserve means an area possessing outstanding or representative features. Ecosystems and / or species, legally set aside primarily for scientific research and/or environmental monitoring, requiring strict protection and minimum intervention.

Box 2: Definition of other Forest Management Types as per the National Forestry Reform Law (2006)

Commercial Use Any use of Forest Products or Forest Land, other than direct use for personal purposes or infrastructure development. Commercial use includes uses involving Trade or any other disposition of Forest Products or Forest Land for direct or indirect financial benefits.

Community Forestry The governance and management of Forest Resources in designated areas by communities for commercial and non-commercial purposes to further their livelihoods and development. "Community" in the sense of community forestry means a group of local residents who share a common interest in the use and management of Forest Resources, with traditional or formal rights to the land and the forests on it.

Forest Management Contract A long-term Forest Resources License issued by the Government that allows a Person to manage a tract of Forest Land and harvest or use Forest Products. "It's a 25-year concession allowing access to up to 400,000 hectares for commercial timber harvests" (World Bank, 2015).

Private Use Permit Forest Resources License issued by the Government under Section 5.6 of this Law to allow Commercial Use of Forest Resources on private land. This category was rescinded in 2013.

Timber Sale Contract A short-term Forest Resources License issued by the Government that allows a Person to harvest Timber from a specified tract of Forest Land. "This contract are valid for less than three years and reserved for areas smaller than 5,000 hectares" (World Bank, 2015).

commercial, and conservation aspects of forestry (World Bank, 2016).

- The **Community Rights Law with Respect to Forest Lands** (2009) aims to empower communities to engage fully in the sustainable management and conservation of forests. It creates a legal framework defining community rights in the management and use of forest resources, including the large-scale commercial operations on community forest lands.

In 2000, Liberia had ratified the Convention on Biological Diversity and committed to produce a **National Biodiversity Strategy and Action Plan (NBSAP)** for the conservation and sustainable use of biological diversity. The first strategy was published in 2004, and a revised strategy for the period 2017–2025 was released in 2017. The mission of the strategy is twofold: (i) "Develop education and information programmes to raise the level of awareness of the population about the importance of biodiversity and place values on ecosystem goods and services through assessment and evaluation" and (ii) "Develop a framework for mainstreaming biodiversity into national accounting systems, development policies, plans and programmes".

In 2016, the **National REDD+ Strategy** and **SESA** were finalised. The National Strategy identifies the main drivers of deforestation and forest degradation and five strategic priorities, described in the next sections of this report. The SESA identifies in detail the potential environmental and social impacts of the implementation of the REDD+ National Strategy,

using the framework of the World Bank safeguards. Adjustments to the strategy, as well as the institutional and legal measures and mitigation measures are also proposed in the SESA.

3.1 The Protected Area Network

The importance of Liberia's forests "as the centre of biological diversity and endemism for the West African moist forest" has been highlighted since the 1970s, when biological surveys were sponsored by UN Environment and IUCN (Verschuren, 1983). At that time no forests in Liberia were protected and the only existing forest management category was that of National Forests, a category established since 1953 aiming to identify forests suitable for timber exploitation. The National Forests system still occupies an area of 15,107 km² (World Bank, 2015). Since then consultations and surveys have reinforced the importance of Liberia's forests for the conservation of the Upper Guinean Forests Ecosystem and made recommendations for priority areas for conservation.

In 2003, the Act for the Establishment of a Protected Forest Areas Network stated that the government had identified 11 areas of existing "National Forests as candidates for the protected forest area classification". Five more areas were added in 2007 after the development of a Forest Management Suitability Study.



As of 2018, Liberia has 11 proposed and 5 designated protected areas (Sapo National Park, East Nimba National Park, Lake Piso Multiple Use Reserve, Gola Forest National Park and Grebo-Krahn National Park; Map 3). The designated areas cover 4.7% of Liberia. Were all the proposed protected areas to be designated, the network would cover roughly 13% of the country.

The unclear situation related to community land deeds, which is just partially shown in Map 3, represents one of the factors that can hinder the establishment of the proposed protected areas. Accurate estimates of the total land transferred to communities is still unavailable, but research by the Land Commission indicates that up to 30 percent of land is owned by

communities, and copies of the original contracts are still in the validation process (World Bank, 2015). When in 2013 the FDA asked all parties with forest land deeds to submit their documentation, land claims for approximately 3.4 million hectares (almost 80% of forested areas) were received. This situation is currently under consideration by the Governance Reform Committee (World Bank, 2015).

Clarification of land tenure issues is a critical factor for the successful implementation of REDD+ since it determines who should receive compensations for reducing deforestation and who should be accountable if deforestation occurs (Larson et al., 2012). Planning for REDD+ represents a good opportunity for these clarifications to be achieved.



Map 3: Protected areas and Community forests in Liberia

This map shows the current protected areas network, including designated and proposed protected areas. The designated areas are classified as National Parks, Multiple Use Reserves or Nature Reserves. Some of the community forests are also shown, but this is probably not a comprehensive overview of designated community forest land. The close proximity of some of the community forests to the proposed protected areas and in one case their overlap, Gba community forest (East) with the proposed protected area Nimba West, could hinder the full designation of the proposed protected areas.



Data sources and methods

Protected areas: dataset provided by the Liberia Institute of Statistics & Geo-Information Services (LISGIS) during the working session held in Monrovia in February 2018.

Community forests: sourced from the Liberia Forest Atlas website (<http://lbr.forest-atlas.org/>), which cites the Forestry Development Authority of Liberia.



4 Biodiversity and ecosystem services

REDD+ interventions have positive effects that go beyond the conservation of carbon stocks, and include biodiversity conservation and the maintenance and enhancement of ecosystem services. The maps in this section aim to identify the areas with high values in forest carbon, biodiversity and two ecosystem services (protection from soil erosion and freshwater provision). The combination of these maps can inform decision-makers on the most suitable areas for REDD+ actions to conserve existing forest, and may help to identify areas where more research should be conducted to collect more detailed information.

4.1 Biodiversity

Liberian forests contain very diverse ecological communities and distinctive flora and fauna. They are home to more than 2,000 flowering plants including about 240 timber species, approximately 125 mammal species, 590 bird species, 850 butterfly species, 74 known reptiles and amphibians, and more than 1,000 described insects (World Bank, 2010). The country is located within the Guinean Forests of West Africa Biodiversity Hotspot, important for mammalian diversity and particularly renowned for the primate diversity, with high level of endemism and of threat (CEPF, 2015; Conservation International, 2017). It's also one of the richest land areas for threatened amphibians, birds, and mammals (Jenkins, *et al.*, 2013, Junker *et al.*, 2015).

Nineteen Key Biodiversity Areas (KBAs) are found in Liberia (Map 5), nine of which are also Important Bird Areas (IBAs). KBAs are identified as important for conservation based on internationally agreed criteria, such as the vulnerability of species and the irreplaceability of the site for species conservation.

Unfortunately, there is a lack of systematic biodiversity surveys for Liberia, with the exception of chimpanzees. Biodiversity surveys are mostly conducted within designated and proposed protected areas, so that there is little data on the status of the biodiversity elsewhere. Between 2010 and 2012, a nationwide survey along approximately 320 km of transect lines was carried out to estimate the abundance of chimpanzee (*Pan troglodytes verus*), the diversity of large mammals and the anthropogenic threats (Tweh *et al.*, 2014). These and other results show that the majority of chimpanzees and some of the most species-diverse mammal communities in Liberia are found outside protected areas (Map 4).

Whilst the resources for REDD+ are limited and there are strong competing interests for land, REDD+ can be a good opportunity to improve biodiversity protection whilst reducing carbon loss. When national data are not available, global information on the distribution of species of conservation concern can be compared with carbon stocks data. The species richness of threatened mammal, amphibian, reptiles and birds is highly correlated with intact forests (Map 5).



Map 4: Protected areas network and records of chimpanzee nests

This map shows the location of chimpanzee nests recorded during surveys conducted in 2010 and 2011 by the World Chimpanzee Foundation (WCF) and in 2012 by the Max Plank Institute (MPI), alongside with the current protected areas network. The map clearly highlights that many chimpanzee records fall outside protected areas and several are found within proposed protected areas.



Data sources and methods

Chimpanzee nests records: Christophe Boesch (WCF and MPI) for the Grebo (2012) and the Mounts Nimba (2011–2012) datasets; Sources: Jessica Junker (MPI) and Hjalmar Kühl for the Nationwide survey in Liberia; IUCN SSC APES database (<http://apesportal.eva.mpg.de/database/archiveTable>).

Protected areas network: dataset provided by the Liberia Institute of Statistics & Geo-Information Services (LISGIS) during the working session held in Monrovia in February 2018

Chimpanzee range: IUCN Red List of Threatened Species. Version 4. <http://www.iucnredlist.org> [Downloaded May 2018].



Map 5: Species richness in Liberia and Key Biodiversity Areas

This map shows the distribution in threatened species richness across Liberia, and the location of Key Biodiversity Areas (KBAs), including Important Bird Areas (IBAs).



Data sources and methods

Species richness: Derived from the ranges of mammal, bird, reptile and amphibian, classified as “Critically Endangered”, “Endangered” and “Vulnerable” in the IUCN Red List of Threatened Species. Version 4. <http://www.iucnredlist.org>. Downloaded May 2018.

KBAs: BirdLife International (2018). World Database of Key Biodiversity Areas. Developed by the KBA Partnership: BirdLife International, International Union for the Conservation of Nature, Amphibian Survival Alliance, Conservation International, Critical Ecosystem Partnership Fund, Global Environment Facility, Global Wildlife Conservation, NatureServe, Rainforest Trust, Royal Society for the Protection of Birds, Wildlife Conservation Society and Worldwide Fund for Nature. Available at www.keybiodiversityareas.org. [Downloaded May 2018].



4.2 Ecosystem services

Liberia is characterised by high rainfall: on average 2,700 mm of water falls each year (Conservation International, 2017; Ndehedehe *et al.*, 2016). Even under these conditions, the supply and use of clean water needs to be carefully managed. Rural and urban populations in Liberia rely upon groundwater resources, with approximately 61% of people lacking access to clean water (Conservation International, 2017). Mapping areas of forest that provide freshwater and regulate the deposit of sediments illustrates the potential co-benefits of REDD+ activities in these forests.

4.2.1 Sediment regulation

Forests, especially those on slopes, can limit sediment deposition by stabilizing soil and preventing erosion. Deforestation and forest degradation diminish the capacity of land to retain soil, by increasing surface runoff, which in turn increases soil erosion and sedimentation, as well as flood risks downstream. Identifying forested areas important in reducing erosion and controlling sediment deposition can inform the location and implementation of REDD+ actions aimed at reducing deforestation and forest degradation.

Some of the areas that most contribute to the provision of sediment regulation services (dark green in Map 6) are already part of designated protected

areas. Others are not, and may be vulnerable to deforestation and forest degradation. This map can help to inform stakeholders on which forested areas should be the target for conservation, and could also input to an analysis of which deforested areas could be restored with sediment control benefits.

4.2.2 Freshwater provision

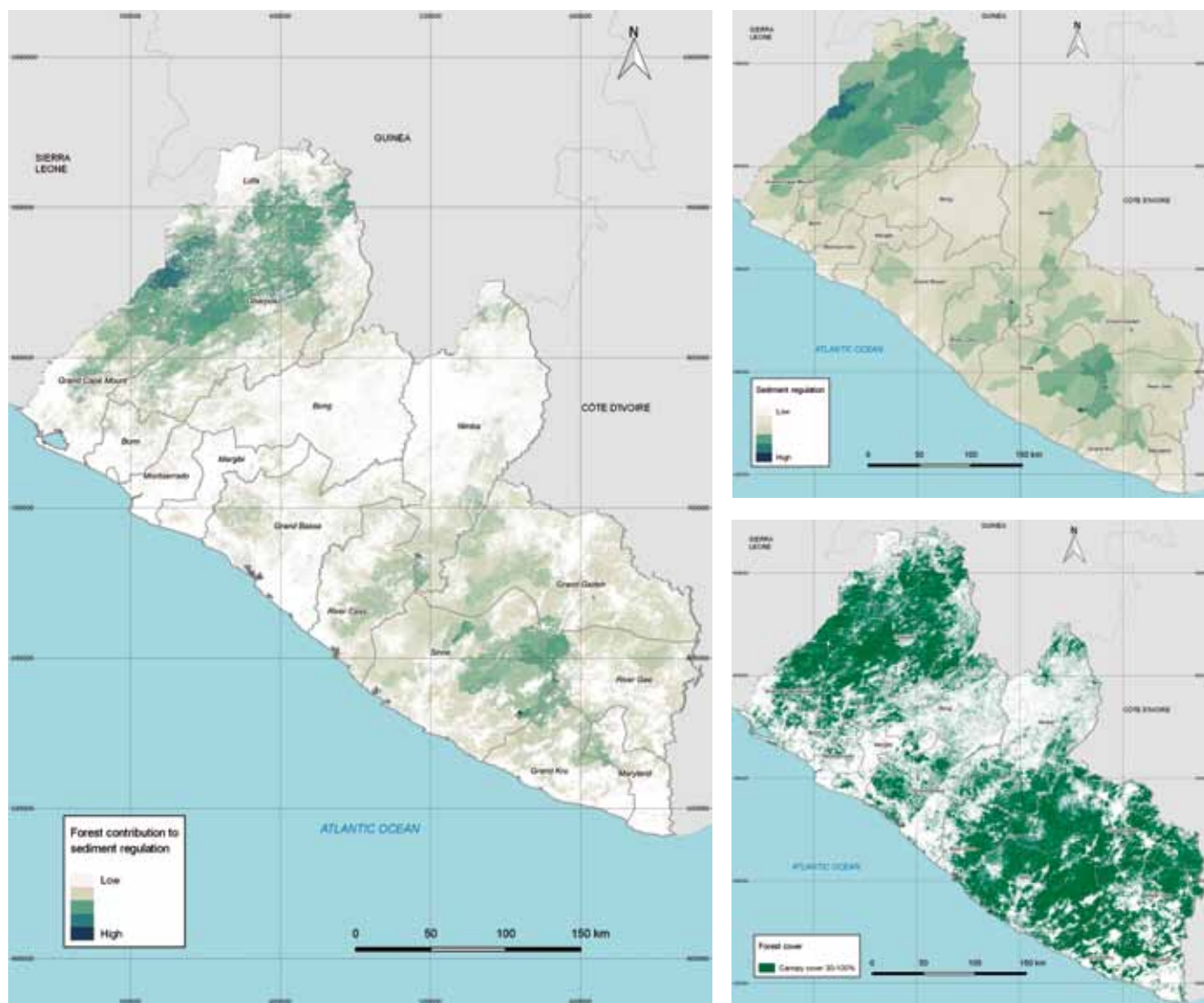
Forests have an essential role in regulating the supply of clean water to population centres, hydropower reservoirs and croplands. Not only do forests filter and clean the water, but they slow down the passage of water from cloud to river, and improve rates of infiltration to ground water, recharging aquifers. Identifying forested areas that provide this service (Map 7) is essential to implement target interventions for forest protection, with the goal of ensuring access to clean water to as many people as possible and avoiding unwanted siltation.

Map 7 identifies the forested areas that contribute most to the provision of freshwater to beneficiaries' downstream, bringing together information on the water captured from rainfall, and the flow of water to its users. These areas are mostly located in the north-west and south. In order to ensure a sufficient amount of water to the main population centres and hydropower dams, these forested areas need to be carefully managed and their retention prioritized. Similar analyses could identify areas that could be reforested to improve clean water provision.



Map 6: Importance of forest for sediment regulation

Most of the forested area that contributes to sediment regulation is located in the north at the boundary with Sierra Leone, in an unprotected zone between Gola National Park and the proposed Foya protected area. A second key area is located in the South in an area occupied by Sapo National Park.



Data sources and methods

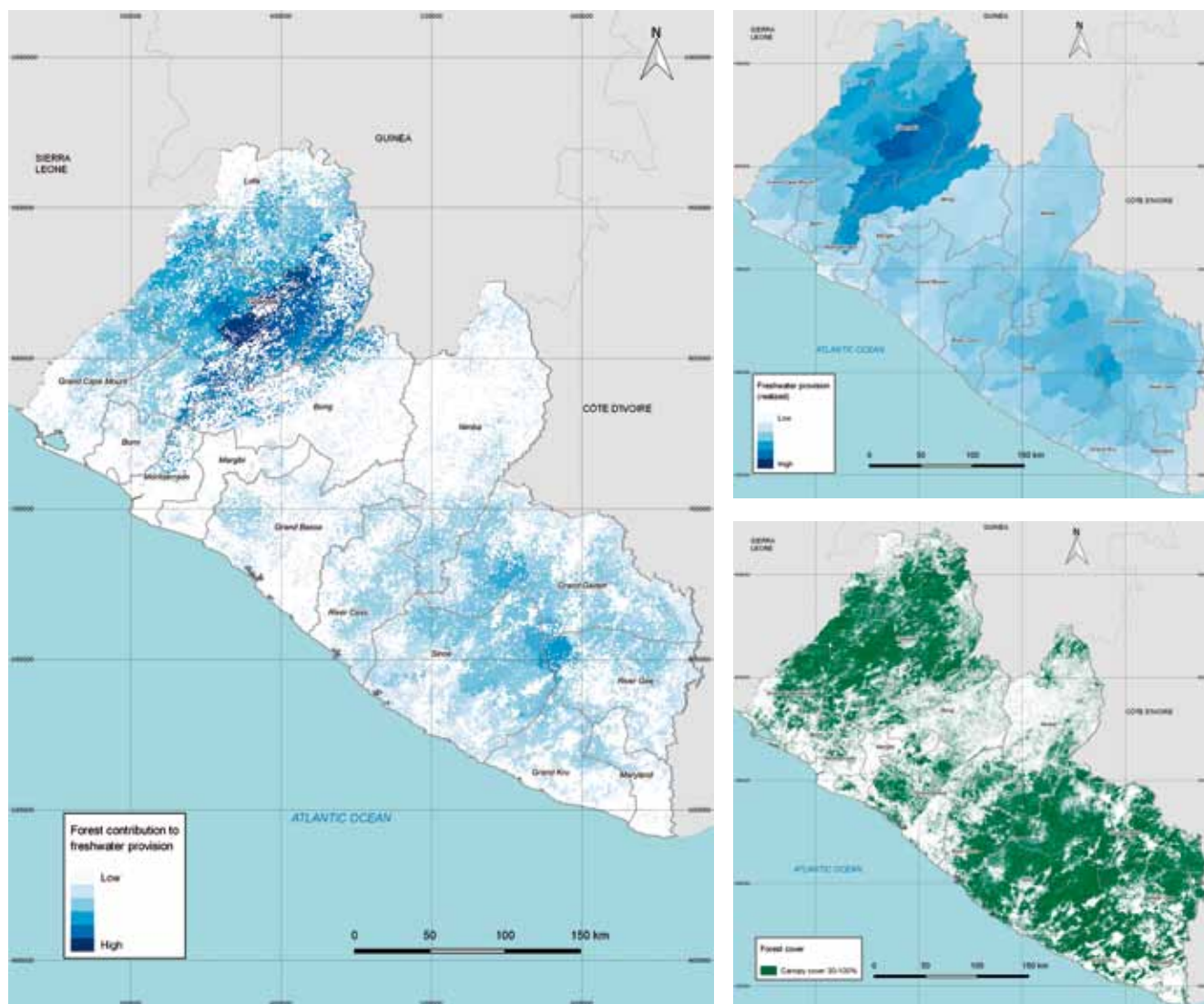
Forest contribution to sediment regulation: the sediment regulation map generated by Conservation International (2017) was masked using forest canopy cover <30% from the 2015 forest cover dataset (JV Metria/Geoville and Forestry Development Authority, 2016).

Sediment regulation map (top right): To produce this map Conservation International used the Unit Stream Power Erosion and Deposition model (USPED; Mitsaova et al., 1996) under current vegetation and under a scenario where all vegetation is removed. The difference between these layers was then calculated to obtain the sediment regulation function of vegetation. The resulting map was then averaged over the level 9 hydrological basins from the HydroBASINS dataset (Lehner, 2013). Source: Conservation International (2017). Liberia: Mapping Natural Capital.

Forest cover map (bottom right): The forest with canopy cover higher than 30% was extracted from 2015 forest cover map (JV Metria/GeoVille and Forestry Development Authority, 2016)

Map 7: Forest contributing to freshwater provision downstream

Most of the forests contributing to the freshwater provision downstream are located in the north, within and around the proposed Kbo Mountains protected area and in the south in the region of Sapo National Park and the proposed Gbi protected area.



Data sources and methods

Forest contribution to water provision map: The freshwater provision dataset generated by Conservation International (2017) was masked using forest canopy cover <30% from the 2015 forest cover dataset (JV Metria/Geoville, 2016).

Freshwater provision (realised) map (top right): The Water World Hydrological Model (Mullgan, 2013), was used to estimate the mean annual water balance under the current vegetation cover and under a scenario with no vegetation cover. The difference between these two scenarios was then calculated and the results averaged at the hydrological level, using level 9 of the HydroBASINS dataset (Lehner, 2013). The realised ecosystem service was obtained by weighting the potential freshwater service with an estimate of the water demand of population centres and active hydropower infrastructure. Conservation International (2017). Liberia: Mapping Natural Capital.

Forest cover map (bottom right): The forest with canopy cover higher than 30% was extracted from 2015 forest cover map, [Source: JV Metria/GeoVille, Forestry Development Authority (FDA) (2016). Liberia Land Cover and Forest Mapping – 2015].



5 Drivers of deforestation and forest degradation

Poverty, land tenure uncertainties and competition among land uses, including commercial and community forestry, mining and agriculture, are the main challenges for biodiversity conservation in Liberia (World Bank, 2015). The National REDD+ Strategy (FDA, 2016) identifies the following most important drivers of deforestation and forest degradation: shifting agriculture, charcoal production, pit-sawing, mining, logging and oil palm concessions. Oil palm concessions are among the drivers considered to determine the highest forest loss, since they involve the complete clearance of forest. Shifting agriculture, charcoal production, pit sawing and logging concessions, do not necessarily result in deforestation, but more often in forest degradation, because of selective extraction of wood (FDA, 2016; LTS, 2016). In Box 3 are summarised the definitions of the drivers of deforestation and forest degradation as are found in the National REDD+ Strategy (FDA, 2016).

Good data on the boundaries of different forest management categories and concessions helps identify areas threatened by deforestation drivers. This is key to the process of finding suitable sites for REDD+ implementation. By 2012, more than 50% of Liberia’s land was allocated to commercial contracts. These are often overlapping, and many exploration licenses (e.g. for mining) might never have been taken advantage of (World Bank, 2015). Planning for REDD+ is an impetus to clarify these and other land tenure issues. A recently launched panel is reviewing the concessions awarded so far, and clarifying their boundaries.

Some of the drivers can be directly mapped (e.g. current and planned roads, urbanisation, etc.), and for others various factors can help in predicting where deforestation might happen (e.g. income level, past deforestation maps, land-use designations).

Past deforestation data such as the global dataset generated by Hansen *et al.* (2013) can inform the identification of areas where deforestation can happen in the future, based on the assumption that sites close to areas where forest has been cleared, are more threatened than others. Map 8 was developed following this approach and shows deforestation risk areas based on forest cover loss from 2000 to 2014. The map shows a widespread risk of deforestation, in particular along the coast where many oil palm and rubber plantations are located, with a hotspot of deforestation and degradation risk in the area around Monrovia (Montserrado County). The area at the border with Guinea and Sierra Leone (Lofa County) at the North, is also prone to deforestation, due to high population and forest fires. Finally a third hotspot is in the centre of the country where there are no plantations, but where the risk is likely due to shifting agriculture (Conservation International, 2017).

Map 9 shows the location of commercial concessions, which include approximately 37% of all forested land in Liberia. The Forest Management Contracts (FMCs) included in Map 9, are a type of commercial logging concession, mostly located in the densest forest and often between designated and proposed protected areas. Not all the FMCs are active, but they have the potential to affect approximately 25% of the total forest area. The map also shows the distribution of oil palm and rubber concessions. More than 150,000 ha of land is likely to be cleared for plantations in the next decade, including also concessions for mining (LTS International and NIRAS, 2016).

Maps 8 and 9 together with maps showing roads and settlements are extremely helpful when planning for REDD+, allowing prioritization of interventions in areas found at risk of deforestation and high in carbon stocks and other benefits.



Box 3: Deforestation and forest degradation drivers (REDD+ National Strategy in Liberia, 2016; Final report for the development of a National REDD+ Strategy for Liberia, LTS International and NIRAS, 2016)

Palm oil concessions: they represent the third largest land use, based on the maximum area that is permitted for development by concession agreements, and it accounts for 5% of the total forest area. It is one of the main drivers of deforestation because the concessions are large, forested, and the area to be planted needs to be completely cleared and replaced with palm oil trees. The main companies are committed to avoid clearance of High Carbon Stock (HCS) and High Conservation Value (HCV) forest, so not the whole concession land will be cleared, but it has been estimated that the forest cleared will be between 160,000–352,000 ha.

Timber Sales Contracts: they account to 3% of total forest and even though most of them are not active, but just proposed, if implemented the complete clearance of forest will occur.

Pit sawing: this is a small-scale commercial and subsistence land use that affect the largest area of forest land. It is estimated that most of the domestic timber comes from pit sawing. This is an unregulated activity, and data on its scale and impact are scarce, but it has been estimated that 24% of total forest is affected by this driver. Increased income levels could cause an increase in demand and thus affect larger areas of forest.

Charcoal production: this is a small-scale commercial and subsistence land use that affect the largest area of forest land. It is an unregulated activity, which makes difficult to estimate its impact. A growing population will determine an increase in the demand of this product, also considering that alternative energy sources are slow to develop.

Shifting agriculture: this is a community specific land use and considered one of the drivers that affects largest area of forest. The area affected by this driver, based on the area of land easily accessible to settlements, is 34% of the >80% canopy forest and 67% of the 30–80% Forest.

Commercial logging: forestry concessions are the second largest category of land use by area, a total of over one million hectares of land is currently under an active Forest Management Contract (FMC), and a further area of 700,000 ha is proposed to be added. Not all the concessions are exploited, but if they were this would affect 24% of the total forest area. The land cover within the FMCs is mostly high canopy cover forest. The road construction to implement forest operations can cause an easier access to unregulated small scale land uses, driving deforestation and forest degradation in neighbouring forests.

Mining: it is expected to become a major industry sector considering that Liberia has rich mineral resources (iron ore, gold and diamonds), and can be among the top 10 iron producers in the world. Over more than 4 million ha of land mineral exploration licenses have been granted in the past and therefore this is considered one of the main threats to forests. Active mining operations are still small, but an estimated 100,000 artisanal miners are operating with an unknown impact. It is estimated that mining might affect in the future more than 200,000 ha of forest.

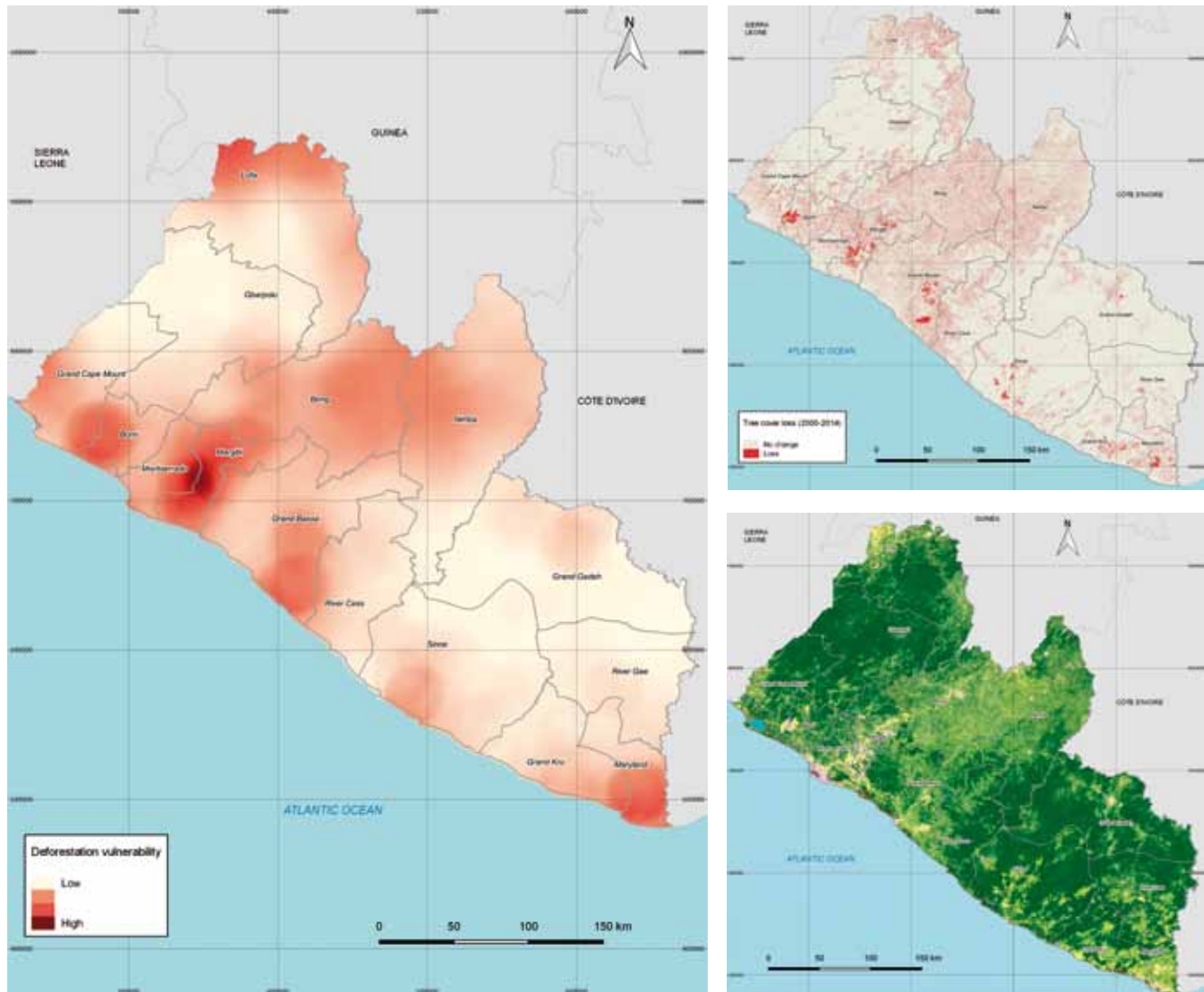


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Map 8: Deforestation risk in Liberia

The deforestation risk map was developed by Conservation International (2017), using the tree cover loss dataset by Hansen et al. (2013) and the 2015 forest cover data (JV Metria/Geoville, 2015). The map shows areas at higher risk of deforestation, along the coast, in the area around Monrovia (Montserrado County), at the border with Guinea and Sierra Leone (Lofa County) at the North, and in the centre of the country where the risk is due to shifting agriculture (Conservation International, 2017).



Data sources and methods

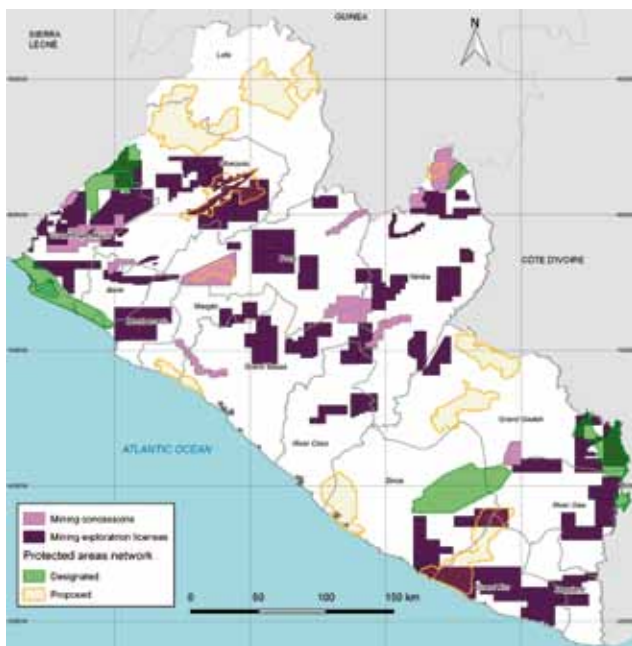
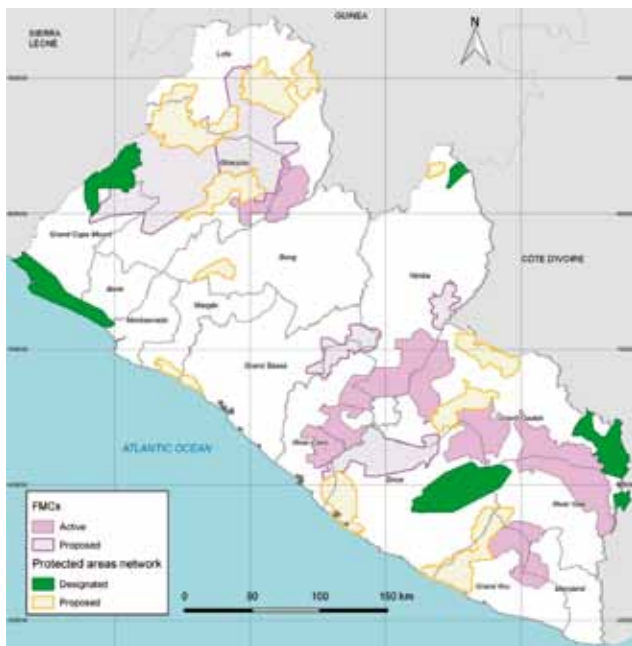
Deforestation vulnerability (left): The map was created by Conservation International (2017) using as input layers the tree cover loss from 2000 to 2014 dataset (Hansen et al., 2013) shown at the top right, and the 2015 forest cover map (JV Metria/Geoville, 2015), at the bottom right. A proximity-based model was applied. Pixels that in 2015 contain forest and are located within 20 km from those cleared between 2000 and 2014 are considered vulnerable to deforestation in the future (Conservation International, 2017). Source: Conservation International (2017). Liberia: Mapping Natural Capital

Tree cover loss (top right): Hansen, M. C., et al. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* 342 (15 November): 850–53. Source: <http://earthenginepartners.appspot.com/science-2013-global-forest>

Forest cover map (bottom right): JV Metria/Geoville

Map 9: Concessions in Liberia

The map on the top left hand side shows the location of the Forest Management Contracts (FMCs), a type of commercial logging concession. The map at the top right hand side, shows the distribution of oil palm and rubber concessions, and at bottom left concessions for mining.



Data sources and methods

Forest Management Contracts: Conservation International (2017). *Liberia: Mapping Natural Capital*. The source indicated is Government of Liberia.

Oil palm and Rubber concessions: Conservation International (2017). *Liberia: Mapping Natural Capital*.

Mining concessions and mining exploration licenses: Conservation International (2017). *Liberia: Mapping Natural Capital*.



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6 Maps to support planning for REDD+ strategy options

In the National REDD+ Strategy, five strategic priorities are identified to address drivers of deforestation and forest degradation and to conserve forest carbon stocks, promote sustainable management of forests and enhance forest carbon stocks:

- **Priority 1:** Reduce forest loss from pit sawing, charcoal production and shifting agriculture.
- **Priority 2:** Reduce impact of commercial logging.
- **Priority 3:** Complete and manage a network of protected areas.
- **Priority 4:** Prevent or offset clearance of high carbon stock and high conservation value forest in agricultural and mining concessions.
- **Priority 5:** Fair and sustainable benefits of REDD+.

To support the implementation of the National REDD+ Strategy, two working sessions were held in Monrovia in February and April/May 2018. Participants from four different government institutions, FDA, LISGIS, EPA and Liberia Land Authority (LLA), and two non-governmental organizations, Conservation International (CI) and the World Research Institute (WRI), attended the workshops. The second working session also included a field component with the learning objectives of understanding the differences among types of spatial data, their limitation, use and the requirements for validation.

Some of the maps in this report were generated during the working sessions and others build upon discussion with the participants.

Three aspects of the use of spatial analyses to inform the identification of suitable areas for REDD+ interventions were covered during the working sessions: production of maps supporting decision making, combination of benefits in a single composite map and development of spatial workflows for REDD+ planning. These three approaches are extremely valuable not just for REDD+ work, but also for the development of any integrated land-use plan.

6.1 Maps for decision makers

Maps can inform the decision making process by helping to visualize the spatial distribution of parameters of interest. The implementation of REDD+ actions aiming towards reduced emissions and increased removals of carbon dioxide from the atmosphere, alongside the maintenance and enhancement of the other benefits forests provide, can be supported by the display, on the same map, of the spatial relationship between the distribution of forest carbon stocks and of any other benefits of interest.

Figure 2: Pictures taken during the two working sessions held in Liberia in February and April/May 2018.



Two-dimensional or 'matrix' legends (Williams, 1998) are used in this report to show the relationship between the spatial distribution of carbon stocks and the other benefits considered in the previous sections. Map 10 shows the relationship between forest carbon and species richness and clearly identifies the two areas in the north-east and south-east as the ones where both these benefits have high values. These are also the two block of intact forest that are at higher risk of deforestation as highlighted in Map 11. If deforestation drivers are not effectively tackled, these last remaining forests will continue to diminish in size.

Maps 12 and 13 focus on identifying areas where high carbon is present alongside sediment regulation and freshwater provision benefits. The two maps show similar patterns, with the forests in the northeast containing high values of the ecosystem services considered, and the forests in the south having a more fragmented distribution of the areas where the values of both benefits are high. In the southern forests, the relationship between forest carbon and sediment regulation appears stronger than between forest carbon and freshwater provision. This is explained by the fact that the freshwater provision dataset considers the realised service, and most of the high population centres, such as Monrovia, and the main active hydropower dams (Mount Coffee dam), are located in the northern part of the country.

6.2 Combining benefits to prioritize areas for REDD+ actions

The selection of locations suitable for the implementation of a REDD+ intervention can be informed by the potential to deliver multiple benefits. In the previous sections, four individual REDD+ benefits were described: retention of carbon stocks, species richness, freshwater provision and sediment regulation. Combining these into a single composite map allows identification of the areas where preventing deforestation or forest degradation could deliver the greatest overall benefit.

Map 14 combines the four potential values in this way. A Multi-Criteria Evaluation (MCE) approach has been used to generate the composite map. This involves the identification of priority areas to achieve a specific objective on the basis of a variety of attributes that the selected areas should possess (Eastman, 1999). The results from these analyses show that 50% of forests providing all four benefits fall in areas awarded as Forest Management Contracts, and 19% within proposed protected areas. Based on these results the designation of the proposed protected areas shouldn't be further delayed, and the sustainable management and if possible protection of part of the FMCs should be a high priority.

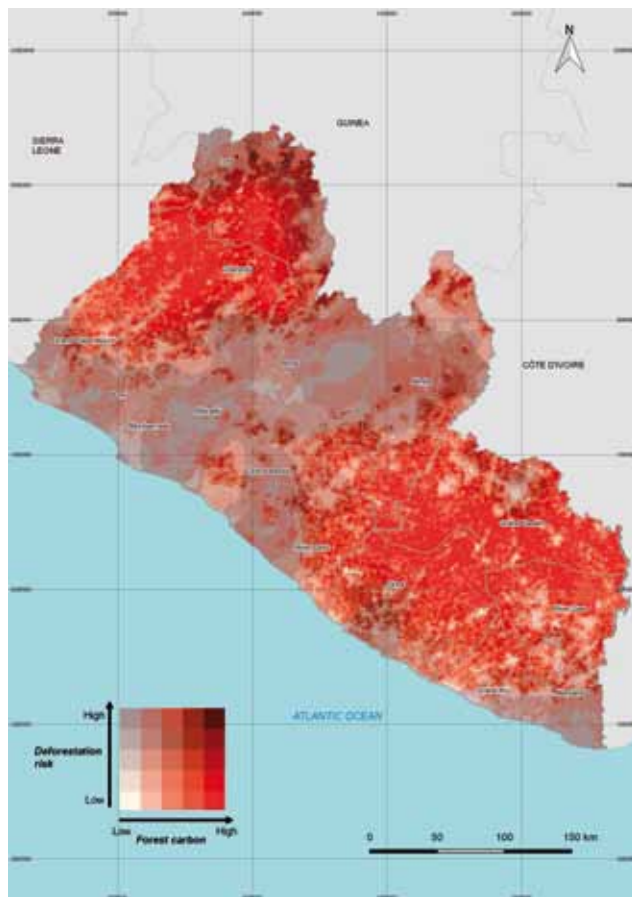
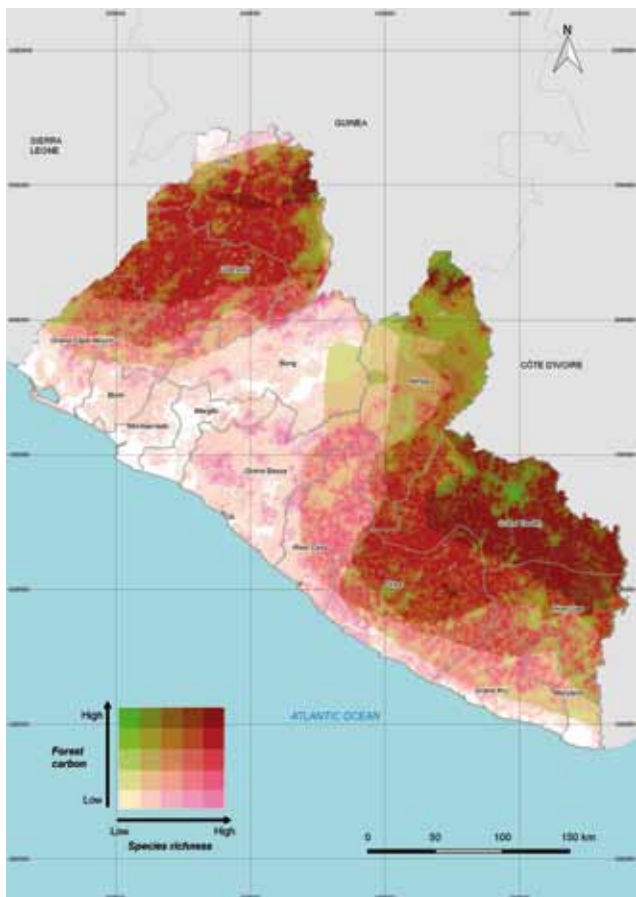


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Maps 10 and 11: Matrix legend maps for REDD+ planning

Map 10 (left) shows the relationship between the distribution of forest carbon and species richness and Map 11 (right) the relationship between forest carbon and deforestation risk.



Data sources and methods:

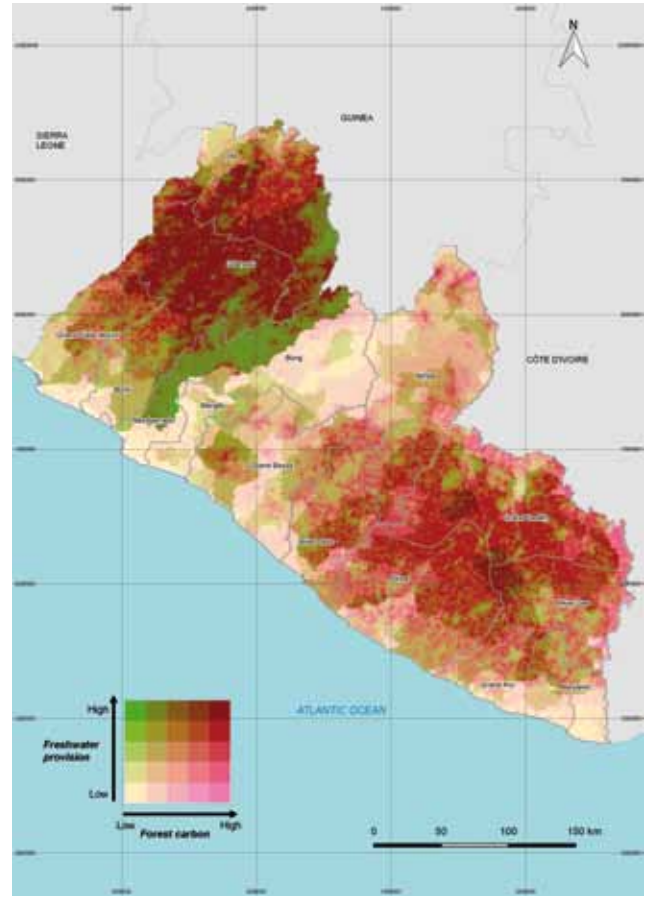
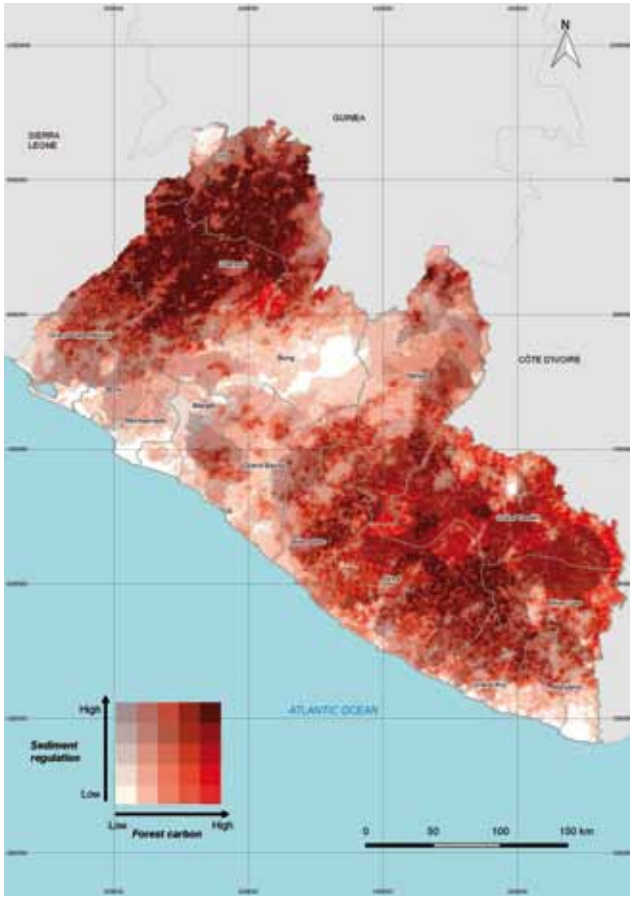
Forest carbon stocks and deforestation risk maps: Conservation International (2017). Liberia: Mapping Natural Capital.

Species richness: IUCN Red List of Threatened Species. Version 4. <http://www.iucnredlist.org>. Downloaded on May 2018.



Maps 12 and 13: Matrix legend maps for REDD+ planning

Map 12 (left) and Map 13 (right) highlight respectively the relationship between forest carbon stocks and sediment regulation, and forest carbon stocks and freshwater provision (realised service).



Data sources and methods

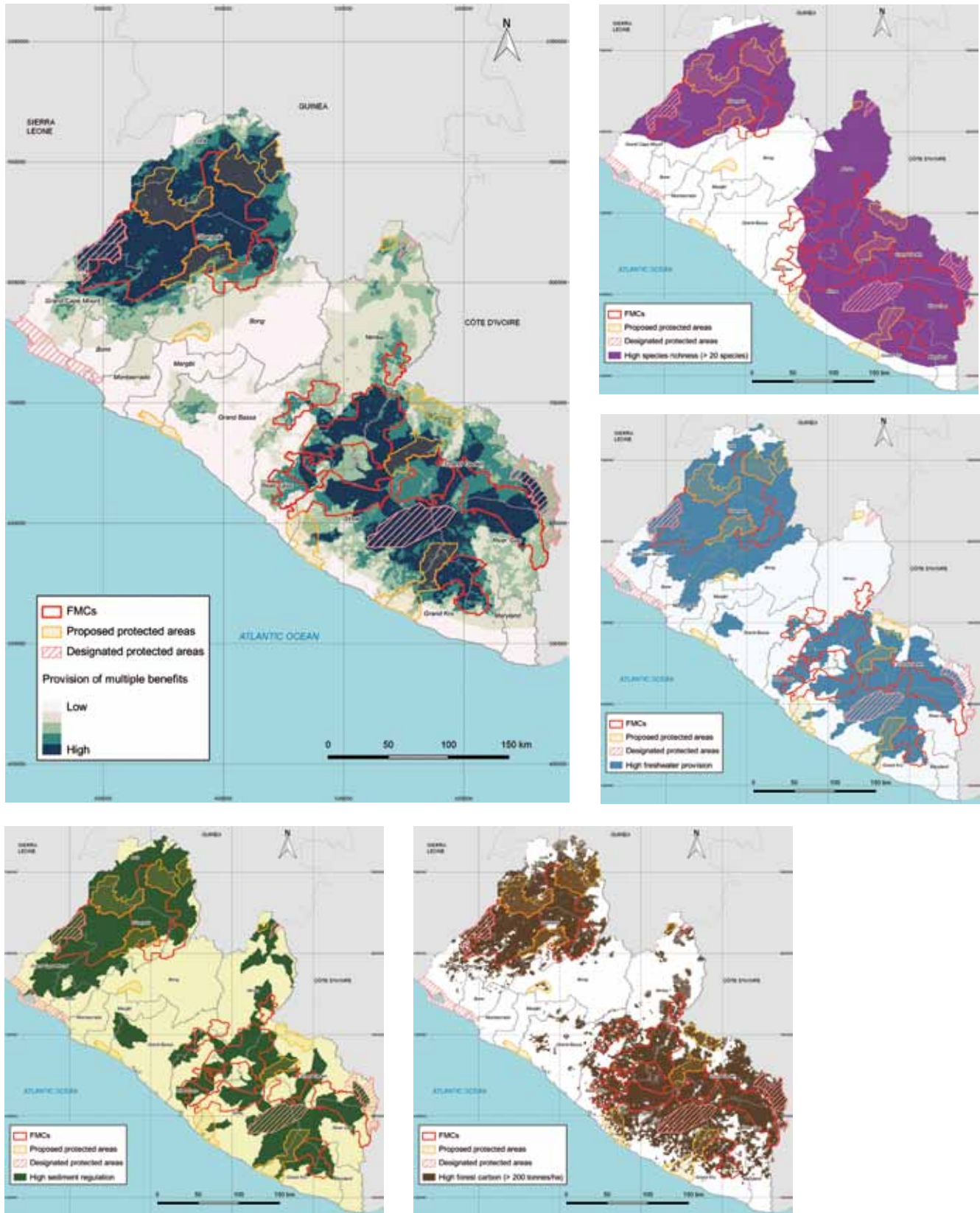
Forest carbon stocks and sediment regulation maps: Conservation International (2017). Liberia: Mapping Natural Capital

Forest carbon stocks and freshwater provision maps: Conservation International (2017). Liberia: Mapping Natural Capital



Map 14: Forests valuable for multiple reasons

This map shows the distribution of the four benefits included in the analyses. In dark blue are highlighted the forested areas where all the four benefits included in the analyses are located. By overlapping this results with the protected areas network and the logging concessions is possible to highlight which areas require more attention in terms of sustainable management and protection.



Data sources and methods

Potential multiple benefits of REDD+: The map was developed by reclassifying the input layers by choosing a value threshold over which the new value is 1 and all the rest 0. The new datasets were then summed together to provide a categorical scale (0, 1, 2, 3 or 4 high values).



6.3 Spatial workflows for REDD+ planning

Maps, despite being very helpful, cannot be the only tool to support the decision-making process. Other useful approaches include stakeholder consultations and participatory mapping, to ensure that local knowledge and aspirations are integrated into the resulting plan. These can both benefit from and input into the maps and analyses.

The development of spatial analysis workflows aiming to where to implement a REDD+ intervention help to clarify objectives and assumptions in a transparent way. During one of the working sessions, spatial workflows were developed aiming to address illegal and unsustainable logging in proposed concessions and within Key Biodiversity Areas. These drivers are identified as priority 1 and 4 in the National REDD+ Strategy. The process followed to develop the final maps, together with the assumptions made, represents a good example of using workflows to plan for REDD+ actions.

During the working session, discussion with the participants identified the following assumptions, which were then used to develop the workflows:

1. Forests in proposed logging concessions, close to roads and villages, can be highly threatened by illegal and unregulated pit sawing.
2. Key Biodiversity Areas located near mining and palm oil concessions, easily accessible from roads, are at risk of illegal logging and hunting.

Map 15 shows the results from the first workflow (assumption 1). It identifies areas with high carbon stock (>150 tonnes C/ha), within proposed FMCs at higher risk of deforestation due to small scale activities (pit sawing and shifting agriculture), located within 5 km from the villages within the FMCs, and at 10km from roads. As discussed above, the FMCs encompass areas with high carbon. This workflow represents an example of how areas at risk of deforestation can be identified and then targeted for conservation management strategies.

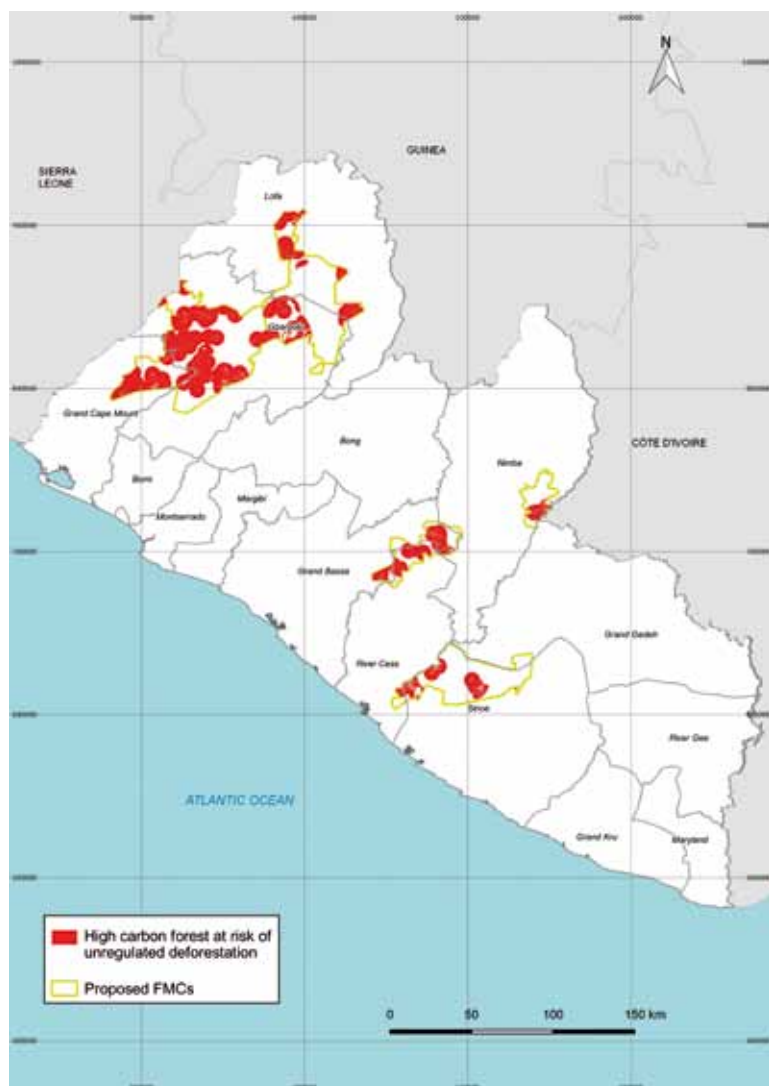
Map 16 based on assumption 2, identifies forested areas high in carbon (> 150 tonnes/ha), located within KBAs, at risk of deforestation due to the proximity to mining and palm oil concessions (within 5 km) and to roads (within 10 km). Considering the importance of KBAs for the protection of biodiversity, careful management of these areas and a particular attention to the drivers identified by the team that developed this map, is necessary.

Figure 3. Picture taken during the workshop held in Monrovia in May 2018.



Map 15: High-carbon forest at risk within proposed Forest Management Contracts (FMCs)

The final map shows areas with high carbon stock (>150 tonnes C/ha), within proposed FMCs at higher risk of deforestation due to small scale activities (pit sawing and shifting agriculture), located within 5 km from the villages within the FMCs, and at 10 km from roads. The distribution of the parameters used to produce the final map, proposed FMCs, villages, roads and forest carbon, are shown at the right side.



Data sources and methods

High deforestation risk: The map was developed in QGIS using the Graphical Modeller tool.

Roads: Conservation International (2017). Liberia: Mapping Natural Capital.

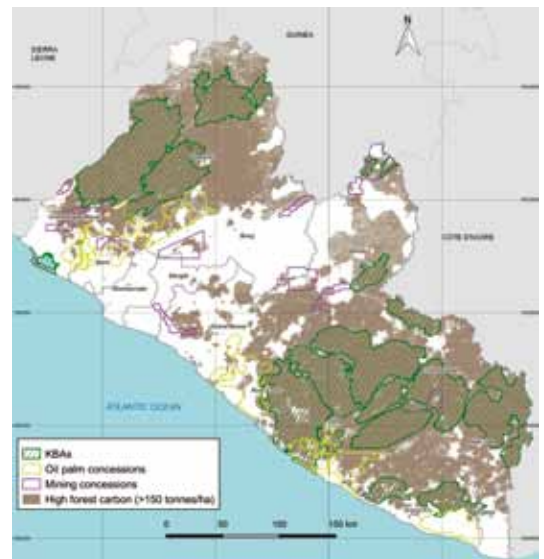
Localities: LISGIS

Forest carbon: Conservation International (2017). Liberia: Mapping Natural Capital.



Map 16: High carbon forest within KBAs at risk of deforestation

This map identifies forested areas high in carbon (> 150 tonnes/ha), located within KBAs, at risk of deforestation due to the proximity to mining and palm oil concessions (within 5 km) and to roads (within 10 km). The distribution of the parameters used to produce the final map, KBAs, oil palm and mining concessions, roads and forest carbon, are shown at the right side.



Data sources and methods

High deforestation risk map: The map was developed in QGIS using the Graphical Modeller tool, using geoprocessing tools

Roads: Conservation International (2017). Liberia: Mapping Natural Capital.

Oil palm and mining concessions: Conservation International (2017). Liberia: Mapping Natural Capital.

Forest carbon: Conservation International (2017). Liberia: Mapping Natural Capital.



7 Conclusions and recommendations

This report and the working sessions held in February and April/May 2018, aimed to support the implementation of Liberia's National REDD+ Strategy. The report gives an overview of the spatial assessments and approaches that can be helpful for designing specific REDD+ interventions based on existing laws and strategies, and uses the current best available data. It covers many, but not all, of the topics that should be considered in the context of REDD+ – the spatial distribution of forests, carbon storage, land management, deforestation and forest degradation drivers, ecosystem services and biodiversity. It reviews some of the forest conservation issues facing the country, such as limited progress in designating protected areas (Map 2). It is recommended that more spatial analyses focusing on the other strategy options are carried out. Since charcoal and fuelwood are the primary energy sources of the country and a major driver of forest degradation, analyses should focus on identifying, for example, which are the charcoal production areas for cities and towns and which is the spatial balance between production and demand. This type of analyses could support the achievement of priority 1 in the National REDD+ Strategy- Reduction of forest loss from pit sawing, charcoal production and shifting agriculture – by informing for example the development of projects focusing on efficient charcoal production.

The maps in this report also highlight that forests outside the protected areas network provide a high number of benefits beyond carbon, such as freshwater and sediment regulation, whose loss would be deleterious to local populations and the wider economy. The analyses developed for this

report, which include four benefits (forest carbon, biodiversity, sediment regulation and freshwater provision), show that 50% of forests providing all these benefits together fall within logging concessions awarded as FMCs. Further spatial analyses including more ecosystem services, should be prioritised to identify for which areas higher levels of protection are required. Ecosystem services spatial assessments could inform for example the development of management plans for the FMCs using a zoning approach with core areas requiring higher protection, areas where commercial logging can be implemented, and where reforestation activities should be preferred. For this report the identification of areas suitable for reforestation interventions haven't been carried out, but it is recommended that these type of investigations are considered. For example, areas affected by shifting agriculture practices, a major driver of forest degradation in Liberia, could be sustainably managed by planning reforestation programmes.

Concessions for agriculture, logging and mining are found to often overlap amongst themselves and in particular with the protected areas network. Our analyses show that areas awarded with mining exploration licenses and mining concessions overlaps for more than 100,000 hectares with protected areas, both designated and proposed, making them the commercial land use with the higher extent overlaying the protected areas network. Even though some of the mining concessions and exploration licenses might never be exploited a better coordination among government institutions is highly recommended to clarify in which areas these commercial activities can be implemented and their clear boundaries



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demarcation. Spatial multi-criteria decision analysis (SMCDA), which takes into account the competing interests in the land, and aims to develop integrated land use plans, should also be generated. This type of analysis by using a participatory approach can also facilitate a coordination among institutions, which is currently missing.

The methods described and the resulting maps can support the identification of suitable areas to implement REDD+ interventions, but also illustrate the main challenges for the conservation of forests in Liberia and the need for more spatial analyses to identify areas important for biodiversity and ecosystem services. As mentioned earlier in this report there is a lack of updated biodiversity data, on species other than chimpanzees, in forests outside protected areas. The collection of this data is critical to identify potential wildlife corridors that need protection and that should be included in the protected areas network.

Even though global or regional scale data can be used to develop a first assessment, it is strongly recommended that the systematic collection of key data and their analyses is planned. The current implementation of the National Forest Inventory is a first step that should be replicated for other key data, such as land use and demarcation of community land boundaries, starting from priority areas and then extended to the rest of the country using a clear strategy and methodology. The analyses of the data

collected will require a national technical capacity that often needs further development before it is independent from external support. Further capacity-building, aiming to train national trainers represents a key priority. At the end of the last working session in May 2018 the participants identified the following GIS topics for which they feel further trainings are needed: field surveys design, development of spatial analyses which include field data (connectivity and suitability models), hotspot analysis, database management, generation of workflows for watersheds extrapolation, in depth satellite images pre-processing and classification and clear methods for land use mapping and land demarcation.

Liberia's forests occupy a large area of land and are still of enormous environmental, livelihood and cultural value to local people, but integrated land-use planning, better coordination among government and non-government institutions and effective technical capacity building, are needed to help stem the loss of this critical resource. The new concession review panel will lead the way in clarifying some of the issues on overlapping land designations. The development of further spatial assessments required to implement REDD+ interventions will be a key addition to the concession review panel work. A strategic plan for technical capacity building trainings, developed in collaboration with all government and non-government institutions (national and international), will be critical for the long term success of the sustainable management of forest and its biodiversity.



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REDD+ aims to mitigate climate change through sustainable forest practices, but it can also contribute to securing additional environmental and social benefits, such as soil erosion control, biodiversity conservation, the provision of food and contributions to local livelihoods.

The Government of Liberia has identified five strategic priorities, to address drivers of deforestation and forest degradation and to conserve forest carbon stocks, promote sustainable management of forests and enhance forest carbon stocks. The priorities for REDD+ planning in Liberia are reducing deforestation from the main drivers of deforestation and forest degradation (pit sawing, charcoal production, shifting agriculture and commercial logging), completing and managing a network of protected areas, preventing or offsetting the clearance of high carbon stock and high conservation value forest in agricultural and mining concessions, and ensuring that benefits for REDD+ are fairly shared.

The goal of this brief is to support the consideration of social and environmental benefits in REDD+ planning in Liberia and to provide recommendations on the next steps for spatial analyses for the country's REDD+ implementation. The maps and spatial workflows included in this brief, to identify which areas could be prioritized for REDD+ actions, were developed during two working sessions held in Liberia in February and April/May 2018, by the national GIS working group. Inputs from the participants on the main needs to successfully achieve the REDD+ National Strategy priorities, as well as other national policies goals, were collected during the working sessions and are the core of the recommendations provided in this report.

Contact:

UN Environment World Conservation Monitoring Centre
219 Huntingdon Road
Cambridge, CB3 0DL, United Kingdom
Tel: +44 1223 814636
Fax: +44 1223 277136
E-mail: climate@unep-wcmc.org
www.unep-wcmc.org

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