

Natural Capital Mapping and Accounting in Liberia

Understanding the contribution of biodiversity and ecosystem services to Liberia's sustainable development

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“Natural capital –our ecosystems, biodiversity, and natural resources– underpins economies, societies and individual well-being. The values of its myriad benefits are, however, often overlooked or poorly understood. They are rarely taken fully into account through economic signals in markets, or in day-to-day decisions by business and citizens, nor indeed reflected adequately in the accounts of society. The steady loss of forests, soils, wetlands and coral reefs is closely tied to this economic invisibility. So, too, are the losses of species and of productive assets like fisheries, driven partly by ignoring values beyond the immediate and private”

- Ellen Johnson Sirleaf, President of Liberia, at the Summit for Sustainability in Africa, Botswana, 2012

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Executive Summary

The importance of *natural capital*, the biodiversity and ecosystems that underpin human well-being and economic activity, has been recognized at national and international levels, including in the United Nations Sustainable Development Goals and the Gaborone Declaration for Sustainability in Africa. Integrating natural capital into sustainable economic growth and production, and achieving the sustainable development goals, requires countries to develop a fundamental baseline that defines the spatial extent, condition, and benefits provided by natural capital. In Liberia, examples of natural capital include IUCN Red List species; forests, mangroves and fisheries that provide sources of food and income; culturally significant species or places; rivers and wetlands that provide drinking water and hydroelectricity; and forests that contain globally significant carbon stocks. In 2016, scientists from Conservation International collaborated with the Liberia Environmental Protection Agency (EPA) to conduct a pilot project to begin to map and account for Liberia's natural capital, in order to better understand and integrate the role of natural capital as Liberia defines and implements a pathway to achieving sustainable growth and production in the future.

In this pilot project, we developed maps of essential natural capital for the following values: biodiversity, forest carbon, non-timber forest products (including bushmeat), freshwater ecosystem services (including flood regulation and sediment regulation for hydropower), and coastal protection from mangrove ecosystems. This critical information can provide a first-cut assessment enabling Liberia to make important natural resource decisions as it develops plans for achieving its national sustainable development targets. We also built one ecosystem account for Liberia's timber sector, to show the linkages between Liberia's natural capital (forests) and its national economy. An ecosystem accounting approach can dramatically strengthen planning, policy, and investor confidence through the inclusion of biodiversity and ecosystem services in a given country's statistical framework. In the future, our goal is to ensure that efforts to integrate nature into decision-making – through *Natural Capital Accounting* – revolutionize development planning and policy-making, sustainable economic growth, and subsequent reporting on for the UN SDGs.

Key findings: Protected areas

Currently, 3.8% of Liberia's land area falls within designated protected areas, and if proposed protected areas were all formally designated, this number would rise to 13.2%. Designated protected areas currently encompass 5.6% of Liberia's densest forests (those with canopy cover of >80%), and 2.7% of Liberia's moderately dense forests (30-80% canopy cover), and 0.6% of more open canopy forests (<30%). Proposed protected areas, if designated, would result in protection of a total of 20.5% of Liberia's densest forests, 9.2% of its moderately dense forests, and 4.8% of its open forests. For mangroves, 22.3% of mangroves currently fall within designated protected areas, but this number would rise to 45.6% of mangroves if proposed protected areas were formally designated.

Forests & timber

Forests in Liberia cover about 4.3 million hectares, representing 45% of the country's land area, and make a large contribution to the economy by employing a large workforce and providing as much as 50% of export revenues. In this pilot study, we developed components of a timber account, as a basis for the future development of more comprehensive Forest Accounts as well as Ecosystem Accounts in Liberia.

Based on harvest volumes recorded in the government documents, we were able to calculate the total economic contribution of the timber industry. In the year 2015 the economic contribution was USD 221 million, of which the bulk was contributed by commercial concessions (USD 212 million). In 2015, Liberia's GDP was estimated at USD 2.05 billion. Therefore, roughly 11% of GDP can be attributed to the timber industry. However, this is an under-estimate of the total contribution of the forestry sector to the country's economy, as data were not available for timber harvested for local use, which are not recorded in government statistics. Moreover, valuable non-timber forest products generated by forests were also not accounted for in this accounting exercise, which would be a component of more complete Forest Accounts. It is important to note that granted commercial concessions overlap with the most intact and biodiversity-rich natural forests in Liberia. While the timber industry makes a substantial economic contribution to Liberia's economy, it is important that development in this sector is sustainable. Nationwide data collection on the local use of timber and forest products, a comprehensive Forest Account and, ultimately a national Ecosystem Account will help ensure that the trade-offs between development and conservation are minimized, and that all the goods and services provided by forests and other ecosystems are accounted for in policy and decision-making processes.

Biodiversity

Ninety-two conservation priority areas have been identified in Liberia based on a nationally representative dataset on chimpanzees, IUCN Red Listed large mammals, and trees (Junker et al. 2015). Only around 9% of these conservation priority areas are contained within designated protected areas and 24% are within proposed protected areas. If proposed protected areas were established, 33% of conservation priority areas would be preserved. However, this would still be insufficient to preserve Liberia's biodiversity, as the 92 priority sites collectively only protect 25% of Liberia's chimpanzees and other large mammals. Nonetheless, due to the large size of some of the priority areas, protecting even 6 out of 92 priority areas would help to ensure the long-term viability of Liberia's chimpanzee population as well as a diversity of other large mammals and tree species.

Very few of the conservation priority areas fall within concessions for mining, oil palm or rubber, but there is significant overlap with timber concessions, and therefore concessions will require careful planning and management to ensure biodiversity is not compromised. New research on Liberia's coastal and marine species, birds, plants, reptiles, amphibians and freshwater fishes would help the people of Liberia understand their own biological wealth. Recommendations for safeguarding Liberia's globally significant biodiversity include innovative large-scale aggregate biodiversity offsets, restoration in conservation priority sites that have already been degraded, allocation of additional resources for monitoring and enforcement of Liberia's wildlife laws, and strengthened management of the country's protected areas.

Forest carbon

The forests of Liberia are the last remaining large intact tracts of forested land in western Africa, and contain some of the highest aboveground biomass carbon stocks of any forests in the world. Despite the acknowledged value of natural forest in Liberia for carbon storage, and other co-benefits, the forest continues to be lost to clearing for oil palm, rubber, and small-scale subsistence agriculture.

We mapped areas of tree cover loss using global data. The global dataset is not able to distinguish the loss of natural forests from loss in plantations or secondary or degraded forests, so we refer to "tree

cover loss”, not “deforestation.” Large contiguous areas of tree cover loss along Liberia’s coast are a result of recent clearing for oil palm. The band of tree cover loss in the center of the country, extending from the coast outside Monrovia to the middle of the country, is driven by rubber plantations. Finally, there are small (<1 ha) patches of tree cover loss scattered through the central corridor of the country. This loss is likely a result of human pressures, such as small scale agriculture, charcoal production, and local timber harvesting. The annual deforestation (tree cover loss) rate in Liberia is approximately 0.31%, however this number may vary significantly depending on the forest definition used, and whether plantation forests are included.

Understanding the spatial distribution of high biomass carbon forests allows decision makers to factor carbon storage into development decisions. There are two distinct regions of very high forest carbon stocks in Liberia, one in the northwest and one in the southeast. These remaining areas of intact forest are critical for carbon storage within Liberia. According to global estimates, the forests in northern Liberia have some of the highest density of above-ground biomass carbon in the world – higher even than in the Amazon rainforest. Liberia has relatively low forest carbon stock values in the central portion of the country. This is likely due to a high level of historic clearing associated with past human use. **As one of the last remaining countries in west Africa with such high carbon stocks, it is imperative that Liberia’s forests are maintained into the future.**

Our analysis indicates that areas around oil palm and rubber plantations have high vulnerability to future tree cover loss. Some of the tree cover loss in these areas is due to clearing of secondary forest or rotational cultivation, therefore it is not possible to determine how much of the vulnerability can be attributed to the loss of natural forest versus clearing of plantation trees. The center of the country, in Bong and Nimba counties, also shows widespread vulnerability to tree cover loss, likely due to small-scale clearing for human use, subsistence agriculture or charcoal production. A third hotspot for tree cover loss is found in Lofa county in the north. This area is on the border of the country where there have been proposals to create a transboundary protected area. This area also has relatively higher population density which may mean that this area is also being subjected to small-scale clearing for agriculture or other human use, and there are reports of forest fires which may explain some of the pattern of vulnerability.

Forested areas of Lofa and Nimba counties, which have both high vulnerability to tree cover loss and high carbon stocks, might be good candidates for carbon financing. More detailed ground truthing and analysis based on field sampling would need to be conducted if a REDD+ or other carbon-based conservation mechanism were to be employed, however.

We also explored rates of tree cover loss and forest carbon stocks by land use designation. Not surprisingly rubber plantations had the highest rate of tree cover loss from 2000-2015, likely reflecting established plantations with regular cultivation cycles. In oil palm plantations, the annual tree cover loss rate between 2000-2015 was twice the national average (0.06%), accounting for almost 15% of the total tree cover loss over the observation period. This could indicate clearing of forested land for new palm oil plantations, rather than a regular cultivation cycle. Interestingly, the tree cover loss rate in proposed protected areas was lower than in designated protected areas during the study period. This may be because areas proposed for protection may not have many competing land-uses, which is not uncommon as it would reduce the opportunity cost for their creation.

The mean forest carbon stock is highest in ratified and proposed timber concessions. This would suggest that high carbon stock forests are preferentially chosen for timber extraction. In terms of green growth this could prove problematic as many of the highest carbon stock forests in Liberia contain essential natural capital and ecosystem service benefits. Another troublesome trend is that the current protected area network captures less than 5% of the forest carbon in the country. **On a positive note, if all the propped protected areas were designated this number would rise to almost 18%.** Finally, we found much lower average carbon content in rubber plantations. This is likely because the rubber plantations are established under a rotating cultivation cycle, but it has large implications for their average biomass. If rubber and oil palm plantations expand in an unsustainable fashion, high carbon natural forest will increasingly be replaced by lower carbon forest crops, which will have broad implications for climate and biodiversity at a global scale.

Freshwater ecosystem services

Although fresh water is not a scarce resource in Liberia, it is vital resource important for people and the economy. People rely on water for drinking and household use as well as for hydropower generation. 61% of people do not have access to clean water, and 95% of people do not have access to public electricity, despite Liberia's high potential for hydropower production. Natural ecosystems such as forests and wetlands regulate water flows, capture sediment, and recycle nutrients, which support the stable production of electricity and improves water quality. Natural vegetation also regulates water flows and provides flood regulation services for vulnerable people downstream. In Liberia, the most important areas for *potential freshwater services* (those that are being provided by nature, even if people are not currently using them) are in three key regions. The northern key region corresponds to the area of natural forest located around the Wologizi and Wonegizi Ranges. The southern two key regions are located around the Putu Range. Based on our analyses, we recommend that vegetation cover should be maintained or restored in these watersheds to reduce erosion, ensure that rivers downstream do not become clogged with sediment, and ensure predictable flows of water for existing or future hydropower generation. In terms of *realized freshwater services* (those that are currently benefitting people), the area upstream of Monrovia is relatively more important due to the demand for water from this large population center and the Mount Coffee hydropower dam. The area upstream of Monrovia should be targeted for conservation or restoration investments to maintain and enhance the provision of freshwater services for Monrovia and the Mount Coffee hydroelectric dam. In terms of existing and planned hydropower production, the upper watershed of the St. Paul River in Lofa county, as well as the upper Cestos River watershed in Nimba county, should be targeted for conservation, to maintain the provision of freshwater ecosystem services for current and future hydropower generation. In terms of flood regulation, our analysis indicates that conserving vegetation cover in the watershed surrounding and immediately upstream of Monrovia is the most important area to reduce the risk of flooding for a large number of vulnerable people downstream.

Food security: Bushmeat and non-timber forest products

Natural capital (biodiversity and ecosystems) provides numerous benefits that support food security. In Liberia, forests provide edible plants, fruits, nuts, and habitat for wildlife which is hunted for bushmeat, as well as firewood used for cooking. About 70 percent of Liberia's rural population earn their living from forests. Freshwater, marine, and coastal ecosystems such as mangroves provide fish, shrimp, shellfish, and other products that support food security. Data on which habitats provide the most food security benefits in Liberia are not available at the national scale. Therefore, we used the accessibility of natural habitats (forests, grasslands, mangroves & swamps, and shrublands) to people as a proxy

indicator. Accessibility was modeled based on population, roads, land cover types, slope, and other variables. This model is based on the assumption that natural habitats that are more accessible to people are providing more non-timber forest products than habitats which are more difficult to access. We found that the most accessible natural habitats are located along the central part of Liberia, along the coast, and along roads.

These areas may be subjected to unsustainable levels of harvest and could be priorities for further research to establish sustainable levels of harvesting for different species. These areas could also be prioritized for the establishment of sustainable management regimes (such as community conservation agreements) to ensure that rare and endangered species are not over-harvested. Finally, these areas could be prioritized for monitoring and enforcement of existing regulations, such as for protected species.

Coastal protection

In Liberia, coastal mangroves provide numerous benefits to people. Mangroves provide fish nursery habitat, as well as providing sources of crabs, crawfish, oysters, fuelwood, and other provisioning services. Mangroves store significant amounts of carbon in their soil, and trap sediment, stabilizing coastlines and reducing coastal erosion. Unfortunately, there are no data on the level of ecosystem services provided by mangroves in Liberia. Therefore, for these analyses, we conducted modeling of a single service only: coastal protection. The model is based on a combination of global data on human population, wind, and wave energy as well as data specific to Liberia on coastal geomorphology, mangrove habitat, and other variables. These results indicate that the most vulnerable coastal areas to erosion are in Bassa, Rivercess, Sinoe, and Grand Kru counties. Coastal protection provided by mangroves is relatively high in Bassa and Rivercess counties, and to a lesser extent in Sinoe county, indicating that these mangroves should be conserved to ensure they continue providing this valuable benefit to people along the coast. In Sinoe county, if environmental conditions are conducive to mangroves, then mangrove restoration or planting might help protect Liberia's coastline where large areas of the coastline are not currently protected by mangroves. Currently the only protected area that includes mangrove areas is located near Lake Piso. Therefore, most mangroves in Liberia are currently unprotected and may be threatened with loss or conversion in the future. Specifically, the mangroves that may be providing the most benefits in terms of coastal protection, according to our model, are currently unprotected. The modeling results have a high level of uncertainty and should be considered indicative of where mangroves are providing protection to Liberia's coastal population: additional field-based research is needed to validate the modeling results.

Combined maps of Essential Natural Capital

We identified the most important areas from each of the maps above. For biodiversity, we directly adopted the existing conservation priority sites (Junker et al. 2015) as "essential natural capital for biodiversity." The FDA has a goal of conserving 30% of Liberia's forest. We used this goal to identify a threshold (233 tC/ha) that would allow us to identify the 30% of Liberia's forest with the highest biomass carbon stocks. For the purposes of this analysis, we define these areas as "essential natural capital for forest carbon." For freshwater, we identified the top 30% of watersheds providing ecosystem services to population centers and existing hydropower facilities. For coastal protection, we identified the top 30% of mangroves that protect Liberia's vulnerable coastal populations. We combined these areas in a single map of "essential natural capital." These areas, which are concentrated in the intact

forested landscapes in the northwest and the southeast, should be targeted for conservation, either through protection or through community-based conservation or other measures, as they represent the most essential of Liberia's natural capital.

We also included essential natural capital for food security, as defined above, as a separate map. These areas, while essential, are also threatened with over-use. Unlike the areas above, which should be targeted for protection, these areas could be targeted for community-based conservation or sustainable management, such as sustainable agriculture and agroforestry, to ensure they continue to provide a sustainable level of firewood, food, and forest products into the future.

By overlaying the map of essential natural capital with the map designated and proposed protected areas, we can see that designated protected areas do capture some (7%) of Liberia's essential natural capital, and if proposed protected areas were to be established, they would capture even more (an additional 19%, for a total of 26%). However, 93% of Liberia's essential natural capital is currently unprotected, and the majority (74%) of Liberia's essential natural capital will remain unprotected, even if all proposed protected areas are established.

By overlaying the map of essential natural capital with other data, such as concession areas, vulnerability to tree cover loss, and accessibility to people, we can get a sense of which factors might be threats to Liberia's essential natural capital now and in the future. These maps indicate that Liberia's essential natural capital is not very vulnerable to tree cover loss, and is relatively inaccessible to people – likely because essential natural capital tends to be located in relatively remote areas. This is good news, as it means these areas are probably less threatened with clearing and over-harvesting. The exception are the mangrove ecosystems along the coastline, which are relatively accessible to people. There are, however, some remote areas that are still targeted for hunting, especially for high value species such as primates, which means that they are likely already subject to unsustainable levels of hunting for certain species.

Most of Liberia's rubber and mining concession areas do not overlap with Liberia's essential natural capital. Some palm oil concessions, however, particularly in the north, do overlap with some areas of essential natural capital. Timber concessions by and large also overlap with Liberia's essential natural capital. Special attention should be paid to these areas to ensure they are sustainably managed. A multitude of management strategies such as community forestry, Payments for Ecosystem Services (PES) schemes, REDD+, or other creative solutions are needed to ensure the flow of benefits from natural capital is sustained.

Introduction

Nature is fundamental to achieving social and economic development. The fundamental role of *natural capital*, the biodiversity and ecosystems that underpin human well-being and economic activity, has been recognized at an international level in the UN Sustainable Development Goals (SDGs). It has also been recognized in multi-country agreements such as the Gaborone Declaration for Sustainability in Africa (GDSA), a multi-country commitment signed in 2013 on the integration of the contribution of natural capital to sustainable economic growth, maintenance and improvement of social capital and human well-being into development and business practice. Yet the integral role of natural capital in achieving those goals is still poorly understood and inadequately represented in business decision making and national development plans.

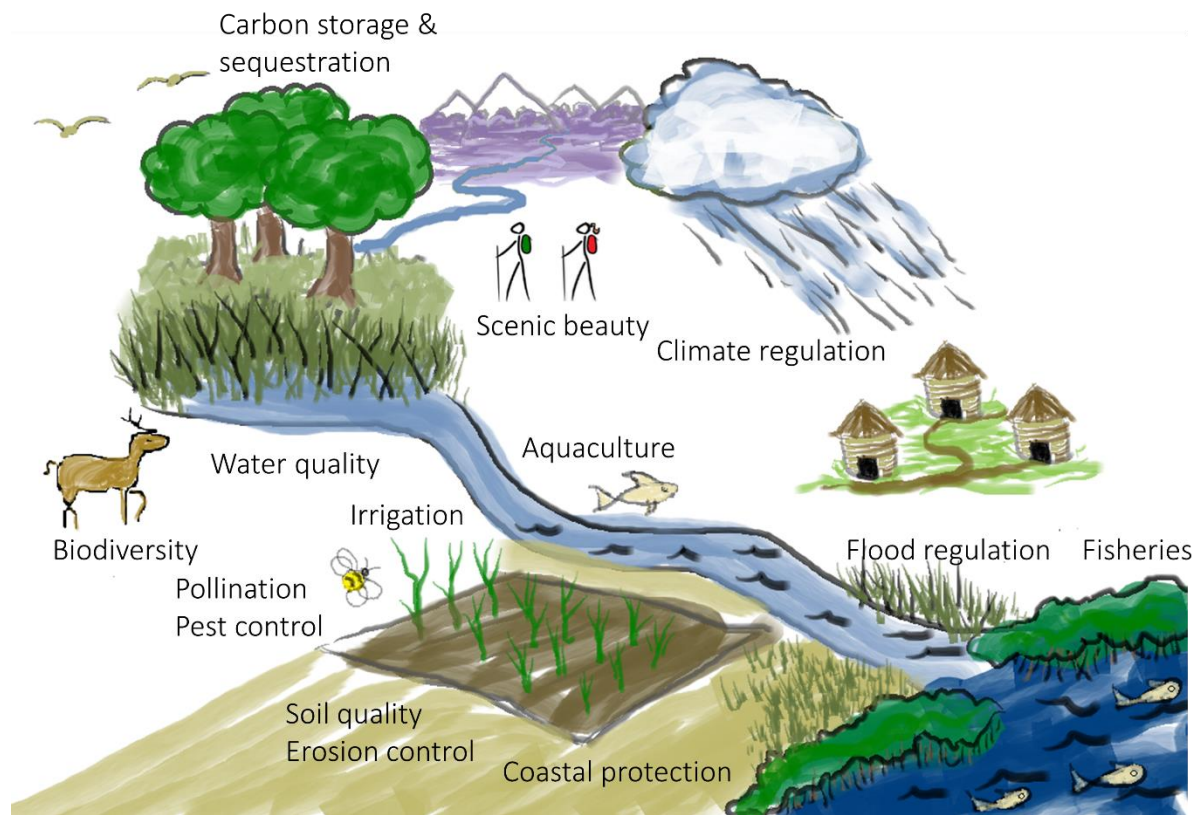


Figure 1. Illustration of some of the ways that natural capital (biodiversity and ecosystems) provide benefits (ecosystem services) that benefit people

Integrating natural capital into sustainable economic growth and production – and ultimately achieving sustainable development goals, requires countries to develop a baseline that defines the spatial extent, condition, and benefits provided by natural capital. In other words, governments need access to information that tells them where different types of natural capital is found, how much of it is within their national borders, and whether it is in good or bad condition.

Scientists from Conservation International have developed and tested approaches for measuring, mapping, and valuing natural capital. In 2016, we collaborated with the Liberia Environmental Protection Agency (EPA) to conduct a pilot project to begin to map and account for Liberia's natural

capital, in order to better understand the role of natural capital in economic growth and production. That understanding will help governments make better decisions about how to best manage their natural capital, to ensure that it continues to provide a flow of economic benefits. By building a foundation of spatial and economic data on natural capital, our aim was also to support Liberia's sustainable development, to safeguard Liberia's biodiversity and ecosystems and the benefits that they provide, in order to secure a more prosperous future and the well-being of its people. This pilot project also assists Liberia in making progress towards the commitments of the Gabarone Declaration for Sustainability in Africa (GDSA), specifically, paving the way to Natural Capital Accounting.

Mapping Essential Natural Capital (MENC)

In order to account for the value of nature, you must first have an understanding of the extent (size) and condition (health) of natural ecosystems, and the flows of benefits they provide to people and the economy (see Figure 1). *Natural capital* is defined as the stock of biodiversity and ecosystems that provides a flow of benefits (ecosystem services) that support human well-being and economic activity. For example, the trees in a forest are a type of 'stock' of natural capital. These trees provide a flow of benefits, including regulating flows of water which reduces flooding downstream. *Essential natural capital* is the sub-set of all natural capital that provides benefits that cannot be substituted or replaced. Some examples include:

- Globally significant biodiversity
- Rivers or streams that provide the sole supply of drinking water for a village
- Forests that provide sources of food to people in times of crisis
- Sacred sites that are part of a culture's identity

In Liberia, examples of essential natural capital include several IUCN Red List species such as the western chimpanzee, pygmy hippo, and slender-snouted crocodile; forests, mangroves and fisheries that provide sources of food and income for poor rural populations; culturally significant species or places; rivers and wetlands that provide sources of drinking water and hydropower production; and forests that contain globally significant carbon stocks.

Mapping Essential Natural Capital (MENC) provides baseline information on the extent, condition, and benefits that natural ecosystems provide to people and the economy. Conservation International has developed a framework for mapping a country's essential natural capital, which includes:

- 1) Defining the objectives of the mapping project;
- 2) Identifying the important human or economic sector beneficiaries of ecosystem services;
- 3) Identifying the most important biodiversity values and ecosystem services provided by ecosystems in the country;
- 4) Collecting relevant spatial data;
- 5) Identifying criteria to distinguish "essential" from non-essential natural capital;
- 6) Conducting spatial analyses using Geographic Information Systems (GIS) and ecosystem service modeling software;
- 7) Reviewing and refining preliminary results with stakeholder input; and
- 8) Sharing results with stakeholders and decision makers (*Figure 2*).

All these steps require consulting with local experts and stakeholders.

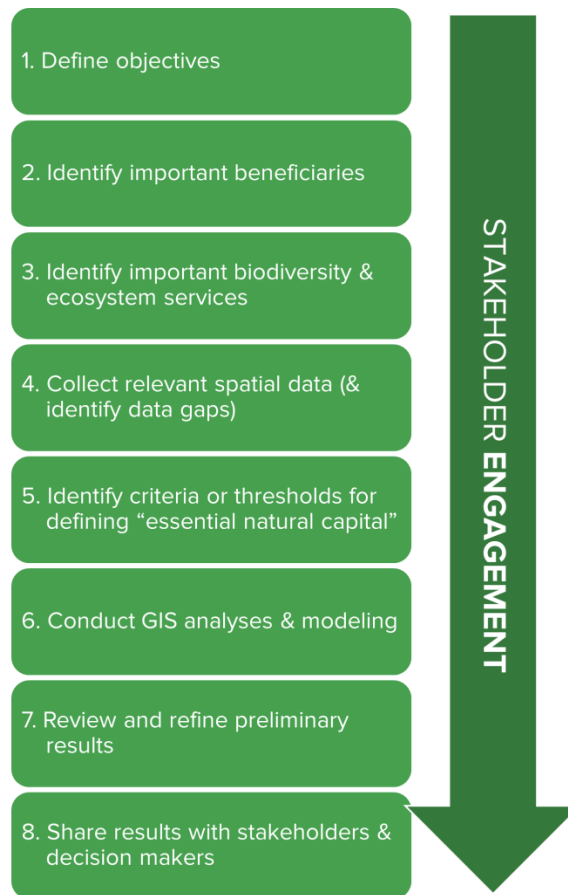


Figure 2. Steps for mapping natural capital

In this project, we developed maps of essential natural capital for the following values: biodiversity, forest carbon, bushmeat and non-timber forest products, freshwater ecosystem services (including flood regulation and sediment regulation for hydropower), and coastal protection from mangrove ecosystems. The methods used for these analyses, results, and maps are described in greater detail in the following sections.

Maps of natural capital provide information that can be used for decision making by spatially identifying key ecosystems and *ecosystem services* (the benefits that nature provides to people), and prioritizing potential actions to conserve and sustainably manage these values. Maps of essential natural capital are needed by governments to support sustainable development planning, for example through evaluation of zoning options and tradeoffs; by development banks seeking to make decisions about project investments; by companies seeking to meet sustainability targets; and by civil society organizations seeking to conserve biodiversity and improve human well-being.

This critical information can provide a first-cut assessment enabling a country to make important natural resource decisions as it develops plans towards achieving its national sustainable development targets. It also provides countries with a foundation of spatial information and an incentive to effect the institutional changes needed to move towards ecosystem accounting. However, the MENC approach is different from natural capital accounting (see below) or ecosystem valuation exercises in a few key

ways. First, MENC is a spatial mapping assessment and is therefore not designed to identify monetary values nor to result in the development of natural capital accounts (such as those that would be directly integrate with a government’s system of national accounts). Another key difference is that the mapping exercise has been conducted by Conservation International, whereas natural capital accounting efforts are ideally conducted by the government itself. However, MENC is an important first step in quantifying and understanding nature, and in the context of this pilot project, was designed to provide information that could help Liberia determine spatial priorities as it builds longer-term strategies for natural capital accounting.

To illustrate the value of this information for multiple sectors and services, we have taken the results of MENC and built one ecosystem account for Liberia’s timber sector, to show the linkages between Liberia’s natural capital (forests) and its national economy. The results of this account are found in subsequent sections of this report.

Natural Capital Accounting (NCA)

One of the commitments agreed to by the GDSA member countries was to integrate, “the value of natural capital into national accounting and corporate planning and reporting processes, policies, and programs.” An ecosystem accounting approach can dramatically strengthen planning, policy, and investor confidence through the inclusion of biodiversity and ecosystem services in a given country’s statistical framework. This enables better understanding of the interactions between the environment and the economy and directly addresses the current lack of ecosystem goods and services in the national balance sheet, while informing on key business impacts and dependencies on natural capital. Our goal is to ensure that efforts to integrate nature into decision-making – through *Natural Capital Accounting* (NCA) revolutionizes development planning and policy-making, sustainable economic growth, and subsequent reporting on these goals for the UN Sustainable Development Goals (SDGs).

CI recognizes that while some countries have strong examples of NCA, most GDSA countries face hurdles in developing their natural capital accounts, which can include needing additional technical capacity, data, and the development of institutional arrangements that support ecosystem accounting. In order to get governments to a stage where they can fully produce different types of natural capital accounts, our NCA strategy focuses on getting a head start on the fundamentals of NCA. CI does this by providing assistance to catalyze capacity, dialogue, organizational ability, and data for countries to conduct systematic and repeated natural capital accounting with a view towards building momentum that grows government and investor confidence. Our objective is to provide countries with the foundations to formulate the right questions, and to assess, plan, and monitor their ecosystems and their contribution to human well-being. In this pilot project, we made a first attempt to develop a natural capital account for Liberia’s timber sector, to build a working example of ecosystem accounting that will demonstrate the contribution of natural ecosystems to Liberia’s national balance sheets.

The Liberian Context

The Republic of Liberia is situated on the west coast of Africa, encompassing a land area of approximately 111,370 km² (about 43,506 square miles) (EPA 2012). It has a population of approximately 4.5 million (World Bank 2015), more than 70% of the population is rural and depends principally on biological resources for livelihoods (EPA 2012). Average annual rainfall along the coastal belt is over 4,000 mm and declines to 1,300 mm at the forest-savanna boundary in the north (EPA 2012).



Figure 3. Map of Liberia

Biodiversity & ecosystems

Liberia has globally significant biodiversity values. The country falls within the Guinean Forests of West Africa Biodiversity Hotspot, which is a global priority for primate conservation due to high levels of endemism (92% of the hotspot’s 30 primate species are endemic) and high level of threat (CEPF 2015). Liberia’s two largest forest blocks in the northwest and southeast have high levels of biodiversity and endemism (CEPF 2003), and are some of the best remaining habitat for chimpanzees, elephants, pygmy hippos, and other large mammals. Liberia’s forests are home to over 7,000 chimpanzees, one of the last viable chimpanzee populations in West Africa and a priority for conservation of the species (Junker et al. 2015a, Tweh et al. 2014). Liberia also has a high diversity of other species, with 2,000 flowering plants (225 timber species), 600 bird species, 150 mammals and 75 reptiles (EPA 2012). Within the country, 92 conservation priority sites have been identified based on recent surveys and modeling of chimpanzees, large mammals, and trees (Junker et al. 2015). The authors found that existing and proposed protected areas were insufficient to conserve chimpanzees and large mammals in Liberia, and that logging and mining concessions largely overlapped with proposed protected areas and conservation priority areas identified in their study. For more details and a map of priority areas, see the section below on Mapping Essential Natural Capital for Biodiversity.

Liberia is dominated by forests, including lowland forests comprised of wet evergreen forests in areas with rainfall above 2,000 mm and moist semi-deciduous forests in areas with rainfall between 1,600 mm

and 2,000 mm (FFI and ProForest 2013). Other ecosystems within Liberia include mangroves, shrublands, and grasslands (Figure 4). Continuous high density forests once dominated the whole territory of Liberia. However, since recent times, land development, timber extraction and introduction of rubber plantations have opened areas of high density forests and resulted in the expansion of agriculture and mining. As a result, man-made savanna is spreading along the coast and extending inland, while the same can be observed along the northern Liberian border. This area is now supporting a diverse mix of vegetation ranging from low bush, patches of high forest, gallery forests near rivers, grass dominated, thorny shrubs, and cultivated land (Gatter 1998).

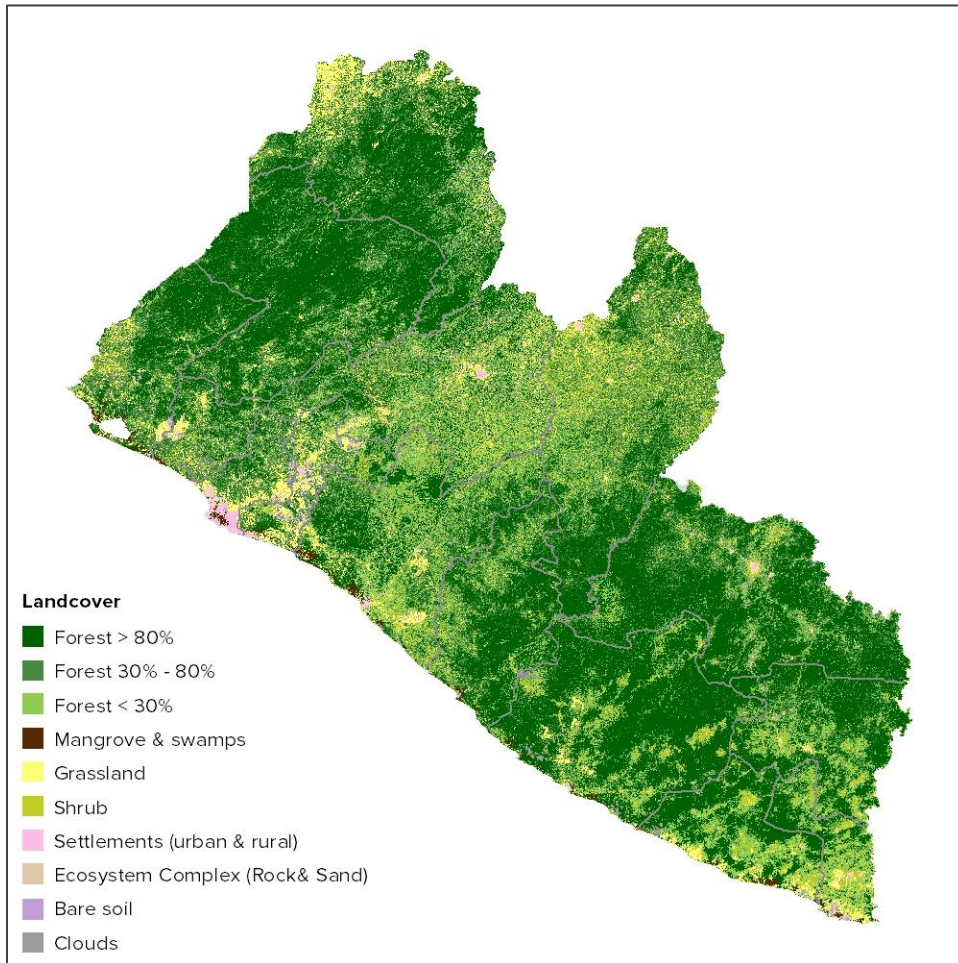


Figure 4. Landcover in Liberia. Data source: JV/Metria Geoville and FDA 2016

Threats to Liberia’s biodiversity and ecosystems include hunting and harvesting of wildlife for food, shifting cultivation practices, unregulated timber extraction, mining, firewood collection, charcoal production (due a lack of public electricity), invasive species, use of agrochemicals, and inadequate law enforcement (EPA 2012).

There is a lack of quantitative data on Liberia’s biodiversity and ecosystems, especially outside of protected areas, and for certain taxonomic groups (for example, freshwater species and plants.) This is

primarily due to the years of civil conflict (1989–1997 and 2002–2003), which made biological surveys impossible. This lack of information severely hampers conservation efforts.

Protected Areas

As of 2016, Liberia has four designated protected areas (Sapo National Park, East Nimba National Park, Lake Piso Multiple Use Reserve, and the newly designated Gola Forest National Park), encompassing approximately 362,000 ha, and twelve proposed protected areas (~910,000 ha). Altogether, these areas comprise approximately 1,272,000 ha.

In 2003, the Liberian Forestry Development Authority (FDA) signed the Act for the Establishment of a Protected Forest Areas Network, which committed the government to establish, “a biologically representative network of protected areas covering at least 30% of the existing forest area” (Junker et al. 2015).

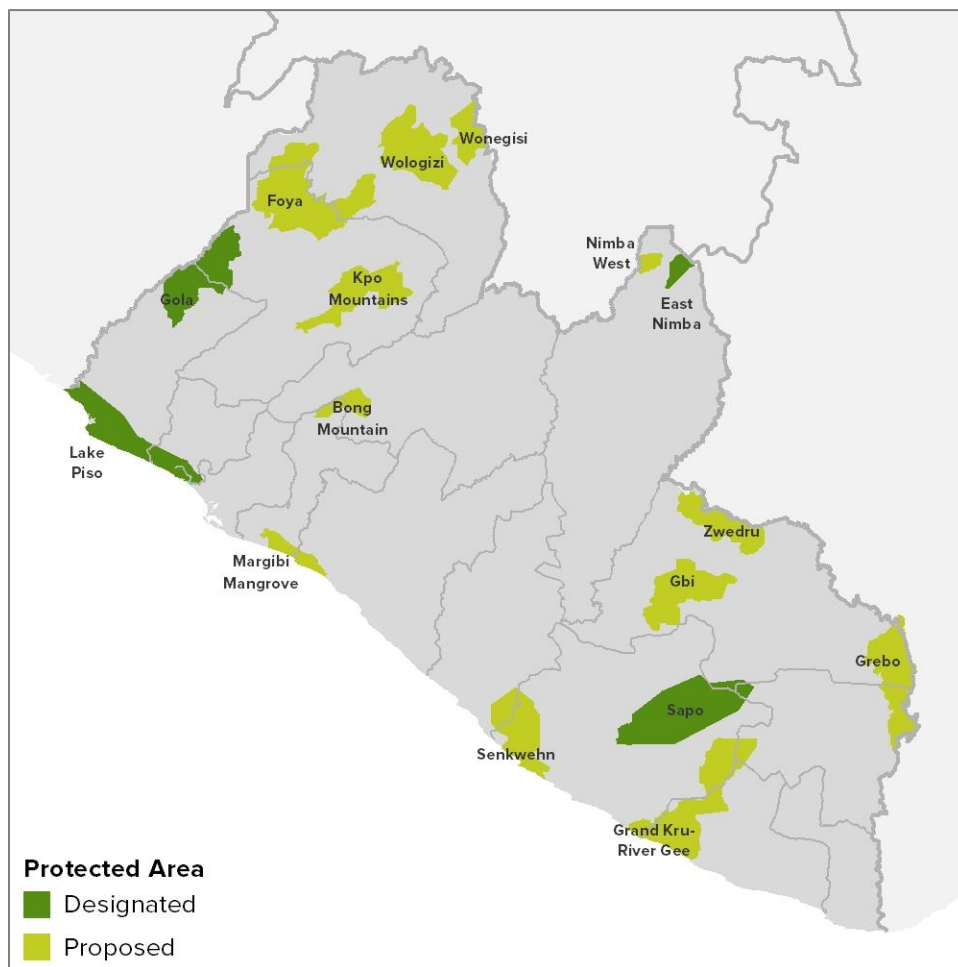


Figure 5. Designated and proposed protected areas in Liberia. Data source: IUCN and UNEP-WCMC 2016.

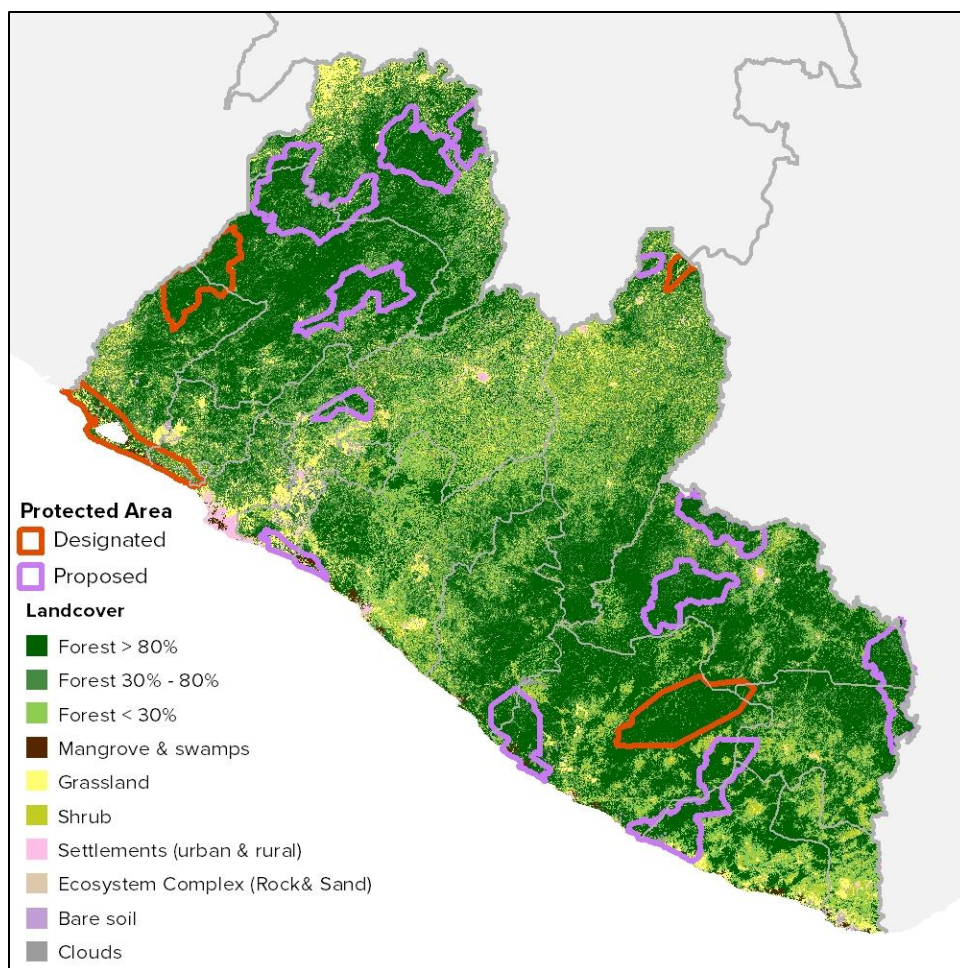


Figure 6. Landcover, designated protected areas, and proposed protected areas.

Based on our analyses, 3.8% of Liberia’s land area currently falls within designated protected areas (Figure 6 and Table 1. Area in different landcover types, and within designated and proposed protected areas (PAs). Data source: JV/Metria Geoville and FDA 2016.), and if proposed protected areas were all formally designated, this number would rise to 13.2%. Designated protected areas currently encompass 5.6% of Liberia’s densest forests (those with canopy cover of >80%), 2.7% of Liberia’s moderately dense forests (30-80% canopy cover), and less than 0.6% of more open canopy forests (<30%). Proposed protected areas, if designated, would result in protection of a total of 20.5% of Liberia’s densest forests, 9.2% of its moderately dense forests, and 4.8% of its open forests. For mangroves, 22.3% of mangroves currently fall within designated protected areas, but this number would rise to 45.6% of mangroves if proposed protected areas were formally designated.

Table 1. Area in different landcover types, and within designated and proposed protected areas (PAs). Data source: JV/Metria Geoville and FDA 2016.

Landcover	Area (ha)	Percent	Area in Designated PAs (ha)	Percent in Designated PAs	Area in Proposed PAs (ha)	Percent in Proposed PAs	Area in Designated & Proposed PAs (ha)	Percent in Designated & Proposed PAs
Forest >80%	4,364,751	45.37%	246,190	5.6%	648,289	14.9%	894,479	20.5%
Forest 30-80%	2,167,707	22.53%	59,081	2.7%	139,961	6.5%	199,042	9.2%
Forest <30%	1,523,056	15.83%	8,538	0.6%	64,380	4.2%	72,918	4.8%
Mangrove	37,142	0.39%	8,268	22.3%	8,656	23.3%	16,924	45.6%
Settlements	44,604	0.46%	254	0.6%	211	0.5%	466	1.0%
Water	60,529	0.63%	15,591	25.8%	4,749	7.8%	20,340	33.6%
Grassland	626,038	6.51%	16,484	2.6%	19,551	3.1%	36,035	5.8%
Shrub	606,919	6.31%	5,666	0.9%	13,936	2.3%	19,601	3.2%
Bare soil	173,917	1.81%	1,738	1.0%	3,831	2.2%	5,568	3.2%
Ecosystem complex (rock and sand)	2,252	0.02%	446	19.8%	386	17.1%	832	36.9%
(Clouds)	14,391	0.15%	0	0.0%	5,553	38.6%	5,553	38.6%
TOTAL	9,621,306	100%	362,256	3.8%	909,503	9.5%	1,271,759	13.2%

Population & socioeconomics

Liberia has a population of approximately 4.5 million (World Bank 2015), of which one-third live in Montserrado (where the capital city of Monrovia is located) (LISGIS 2016) (Figure 7). Liberia has more than 16 major ethnic groups, the largest ones include the Kpelle, Kru, Bassa, Krahn, Grebo, and Lorma. Smaller ethnic groups include Belle, Sapo, Mende, Gbandi, Vai, Mandingo, Gio, Mano, Kissi and Gola (EPA 2012). These ethnic groups constitute 97% of the population. More than 70% of the population is considered rural and depends principally on biological resources for livelihoods (EPA 2012). Liberia's poverty rate is high, with 83.8% living on less than USD 1.25/day (UNDP 2013). As of 2008, nearly 52% of households in the country had poor access to health facilities, with travel times of more than 40 minutes to the nearest facility (LISGIS 2011). In 2001-2002, human mortality per annum was caused mainly by malaria (16.5%), anemia (12.6%), respiratory infections (12.5%), diarrhea (5.6%), hypertension (4.6%), and malnutrition (4.4%) (EPA 2012). Infant mortality, under-five mortality, and child mortality are still relatively high in Liberia.

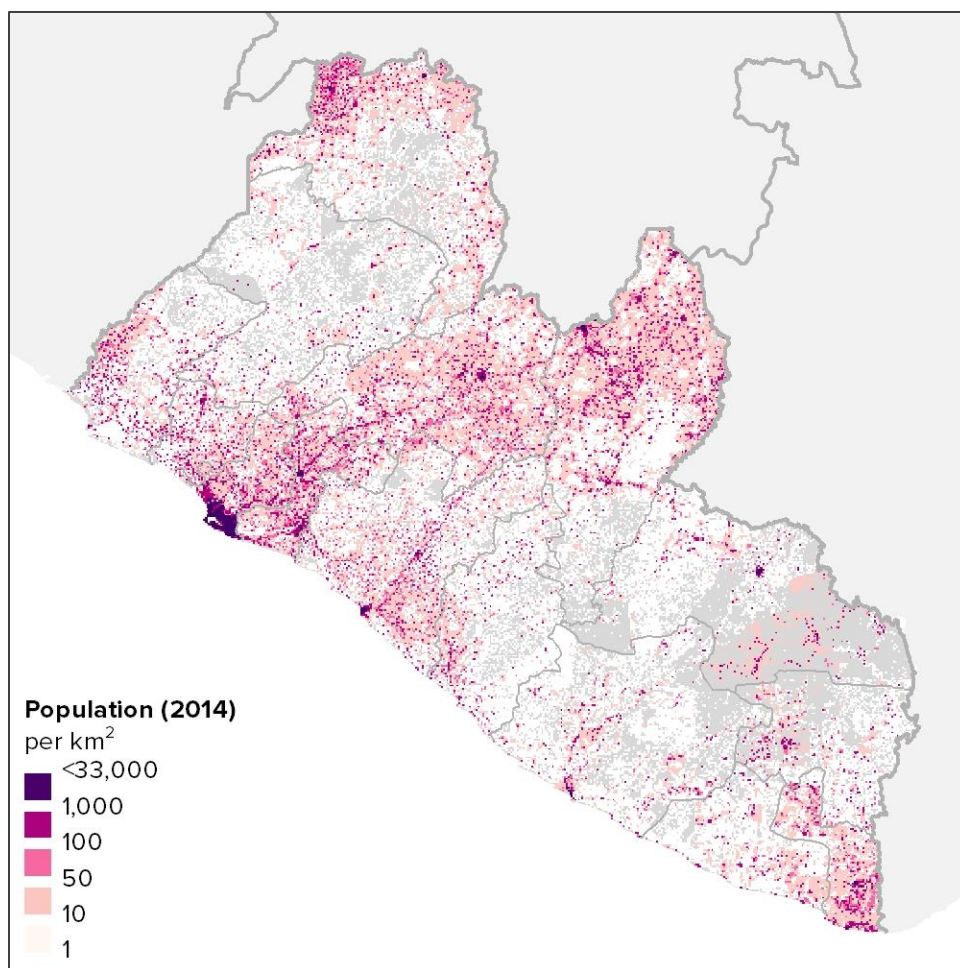


Figure 7. Ambient population density in Liberia (people per km²). Data from LandScan (Bright et al. 2014).

In 2014, 49.0% of households reported suffering from food shortages in the 12 months prior to being interviewed (LISGIS 2016). Food insecurity was higher in rural areas with 60.3% of households reporting such shortages, than in urban areas where 41.6% of households reporting the same.

Ecosystem services

Natural ecosystems in Liberia provide critically important benefits to its people, including providing sources of food, energy, water, building materials, as well as cultural identity. Natural ecosystems provide services that benefit agriculture in the form of soil quality, pest regulation, and local climate regulation. Rice is Liberia's staple food, but cassava, eddoes (a tuber), sweet potatoes, hot red peppers, and bananas also contribute to the Liberian diet (EPA 2012).

Natural ecosystems provide sources of fish and bushmeat which are critical to Liberia's food security. Along the coast, people receive a large portion of their protein intake from fish. Nearly 58% of Liberia's population lives in coastal regions, and the fisheries sector provides about 65% of the population's protein needs (TEEB Liberia). Consumption of bushmeat is also widespread; based on a 2002 survey, 96% of respondents reported eating bushmeat (Hoyt and Groff 2002). Bushmeat may represent 75% of Liberia's meat consumption, with an approximate replacement value of USD100 million (Hoyt 2004).

Forest products are critically important sources of food and income; about 70% of Liberia's rural population earn their living from forest-related products (USAID 2009). Natural ecosystems also provide the majority of water for drinking and household use, especially in rural areas; in 2014, rivers, lakes or creeks were the largest sources of drinking water in rural areas (LISGIS 2016). Forests, wetlands, and other ecosystems provide various hydrological services which are essential for Liberia's people and economy, such as flood regulation, protecting water quality, regulating water flows, and controlling erosion and sediment deposition (CEPF 2015). All these services help protect people from catastrophic flooding and support the provision of hydropower, which will be critical to Liberia's energy future.

Natural ecosystems also provide sources of fuelwood and charcoal for cooking. As of 2008, 57% of all households used wood as their main source of cooking fuel, and 37% used charcoal (LISGIS 2011). In 2014, 81.3% of households did not have access to electricity; in rural areas this proportion was much higher (94.2%, LISGIS 2016). Natural ecosystems provide a source of timber and other raw materials. In 2014, the majority of households had walls made of mud and sticks (40.5%) (LISGIS 2016). Concrete and cement blocks (25.2% of households) and mud bricks (22.2%) are the next most common materials for the walls. In rural Liberia, the use of mud and sticks and mud bricks are ubiquitous (94.4%).

Globally, Liberia's forests are important for regulating the climate as they absorb and store carbon dioxide from the atmosphere. The nation's forests are estimated to have some of the highest carbon stocks in the world; over 300 tonnes of carbon per hectare in some areas, which is higher even than the Amazon rainforest (see section on Mapping Essential Natural Capital for Climate Mitigation, below).

Coastal ecosystems such as mangroves are important for stabilizing Liberia's coastline and preventing erosion, as well as providing breeding grounds for fish and shrimp, which supports both small-scale subsistence fisheries as well as offshore commercial fisheries. Mangroves hold great significance for local communities who depend on mangrove wetlands for subsistence and local commerce, using the wood to provide energy supplies, food, shelter and other ecological services (Clark 2016).

Lastly, natural ecosystems provide important cultural services to Liberia's people, including cultural identity, recreation, and tourism. Examples of culturally important sites include ancestral burial grounds, sacred groves, culturally protected forests such as the Poro bush, shrines, river deities, mountains, waterfalls and other deities, individual species of plants or animals that are culturally protected as totems, and forest products that are used for religious rituals such as raffia (FFI and ProForest 2013). Within Liberia, coastal promontories such as Cape Mount, Cape Mesurado and Cape Palmas and beaches together with Lake Piso and Lake Shepherd have potential for tourism (EPA 2012).

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Accounting for timber resources in support of ecosystem accounting in Liberia

Compiled by Mahbubul Alam and Daniel Juhn

Introduction

Forests in Liberia cover about 4.3 million hectares, representing 45% of the country's land area (JV/Metria Geoville 2015). These forests harbor a rich diversity of flora and fauna. A total of 600 bird species, 150 mammals, 75 reptiles and more than 2,000 plant species have been recorded in the country (EPA 2012). These forests also make a large contribution to the economy by employing a large workforce and earning revenue, which made up as much as 50% of export revenues in the 1980s, 1990s, and 2000s (FDA 2006). Despite such economic potential, the UN Security Council sanctioned a ban on timber export in 2003 since forest products revenues were fueling decade-long armed conflicts; the sanction was eventually lifted in 2006.

To manage the rich natural resources of Liberia, the Forestry Development Authority (FDA) was created in 1976 by a Special Act that repealed all previous forestry and wildlife laws and, "granted the Forestry Development Authority the power to issue, amend and rescind forestry and wildlife regulations" (FDA 2006). Three decades later, in 2006, the government released its "National Forestry Policy and Implementation Strategy", with a focus on maximizing the benefits of the forestry sector to Liberian society, but with a special emphasis on the contribution of the sector to poverty alleviation. The aim of national forest policy is:

To conserve and sustainably manage all forest areas, so that they will continue to produce a complete range of goods and services for the benefit of all Liberians and contribute to poverty alleviation in the nation, while maintaining environmental stability and fulfilling Liberia's commitments under international agreements and conventions. (FDA 2006, 10p)

However, as is common in many countries around the world, this means that competing interests between production of goods and services (including agricultural commodities) and conservation of forests and its resources will likely follow. In such a situation, Natural Capital Accounting (NCA) is regarded as a powerful framework to measure ecosystem goods and services, develop indicators to monitor them, and formulate appropriate policy responses so that those tradeoffs are minimized.

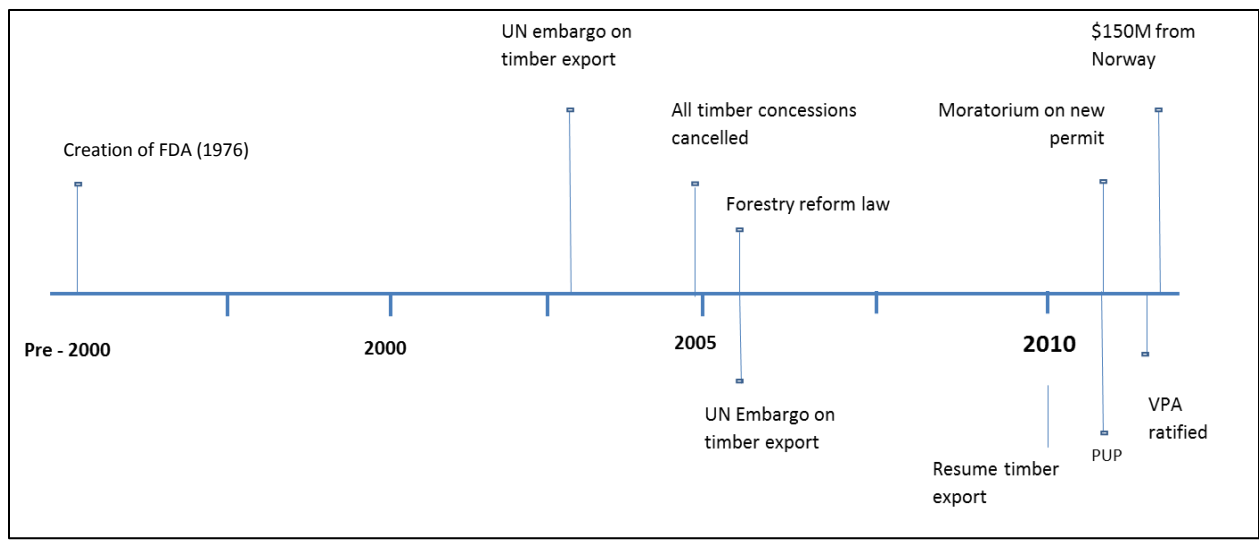


Figure 8. Major events, policies and processes related to forestry sector in Liberia

NCA is a structured way for collecting, organizing, analyzing, and presenting data on stocks and flows of nature’s benefits and their contribution to the economy¹. The United Nations System of Environmental-Economic Accounts (SEEA) has been developed to support the development of statistics on the relationship between the environment and the economy (United Nations. 2003). Timber resources of countries are measured and reported following the Central Framework (CF) guidelines of SEEA².

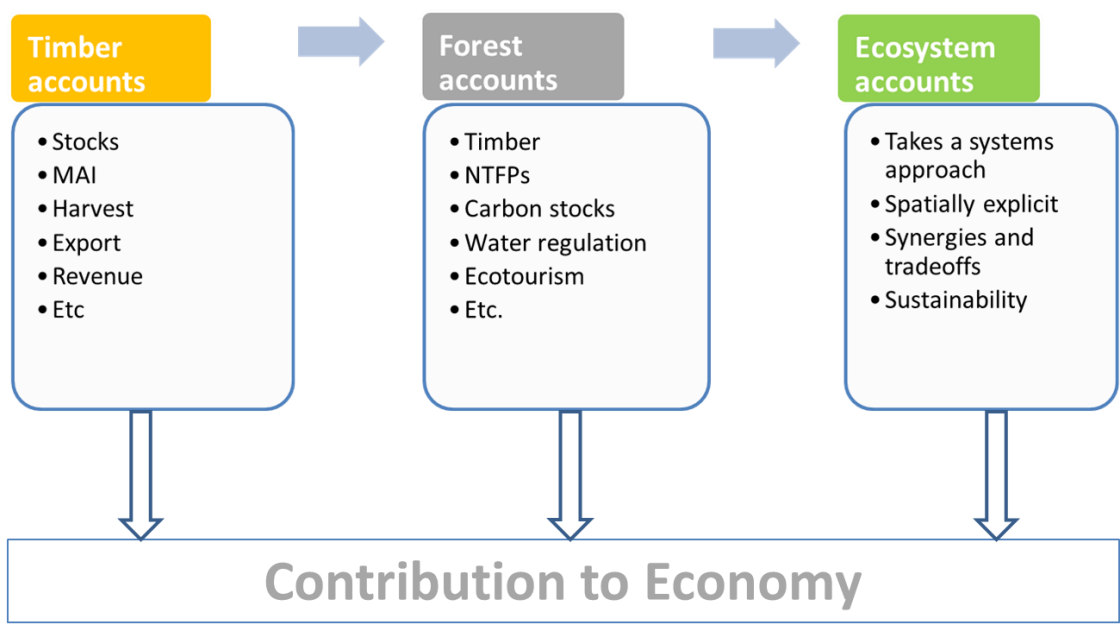


Figure 9. Components and characteristics of timber, forest and ecosystem accounts

¹ For further information on Natural Capital Accounting refer to the following website: <http://www.wavespartnership.org/>
² See for further information: https://unstats.un.org/unsd/envaccounting/seeaRev/SEEA_CF_Final_en.pdf

The goal of this pilot project, as reported here, was to develop components of timber accounts, in support of a broader NCA in Liberia conducted by CI in collaboration with government agencies. Data and analyses reported in this document can be used as a basis for comprehensive Forest Accounts (see examples in Goio et al 2008; Sekot 2007) as well as Ecosystem Accounts (Figure 9). Specific objectives of the analysis were:

- To review policies relevant to timber extraction
- To understand the distribution of timber extraction
- To analyze contribution of timber to economy
- To address general implications for NCA in Liberia and recommend future directions

Data and Methodology

Four different data sets were used in the analysis: 1) timber concession GIS layers (for concessions which were ratified or proposed (see Figure 10); 2) location and quantity of timber harvest in those concessions; 3) quantity of timber harvested through chain-saw logging; and 4) financial data to calculate “resource rent”. Most of the datasets were collected from government sources (mostly FDA); some of them, especially financial data, were verified and adjusted reviewing alternative data sources in a few instances.

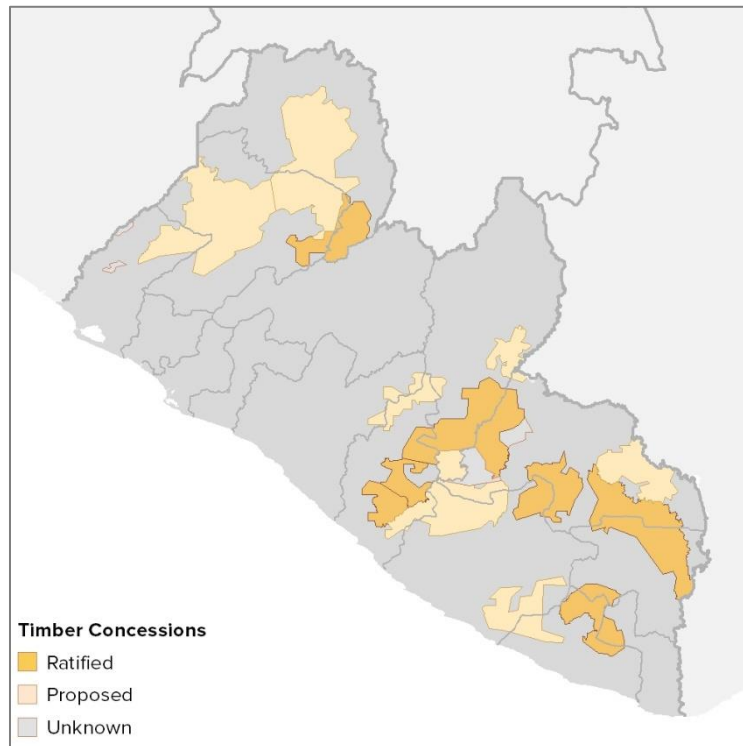


Figure 10. Proposed and ratified timber concessions in Liberia (Source: GoL)

Table 2, below, presents commercial concession data on contract types, operating hectares and harvested volumes. Data reveals that about 1.2 million ha of concession areas were harvested in the year 2015 from three contract types: Forest Management Contract (FMC), Timber Sales Contract (TSC) and Community

Forest Management Agreement (CFMA). A total of 1 million m³ of timber were harvested through these contracts. Roughly, the intensity of harvest is 1 m³/ha.

Table 2. Timber concession contracts, operating hectares and volume harvested (Source: FDA)

Contract Type	Contract location	Operating hectares	Volume (m ³) harvested
FMC – A	Lofa County	119,240	0
FMC – B	Rivercess County	57,262	748,738
FMC – C	Nimba, Gibi & Doru	59,374	15,416
FMC – F	River Gee & Grand Gedeh	254,583	17,778
FMC – I	Grand Gedeh & Sinoe	131,466	25,573
FMC – K	Nimba, River Cess & Grand Gedeh	266,910	164,728
FMC – P	Grand Kru, Maryland & River Gee	119,344	14,345
TSC A15 & A16	Grand Cape Mount	5,000	623
CFMA- 2	Grand Gedeh	135,667	32,219
CFMA- 4	Nimba, Gibi & Doru	66,150	7,343
TOTAL		1,214,996	1,026,763

Chain-saw logging is the other primary form of timber harvest in Liberia, although relatively small in extent compared to commercial concessions. 43,000 m³ of chain-saw harvest were reported in the year 2015, slightly higher than the previous year (39,000 m³) (Table 3). Harvested timber is transported in two forms: sawn timber and round pole. Chain-saw logging remains less significant in terms of total volume, although the volume reported here is clearly an underestimate, since this record represents timber transported only towards Monrovia, the capital city. Any timber harvest and those used locally in other cities, towns, and villages are not recorded, and could be significant. Further research is needed to quantify the remaining timber volume.

Table 3. Quantity of timber harvested and transported through chain-saw logging (Source: FDA)

Quarter	Wood type	2014		2015		Change
		Quantity	m ³	Quantity	m ³	
Q1	Sawn (pieces)	99,587	5,278	184,875	9,798	4,520
	Round pole (loads)	93.5		115		

Quarter	Wood type	2014		2015		Change
		Quantity	m ³	Quantity	m ³	
Q2	Sawn	337,517	17,888	281,492	14,919	-2,969
	Round pole	2101/2		273		
Q3	Sawn	69,442	3,680	165,356	8,764	5,083
	Round pole	603/4		167		
Q4	Sawn	228,998	12,137	177,885	9,428	-2,709
	Round pole	1903/4		228		
Total			38,984		42,909	3,925

Analysis, Results and Discussion

Resource rent

'Resource rent' in economics is defined as the surplus of monetary value of resources after all cost and normal return on investment have been accounted for. This is an accepted method of economic valuation within SEEA Experimental Ecosystem Accounting guideline (UNSD 2014). A generic formulation for calculation of resource rent as follows:

$$RR = TR - (IC + CE + CFC + NP); NP = r \times K$$

Where, RR is Resource rent; TR is Total revenue; IC is Intermediate consumption; CE is Compensation of employees; CFC is Consumption of fixed capital; NP is Normal profit; r is the opportunity cost of capital; K is the value of fixed capital stock invested in the industry.

In this analysis, separate RRs were calculated for commercial concessions and chain-saw logging because of several different revenue/cost components. In Liberia, timber species are classified into three classes (Class A, B and C) based on their commercial value and RRs were calculated for each classes separately as well. A list of species and their respective classes can be found in FDA website (<http://www.fda.gov.lr/>).

The main inputs going into RR for commercial concessions are listed in Table 4. Fee on Board (FOB), stumpage fees, and forest products fees vary widely depending on classes of timber, while land rental, material, labor, and transport cost remains constant. Rental rate as calculated in the analysis is 41-49% depending on species classes. Unit rents are USD 128/m³ for class A, USD 82/m³ for class B, and USD 70/m³ for class C.

Table 4. Inputs into calculation of resource rent for commercial concessions timber

Sources of revenue and costs (USD/m ³)	Species classes		
	Class A	Class B	Class C
Price (FOB)	260	190	170
Stumpage fee	26	9.5	4.25

Sources of revenue and costs (USD/m ³)	Species classes		
	Class A	Class B	Class C
Forest product fees	13	4.75	2.55
Land rental	0.42	0.42	0.42
Materials and labor	64.24	64.24	64.24
Transport	28.2	28.2	28.2
Rental rate	0.49	0.44	0.41
Unit rent	128.14	82.89	70.34

For chain-saw logging, a slightly different set of inputs were used, by including community fees and depreciation and by excluding land rental fees. FOB and cost of materials, labor, and transport remains the same as in commercial concessions. Rental rate of class A (57%) is higher in chain-saw logging than commercial concessions, whereas it is lower in class B (77%) and class C (34%). Unit rents are USD 147/m³ for class A, USD 77/m³ for class B, and USD 57/m³ for class C (Table 5). This means that class A timber is more profitable in chain-saw logging than in commercial concessions.

Table 5. Inputs into calculation of resource rent for chain-saw logging

Sources of revenue and costs (all USD/m ³)	Chain saw logging		
	Class A	Class B	Class C
Price (FOB)	260	190	170
Forest product fees	11.3	11.3	11.3
Materials and labor	64.24	64.24	64.24
Community/County fee	7.28	7.28	7.28
Transport	28.2	28.2	28.2
Depreciation	1.72	1.72	1.72
Rental rate	0.57	0.41	0.34
Unit rent	147.26	77.26	57.26

Contribution to the Economy

Unit resource rents calculated above were allocated to four different sectors of economy according to SEEA guidelines: government, businesses, households, others. As reported in Table 6, businesses benefit the most - receiving 45% (USD 93/m³) of the resource rent - followed by households (30% for commercial and 35% for chain-saw operations).

Table 6. Allocation of resource rent to different sectors of economy

Sector	USD/m ³	
	Chainsaw	Concession
Government	11.30	20.44
Businesses	93.93	93.79
Households	71.52	64.24
Rest of world	29.92	28.20
Total	206.67	206.67

Based on harvest volumes recorded in the government documents and reported in the methods section, we were able to calculate total economic contribution of timber industry. In the year 2015, the economic contribution was USD 221 million, of which the bulk was contributed by commercial concessions (USD 212 million). We were not able to compare relative contribution of timber sector to the economy due to time constraints. In 2015, Liberia's GDP was USD 2.05 billion (The World Bank, 2016). Therefore, roughly 11% of GDP can be attributed to timber industry. It must be cautioned that this is clearly an under-estimate of the total contribution of forestry sector to country's economy. Data were not available for timber harvested for local use, which were not recorded in government statistics. Moreover, valuable non-timber forest products generated by forests were also not accounted for, which would be a component of more complete Forest Accounting exercise (Figure 10).

Table 7. Economic contribution of timber industry to different sectors

Sector	2015 total economic contribution (USD)		
	Chainsaw	Concession	Total
Government	484,874	20,983,610	21,468,484
Businesses	4,030,320	96,300,086	100,330,406
Households	3,068,868	65,959,244	69,028,112
Rest of world	1,283,844	28,954,712	30,238,556
Total	8,867,906	212,197,651	221,065,558

Liberia's forestry sector outlook and conservation implications

Liberia's timber industry can continue to fuel the economic engine of the country, but at the same time, if managed unsustainably, could have negative consequences biodiversity and conservation. Approximately one-third of Liberia's forests (1.2 million ha) is currently under active or proposed timber concessions. Assuming an average standing stock of 153 m³/ha, the volume of biomass contained in these concessions is about 180 million m³. Taking into consideration of 0.6% mean annual increment (MAI), up to 212 million m³ of biomass is potentially available for removal. That means, with an FOB (free on board) of USD 180/m³, the value of Liberia's timber stock is about USD 40 billion at current market price. But not all that standing biomass is commercially viable. Assuming 50% (or 100 million m³) of that biomass as merchantable timber, this translates into USD 18 billion potential revenue.

However, if harvested unsustainably, these forests will deplete and degrade rapidly. At a harvest rate of 2 million m³/year will take only 40-50 years to deplete all standing stock. Although 7 m³/ha is a recommended harvest intensity, which is much higher than the regeneration rate (i.e. MAI, mean annual

increment), studies have shown that 20-30 m³/ha is the break-even point. This means, for companies to become profitable, at least 20-30 m³/ha will need be removed. In that worst case scenario, it will be sooner rather than later that Liberia's forest resources will be degraded, to a point where the country's remaining biodiversity will be at serious risk. This is likely an underestimate, as it does not account for illegal or informal removal of trees, which are often not recorded in official statistics.

Conclusions and Future Directions

As can be seen in Figure 11, granted commercial concessions are spread across the country, and overlap with the most intact and biodiversity-rich natural forests. While the timber industry makes a substantial economic contribution to Liberia's economy, and will continue to do so in the future, it is important that the development of this sector is sustainable. A comprehensive Forest Account and, ultimately a national Ecosystem Account, will ensure that the trade-offs between development and conservation are understood, and that all the goods and services provided by forests and other ecosystems are accounted for in policy and decision-making processes.

To achieve those goals, the development of national datasets is an important first step. Nationwide household, forest, and market surveys are required to quantify the extent and trend of forest products use. Some of those data collection efforts can be integrated within existing national surveys and census efforts (e.g. the agricultural census). Given the nature of Ecosystem Accounts and recent progress in Forest Accounts in other countries, those data need to be spatially explicit as much as possible. This spatially explicit data can help provide an understanding of where the products and services are coming from, and where people are benefiting.

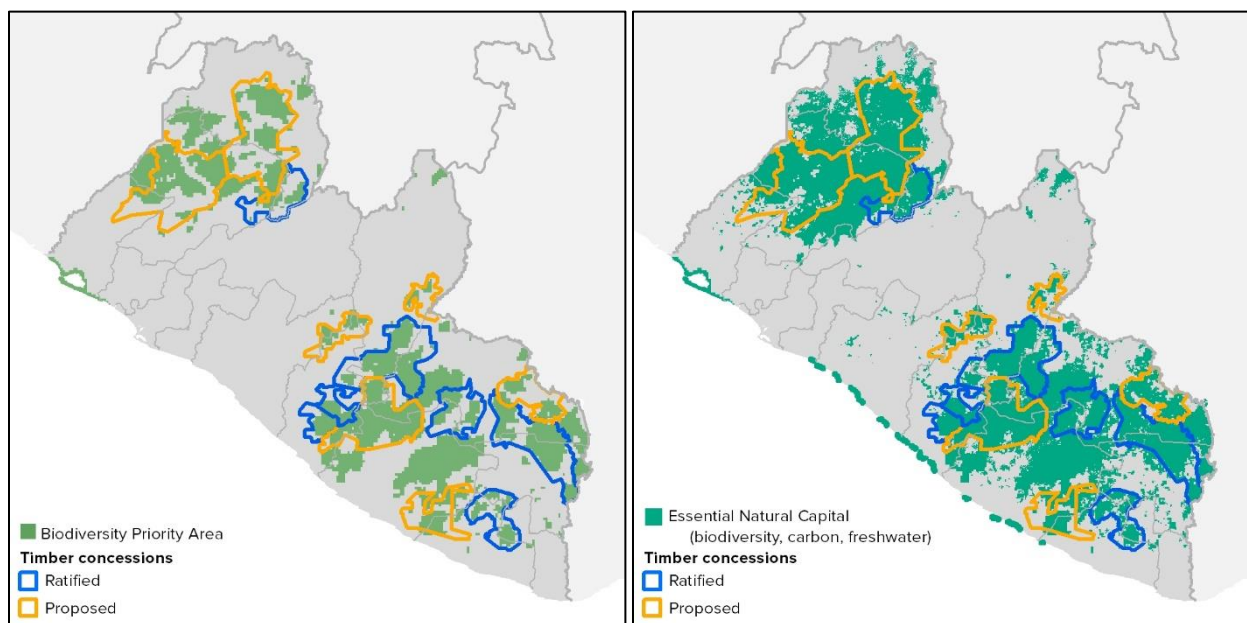


Figure 11. Conservation priority areas and timber concessions (left), essential natural capital and timber concessions (right). For more information on essential natural capital, see following sections.

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Mapping Essential Natural Capital for Biodiversity

Compiled by Trond Larsen and Rachel Neugarten, with contributions from Jessica Junker

Biodiversity—the variability among species, ecosystems, and ecological processes—is fundamental to the planet’s health and humanity’s survival. Areas of essential natural capital for biodiversity can include habitats harboring threatened and protected species, threatened and unique/rare ecosystems, exceptionally high species richness, endemic and restricted range species, migratory and congregatory species, including spawning grounds, and where key evolutionary and ecological processes occur.

Liberia supports extremely high biodiversity as well as many threatened species, providing a stronghold for 18 Critically Endangered species and 44 Endangered species, according to the IUCN Red List. These include, among others, the western chimpanzee, pygmy hippo, and slender-snouted crocodile. The country falls within the Guinean Forests of the West Africa Biodiversity Hotspot, which is a global priority for primate conservation due to high levels of endemism (92% of the hotspot’s 30 primate species are endemic) and high level of threat (CEPF 2015).

Liberia’s two largest forest blocks in the northwest and southeast have high levels of biodiversity and endemism (CEPF 2005), and present some of the last continuous and relatively intact habitat for chimpanzees, elephants, pygmy hippos, and other large mammals. Liberia’s forests are home to over 7,000 chimpanzees, one of the last viable chimpanzee populations in West Africa and a priority for conservation of the species (Junker et al. 2015, Tweh et al. 2014). Liberia also has high diversity of other species, with at least 2000 flowering plants (225 timber species), 600 birds, 150 mammals and 75 reptiles (EPA 2012). However, despite its wealth of biodiversity, biological and socio-economic datasets in Liberia are not centralized and not accessible to decision makers or the public. While studies exist for a variety of taxonomic groups, most have not been sampled broadly enough across the country to assess patterns at the national scale.

The primary threats to Liberia’s biodiversity and ecosystems include hunting and harvesting of wildlife for food (especially bushmeat), shifting cultivation practices, unregulated timber extraction, mining, firewood collection, charcoal production (due a lack of public electricity), invasive species, use of agrochemicals, and inadequate law enforcement (EPA 2012, Tweh et al. 2014).

Methods

We first assessed existing literature and datasets for biodiversity in Liberia, through literature and online searches as well as through expert consultation. Based upon review of existing data, we opted to focus only on the best available dataset which represented taxonomic coverage at the national scale (Tweh et al. 2014), based on transects and surveys conducted systematically throughout the country (Figure 12) and focused on large mammals and trees. A single study, ‘Integrating wildlife conservation with conflicting economic land-use goals in a West African biodiversity hotspot’, summarized these data, and the authors provided us with their raw and modeled datasets and maps for input into the project (Junker et al. 2015).

Junker et al. 2015 used MARXAN analysis to identify overall conservation priority areas for the 30% of all Liberia’s forests that would preserve the most important biodiversity. This cut-off was used because in 2003, the Liberian Forestry Development Authority (FDA) signed an agreement to establish “a

biologically representative network of protected areas covering at least 30% of the existing forest area” (MFA 2003). Inputs into the conservation priority areas included:

Continuous conservation features (modeled based on quantitative data):

- Chimpanzee abundance (>25%³ of areas with the highest density of chimpanzee nests) (Figure 12)
- IUCN threat-weighted large mammal species richness (>25%) (predicted number of large mammal species per unit area, weighted (summed) by IUCN threat category, (1 = Least Concern, 2 = Near Threatened, 3 = Vulnerable, 4 = Endangered) (Figure 13)
- Tree species richness (>25%) (Figure 13)

Binary conservation features:

- Forest cover (forest present or absent; >30% of forested areas)
- Elevation (high or low; >30% of high elevation areas (>300m above sea level). Elevation was used as a proxy for future threat from resource exploitation, e.g., logging, with greater exploitation at low elevations.)
- Known elephant occurrence (presence-absence; >25% of areas where elephants are present) (Figure 14)
- Known threatened large mammal occurrence (presence-absence; >25% of areas where threatened large mammals occur) (Figure 14)

Conservation cost:

- Modeled empty gun shell and snare density (Figure 14)

We then compared the conservation priority areas identified by Junker *et al.* 2015 to protected areas and proposed protected areas, Key Biodiversity Areas (KBAs), and concessions (timber, mining, oil palm and rubber). Key Biodiversity Areas represent the most important nationally-identified sites for global biodiversity conservation based upon vulnerability (presence of IUCN Red List Endangered and Critically Endangered species and abundance of Vulnerable species) and irreplaceability (high proportion of species’ global population). While we considered both the conservation priority areas identified by Junker *et al.* 2015 and KBAs, we focused primarily on the Junker *et al.* sites. The KBA delineation is an important contribution to a better understanding of the country’s biodiversity, but has also been criticized for not including broader consultation with a larger range of stakeholders and for not utilizing the most recently available data or best scientific practices.

³ Percentages in parentheses for this list indicate the conservation target of the total area considered for each variable, i.e. >25% of chimpanzee abundance indicates the smallest set of areas that protect at least 25% of area with highest density of chimp nests

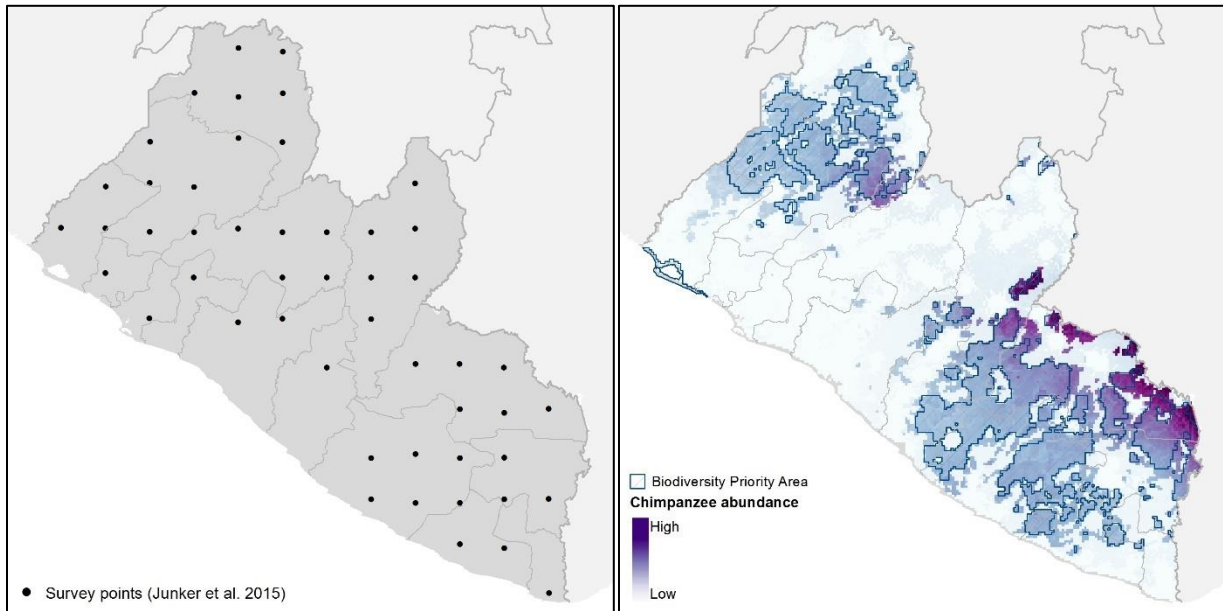


Figure 12. Survey points for Junker et al. 2015 biodiversity study (left) and modeled chimpanzee abundance overlaid with final priority areas identified by Junker et al. (right)

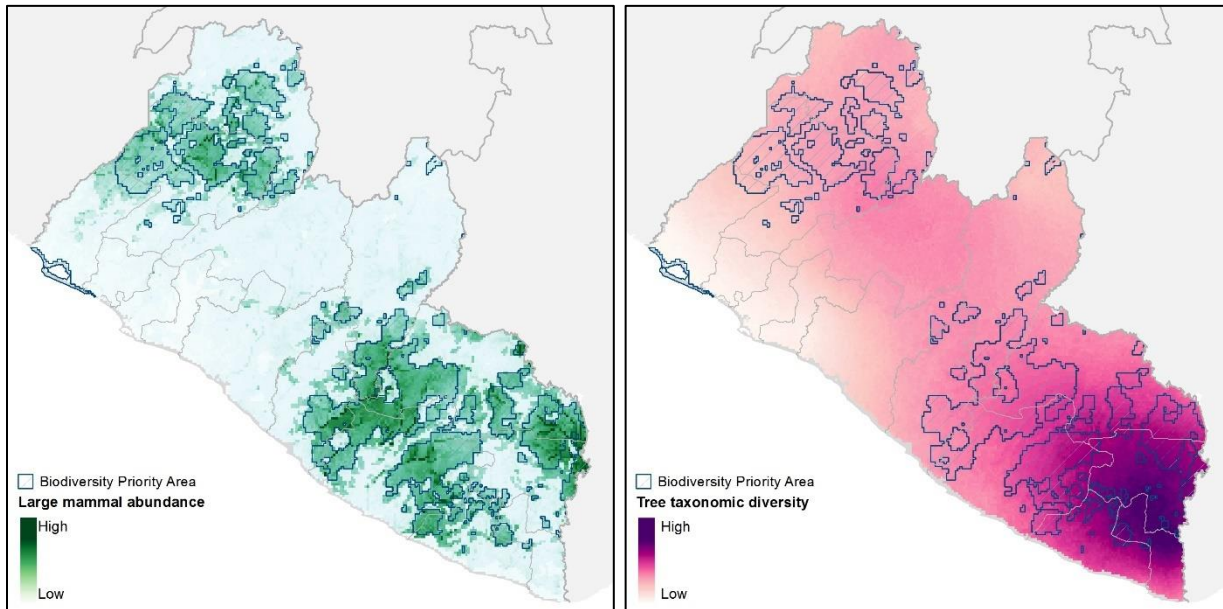


Figure 13. Modeled large mammal abundance (left) and modeled tree taxonomic diversity (right)

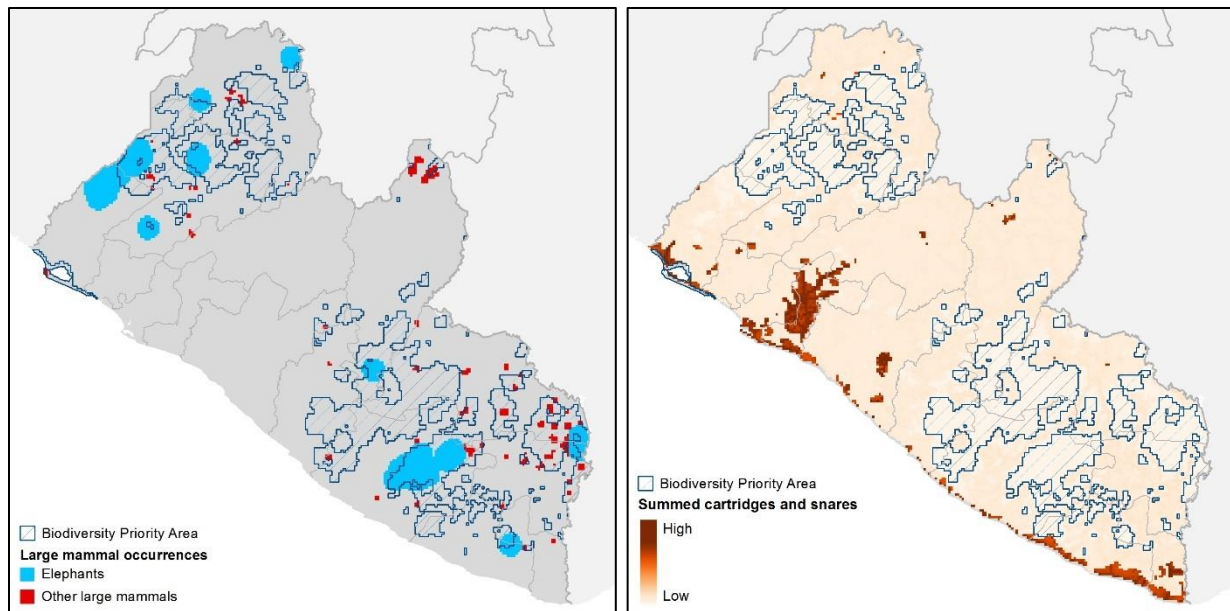


Figure 14. Occurrences of elephants and other large mammals, with buffers sized according to the respective approximate species-specific home range size (left) and evidence of hunting (cartridges and snares) (right)

Results

The MARXAN analysis identified 92 discrete conservation priority areas (Junker *et al.* 2015; Figure 15). Only around 9% of these conservation priority areas are contained within designated protected areas and 24% are within proposed protected areas (Figure 15). If proposed protected areas were established, 33% of conservation priority areas would be preserved. Conservation priority areas (defined using only terrestrial large mammal species) align relatively well with terrestrial Key Biodiversity Areas but not with freshwater and coastal Key Biodiversity Areas (Figure 16). Very few of the conservation priority areas fall within concessions for mining, oil palm or rubber, although this is not the case for timber concessions (Figure 16).

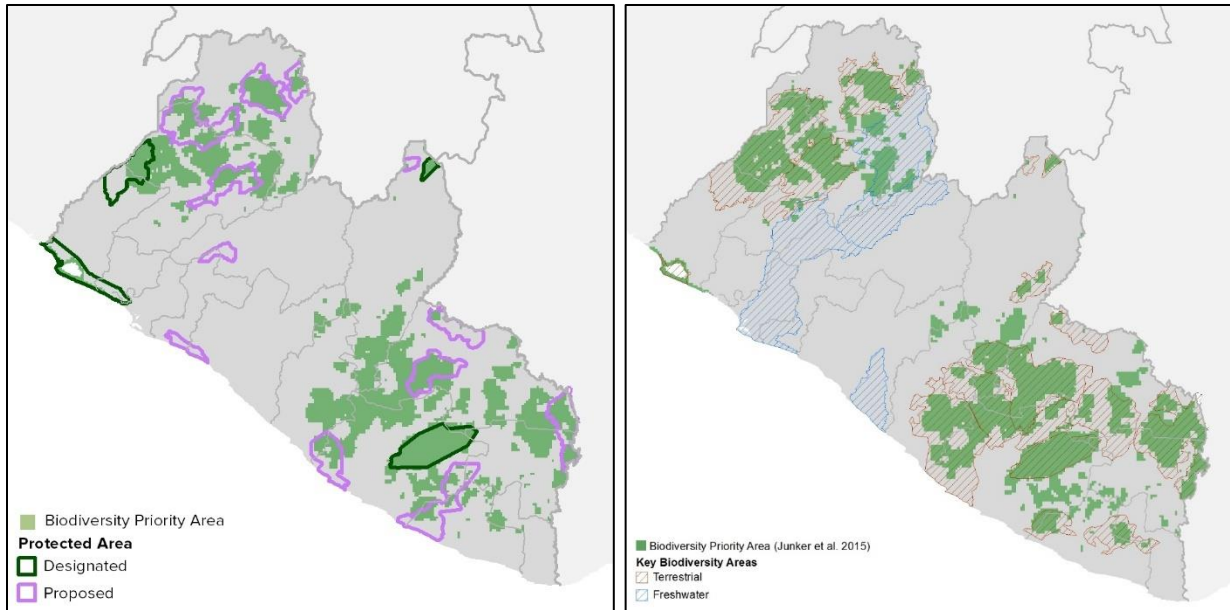


Figure 15. Conservation priority areas, designated protected areas, and proposed protected areas in Liberia (left). Conservation priority areas and Key Biodiversity Areas in Liberia (right).

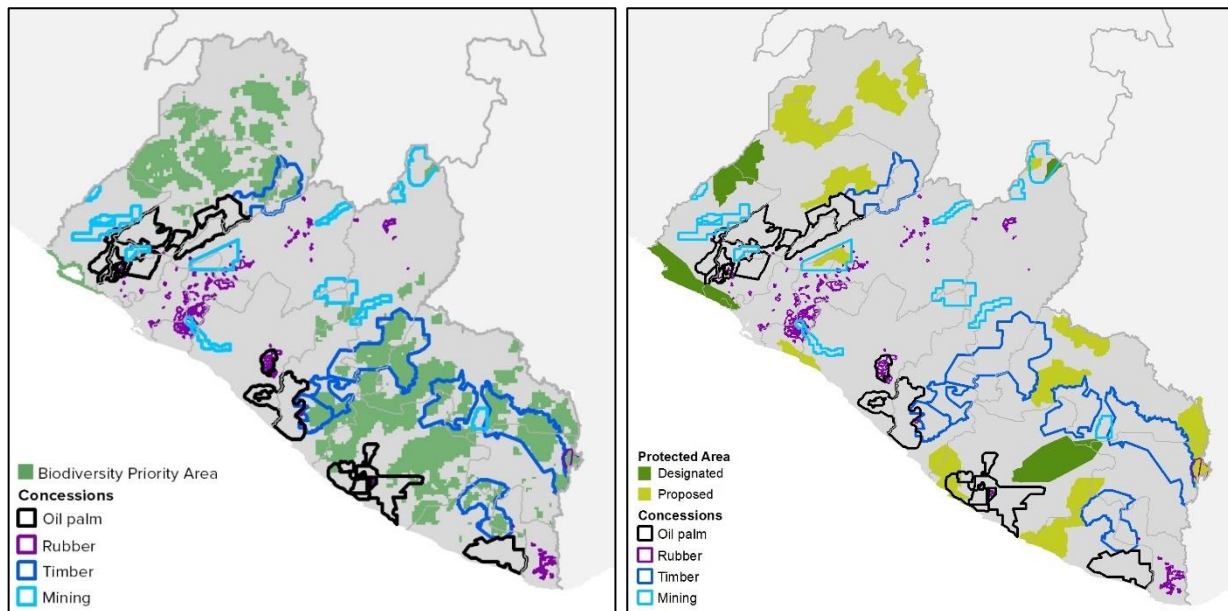


Figure 16. Conservation priority areas and concessions in Liberia (left). Proposed and designated protected areas and concessions (right).

Conclusions

Currently, only 3.8% of Liberia’s land area is formally protected. If the protected area network was increased to 30% of Liberia’s forested areas, as has been proposed by the FDA, it would significantly contribute to conserving the most important areas for biodiversity. However, the proposed protected areas would be more effective at conserving Liberia’s globally significant biodiversity if they were aligned with the new conservation priority areas identified by Junker et al. 2015. Due to the large size of some of the Junker et al. priority areas, protecting even 6 out of 92 priority areas would help to ensure the long-term viability of a chimpanzee population of 2,500 individuals, as well as a high diversity of

trees and other large mammals. This is extremely important for the western chimpanzee, whose IUCN Red List status has recently been updated to "critically endangered."

Proposed protected areas and conservation priority areas overlap with oil palm, timber and mining concessions in some cases, and therefore concessions will require careful planning and management to ensure biodiversity is not compromised. Future expansion of palm oil into Liberia's forests, if it is not carefully planned and sustainably managed, may threaten the nation's biodiversity, particularly chimpanzees (Wich et al. 2014). The potential application of innovative large-scale aggregate biodiversity offsets may be one way to help preserve biodiversity in Liberia (Junker *et al.* 2015). Many biodiversity priorities also occur in degraded landscapes, and therefore restoration could be a valuable conservation contribution in addition to new protected areas. Allocation of additional resources for monitoring and enforcement of Liberia's wildlife laws, to strengthen management of the country's protected areas and reduce hunting of protected species, would help ensure the long-term viability of Liberia's globally significant biodiversity.

Limitations

Conservation priority areas for this project are provided by a single study, which focused on chimpanzees, large mammals (including threatened species), and trees. Other studies could not be included due to insufficient sample sizes or because they were conducted at local or site scales, which was not sufficient to represent biodiversity at the national scale. Even the Junker et al. study is limited because it included only a few taxonomic groups and relied on rapid site-scale transects across the country, which could only sample a fraction of the species occurring at each site. This makes it difficult to understand the national distribution of species. New survey data for other types of species would greatly enhance the identification of the most critical sites in Liberia for biodiversity. Research on Liberia's coastal and marine species, birds, plants, reptiles, amphibians and freshwater fishes would help the people of Liberia understand their own biological wealth, which is the first step towards achieving the country's conservation and sustainable development goals.

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Mapping Essential Natural Capital for Climate Mitigation

Compiled by Max Wright

Introduction

Tropical forests are critically important to long-term global climate regulation because they sequester and store carbon dioxide (CO₂) from the atmosphere and, when forests are lost, CO₂ is emitted back into the atmosphere. Recent studies have shown that deforestation accounts for between 12-20 percent of global greenhouse gas (GHG) emissions, making it the second biggest contributor to global emissions after the consumption of fossil fuels (Van Der Wurf et al., 2009). The forests of Liberia are the last remaining large intact tracts of forested land in western Africa, providing critical habitat for biodiversity and ecosystem services for people. Liberia forests also contribute to climate mitigation; containing some of the highest above-ground biomass forests in the world (Avitabile 2016). Despite the acknowledged value of natural forest in Liberia for carbon storage, and other co-benefits, forest continues to be lost to clearing for oil palm, rubber, and small-scale subsistence agriculture. The ability to quantify the amount of carbon that is stored in Liberian forests and where it is being lost is essential for informing national sustainable development targets and green-growth policies.

The mapping of essential natural capital for climate mitigation involves identifying areas of importance for the long-term maintenance of biotic carbon stock within natural ecosystems and the reduction of potential greenhouse gas emissions from anthropogenic activities within those ecosystems, such as from land-use change. To achieve these objectives two aspects of natural capital need to be mapped; biomass carbon stock and potential CO₂ emissions from tree cover loss. Both indicators need to be mapped in a way that is both spatially explicit and can be updated over time.

Mapping biomass carbon stock requires information on the current land cover (LC) and the density of vegetation biomass. It is important that the methods used for mapping biomass carbon be easily updated, so that the results can be monitored over time and that the framework can be adaptable so that it can take advantage of the best available scientific data for a given region of interest. Although forest biomass data is often only available for a single period, there are datasets which monitor *tree cover loss* (which includes loss of both natural and non-natural forests, such as plantations) on an annual basis. Therefore, a method of interpolation and updating was used to create a map of forest carbon stock that can be updated as additional deforestation information becomes available. For this analysis, only forest biomass, both above-ground and below-ground, were considered. Soil carbon was not included in the biomass carbon assessment, nor was post-deforestation land-use emissions, such as emissions associated with agriculture.

We also calculated the potential emissions from tree cover loss, by combining forest biomass information with the likelihood that a forested area will be deforested to assess areas that are both important CO₂ stores and are highly vulnerable to tree cover loss. There are multiple spatial modeling methods for assessing vulnerability to tree cover loss. For this analysis, a simple proximity-based model was used to calculate the future predicted rate of tree cover loss, based on the historical tree cover loss

within 20 kilometers of a given forested pixel. (That is, if a given forested patch is within 20 km of areas that have recently experienced tree cover loss, we assume that those patches are more vulnerable to loss in the future.) This predicted rate was combined with the remaining forest biomass carbon to get the projected carbon loss per year, and then converted to CO₂ equivalents (CO₂e) to get the projected annual emissions.

The outputs for this analysis are continuous maps of forest biomass carbon stock in the years 2000 and 2015 across Liberia, and a continuous map of potential future emissions from tree cover loss, based on historical trends from 2000 to 2015. All the final climate mitigation maps cover the entire country and have a spatial resolution of 30 meters.

Methods

To create the maps of forest biomass and potential emissions three input datasets were used:

- 2015 land-cover map of Liberia created by Geoville and the Liberian Forest Development Authority (JV/Metria Geoville 2016)
- Global tree cover loss data from 2000-2014 (Hansen et al., 2013)
- Global above-ground biomass map (Avitabile et al. 2016)

Unfortunately, there is no consistent forest cover or deforestation data from Liberia. While different products exist, they were developed using different methods and cannot be compared. Therefore, the first step in the analysis was to use the 2015 national land-cover data in conjunction with global tree cover loss data 2000-2014 to create a circa 2000 forest cover map. The input LC map contains 11 classes (see Table 8) and has a spatial resolution of 10m, it was reclassified to forest/non-forest (mangrove was considered a forest class, as were all three forest classes) and resampled to 30-meter resolution to match the tree cover loss data from Hansen et al. 2013. The tree cover loss from 2000-2014 was then used to backdate the 2015 forest/non-forest map using the following logic; if an area was classified as non-forest in the 2015 map, and it had experienced tree cover loss between 2000 and 2014, then it was assumed to have been forested in 2000. All other areas were given the same landcover classification in 2000 as they had in 2015. The result is a forest/non-forest map for the year 2000. We note that the term “forest” here includes plantations, such as rubber plantations, which are not natural forest areas. The global dataset is not able to distinguish the loss of natural forests from loss in plantations or secondary or degraded forests, so we refer in this section to “tree cover loss”, rather than “deforestation.”

We also note that the definition of forest used here includes mangroves as well as all three forest classes from Geoville, and therefore includes open-canopy forest (<30% canopy cover). This is a much broader definition of “forest” than the official definition of forest proposed by the Liberian Forestry Development Authority (which defines “forest” as having a minimum of 30% canopy cover, 5 meters in height, and minimum patch size of 1 hectare). (This also differs from the FAO definition of forest in Liberia, which includes areas spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10%, or trees able to reach these thresholds in situ (FAO 2014). We are not

promoting a broader definition of forest, we only used the Geoville data for the purposes of this analysis, to highlight patterns of tree cover and tree cover change in all forest classes included in the Geoville map.

Table 8. Landcover classes from Geoville 2015, areas, and reclassified forest/non-forest categories

Landcover 2015	Area (ha)	Percent	Reclassified	Percent
Forest >80%	4,364,751	45.37%	Forest	84.12%
Forest 30-80%	2,167,707	22.53%		
Forest <30%	1,523,056	15.83%		
Mangrove	37,142	0.39%		
Settlements	44,604	0.46%	Non-forest	15.11%
Grassland	626,038	6.51%		
Shrub	606,919	6.31%		
Bare soil	173,917	1.81%		
Ecosystem complex (rock and sand)	2,252	0.02%		
Water	60,529	0.63%		
Clouds	14,391	0.15%	Background	0.78%
TOTAL	9,621,306	100%		

To calculate the forest biomass in Liberia and to understand changes in biomass over time, a forest biomass map was created. The Liberia forest biomass map is based on a 900m resolution global above-ground biomass map (Avitabile et al. 2016). The biomass information needed to be resampled to 30m resolution to combine it with the forest/non-forest maps for 2000 and 2015. There are multiple methods that can be used to resample the biomass map. One important consideration is that within a 900m biomass pixel there will likely be a mix of forest and non-forest land-cover, therefore, the biomass density in each 900m pixel will contain a mixture of both forest and non-forest. If we are only interested in forest biomass and change in forest biomass, then we need to use forest biomass densities. To do this we identify 900m biomass pixels which are greater than 95 percent forested, and then interpolate those values across the rest of the country, creating a wall-to-wall map of forest biomass in Liberia. The output is then clipped to the 2000 and 2015 forest extent, at 30m resolution, to create the 2000 and 2015 forest biomass maps, respectively.

Aboveground biomass (e.g. tree trunks, branches, and other aboveground vegetation) does not account for belowground biomass (such as root systems). The below-ground biomass (BGB) was therefore calculated based on the above-ground biomass (AGB) maps using the following equation from Mokany et al. 2006. The below-ground biomass was added to the above-ground biomass, to estimate the total forest biomass in each pixel. Biomass (organic material) is not equivalent to carbon (the carbon content of the biomass.) Biomass is approximately 50% carbon, therefore the 2000 and 2015 forest biomass

values must be divided by two to calculate their carbon stocks, in units of tons of carbon per hectare (tC/ha).

$$BGB = 0.489(AGB)^{0.89}$$

To generate the map of potential emissions from tree cover loss, a map of vulnerability to tree cover loss was created and multiplied by the map of forest carbon stock in 2015. To create the map of vulnerability to tree cover loss, a simple proximity-based model was applied. The model assigned an annual rate of tree cover loss to each pixel based on the observed historical annual rate of tree cover loss from 2000-2015 within a 20-km moving window. In other words, pixels that had forest cover in 2015, located within 20km of pixels that were recently cleared, were considered “vulnerable” to tree cover loss in the future. The projected annual rate of tree cover loss for each pixel was estimated, based on past trends. After the projected annual rate of tree cover loss was calculated, the result was multiplied by the forest carbon stock in 2015 to calculate the projected annual change in carbon stock. The projected annual change in carbon stock can be interpreted as the amount of carbon that would be lost if the past trends in tree cover loss were to continue. The projected annual change in carbon stock was then converted from tons of carbon (the solid form that exists in biomass) to tons of carbon dioxide equivalents (CO₂e, which is the gaseous form of carbon that is released to the atmosphere) by multiplying by 44/12, which is the difference in the atomic weights of carbon and carbon dioxide. The resulting map shows the potential emissions from tree cover loss – the emissions that would result if past trends were to continue in the future. In other words, the map shows emissions that will be emitted under a business as usual scenario.

Results: Land cover and tree cover loss 2000-2015

The below map shows the estimated tree cover loss from 2000-2015 (Figure 17). Areas in red represent pixels that were classified as non-forest in 2015 and were recorded as a loss in the Hansen et al. 2013 tree cover loss data. There are a few spatial patterns of loss that are apparent in Liberia. The large contiguous areas of loss along the coast are a result of recent clearing for oil palm. The band of forest loss in the center of the country, extending from the coast outside Monrovia to the middle of the country, is dominated by rubber plantations. Finally, there are small (<1 ha) patches of forest loss scattered through the central corridor of the country. This loss is likely a result of human pressures, such as small scale agriculture, charcoal production, and local timber harvesting. The annual deforestation (tree cover loss) rate in Liberia is approximately 0.31%, however this number may vary significantly depending on the forest definition used, and whether plantation forests are included.

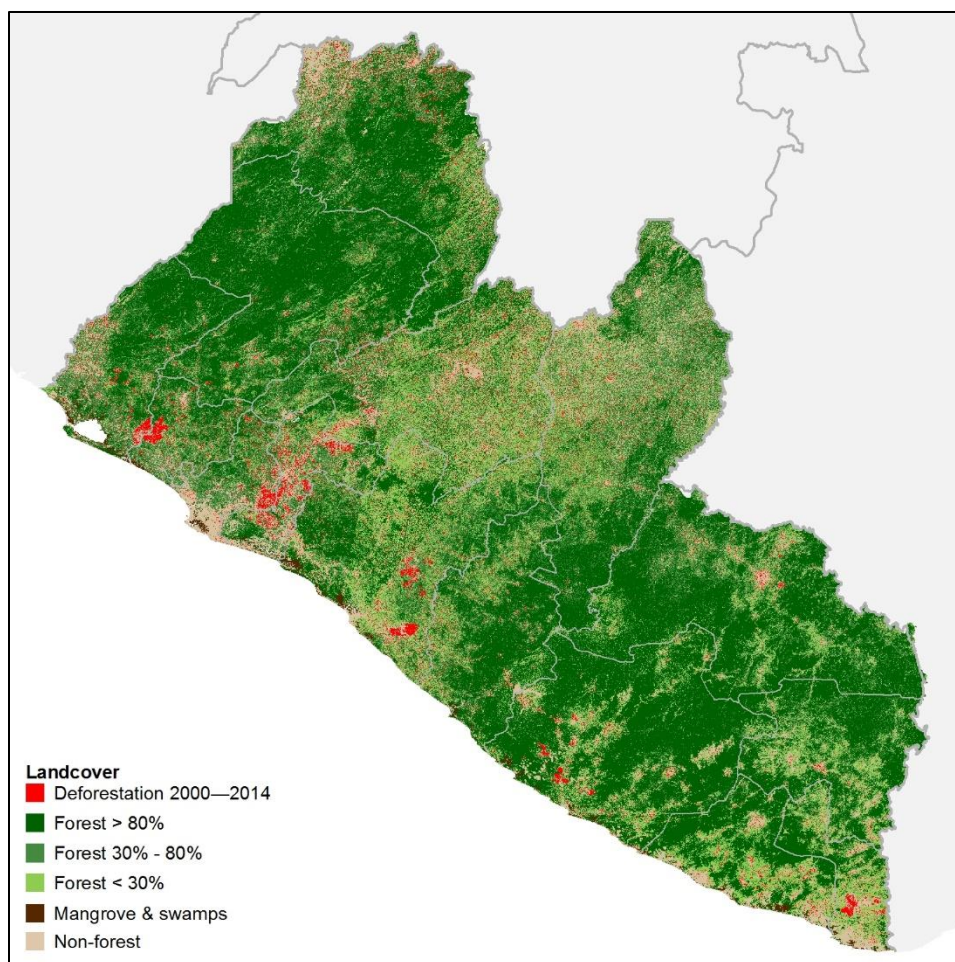


Figure 17. Estimated tree cover loss from 2000-2015

Results: Forest carbon stock 2015

The maps of forest carbon stock for Liberia in 2015 shows some interesting patterns (Figure 18). One of the most obvious patterns is the very low carbon stock values in the central portion of the country. This is likely due to high level of historic clearing associated with past human use. Another interesting pattern is that there are two distinct regions of very high carbon stock, one in the north of the country and one in the south. These remaining areas of intact forest are critical for carbon storage within Liberia. According to global biomass estimates (Avitabile et al. 2016), forests in Liberia have some of the highest above-ground carbon stocks in the world, higher even than those in the Amazon rainforest. Understanding the spatial distribution of high biomass carbon forests allows decision makers to factor carbon storage, an ecosystem service with global beneficiaries, into development decisions. As one of the last remaining countries in west Africa with such high carbon stocks, conserving Liberia’s forests is critical for achieving national and global climate targets.

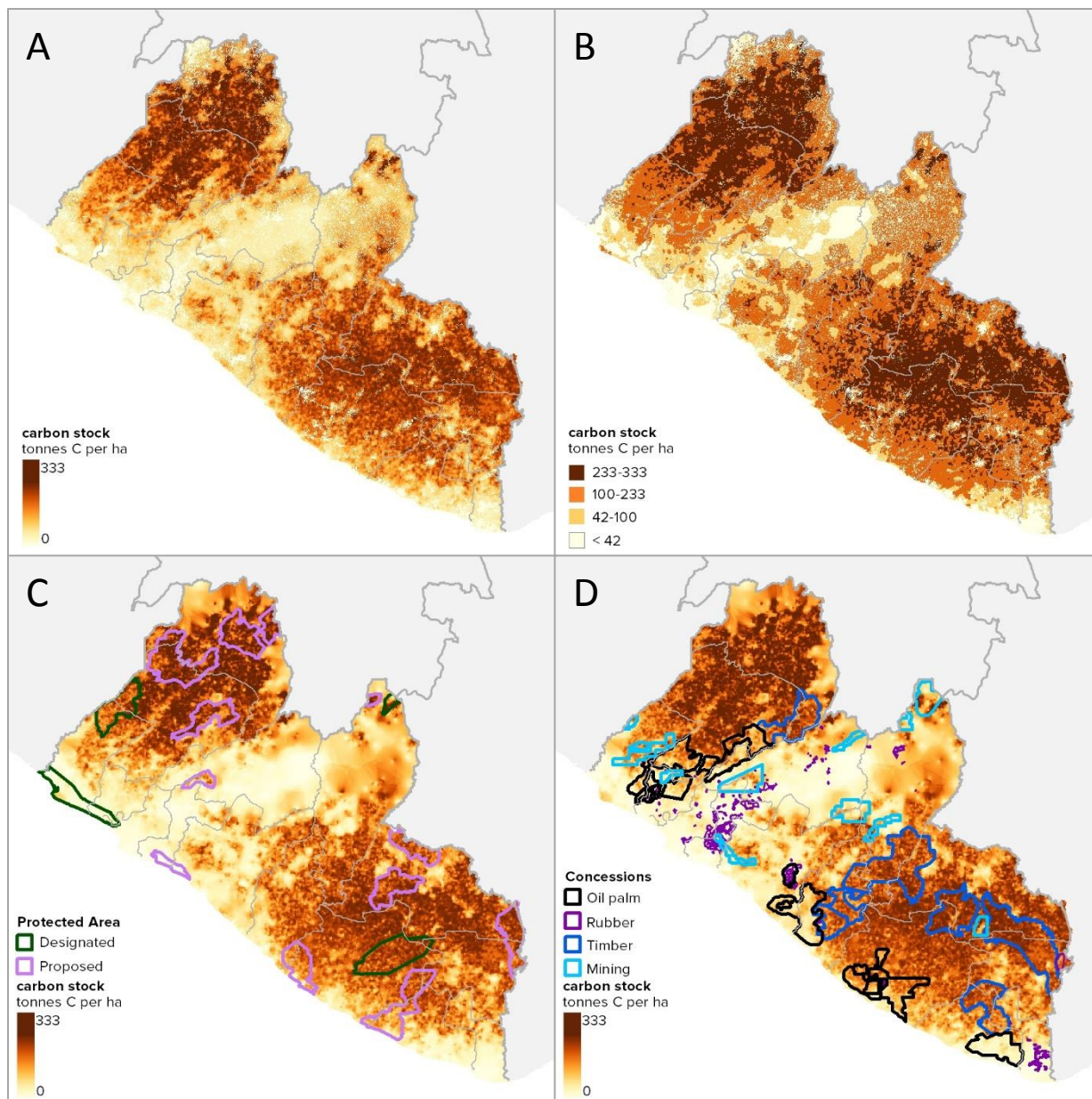


Figure 18. Liberia forest carbon 2015. Areas in brown contain a greater density of carbon, while areas in white contain a lower carbon density. The maps show the total carbon stock of Liberian forests (A), the carbon stock stratified by HCV categories (B), the carbon stock overlaid with protected areas (C), and the carbon stock overlaid with other land-use designations. All the maps presented account for above-ground and below-ground biomass.

Results: Vulnerability to tree cover loss

The map of vulnerability to tree cover loss is shown below (Figure 19). The map was created using a proximity-based model using historical tree cover loss from 2000-2014 and a 20km moving window analysis. That is, pixels that currently contain forest, that are within 20km of pixels that were cleared from 2000-2014, are considered vulnerable to clearing in the future. The most obvious patterns in the vulnerability to tree cover loss map is that it shows high vulnerability around oil palm and rubber plantations. However, some of the tree cover loss in these areas is due to rotational cultivation,

therefore it is challenging to determine how much of the vulnerability can be attributed to the loss of natural forest versus plantation trees. Another significant pattern is the widespread vulnerability in the center of the country, in Bong and Nimba counties. This region has almost no plantations and the vulnerability in this region is almost exclusively due to small-scale clearing for human use, likely small-scale subsistence agriculture or charcoal production. Finally, a third hotspot for tree cover loss is found in the northern part of the country, in Lofa county. This is particularly interesting because this area is on the border of the country and is an area where there have been proposals to create a transboundary protected area. This area also has relatively higher population density (see Introduction) which may mean that this area is also being subjected to small-scale clearing for agriculture or other human use. We also heard that this area has experienced forest fires (although it is not clear if they are natural or human-caused) which may explain some of the pattern of vulnerability.

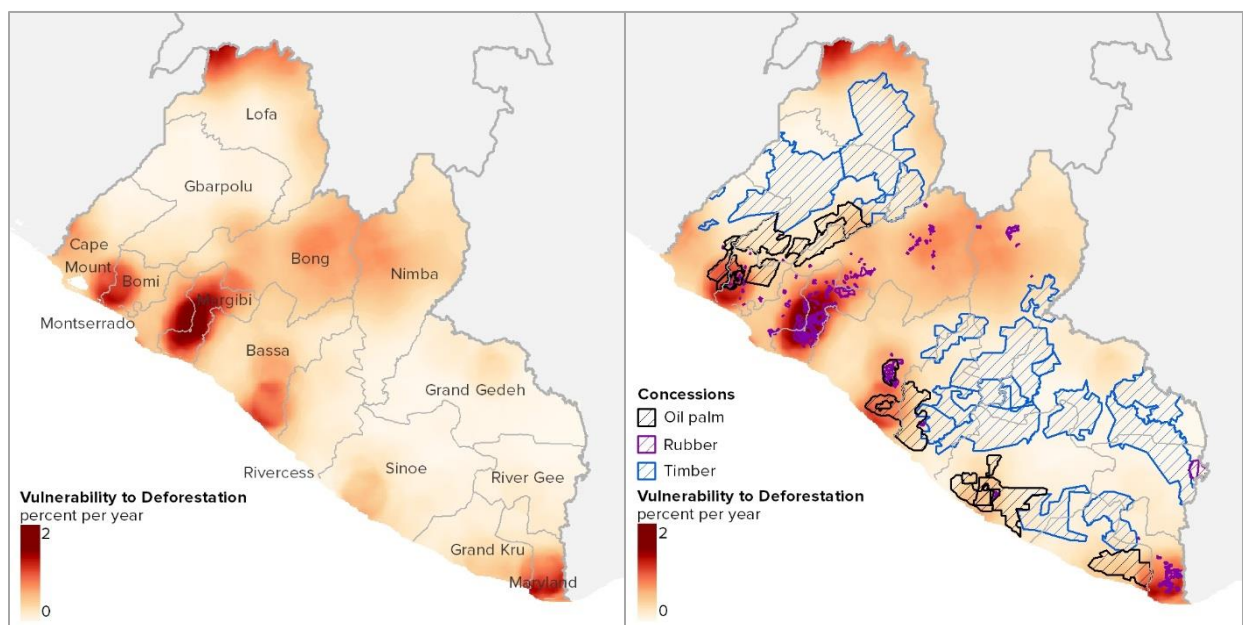


Figure 19. Vulnerability to tree cover loss in Liberia, based on historical tree cover loss from 2000-2014. The map on the left shows vulnerability overlaid with districts. The map on the right shows vulnerability overlaid with plantations and concessions

Results: Potential emissions

The map of potential emissions shows areas in Liberia that have both high vulnerability to tree cover loss and high forest carbon stocks (Figure 20). These areas may be places where conservation interventions will have the greatest impact on reducing emissions from tree cover loss, which could include regions suitable for carbon financing. We note that some such areas are in and around plantations and therefore may be less suitable for carbon finance, depending on whether they contain natural forest cover (i.e. primary forests) or are secondary or plantation forests. Most of the areas with high potential emissions are located near plantations, which have relatively high historical rates of tree cover loss. However, there are a few notable areas in the north where there is tree cover loss but not plantations. In Lofa county there is both high vulnerability and high carbon stocks, making it a good candidate for carbon financing. There is another area in Nimba county that also exhibits a combination

of high vulnerability and high carbon stocks. This region will like become degraded, as has happened in Bassa and Bong counties, if the historical trends continue unchecked. It is important to note that the potential emissions are only an indicator of forest carbon loss, more detailed ground truthing and analysis based on field sampling would need to be conducted if a REDD+ or other carbon-based conservation mechanism were to be employed.

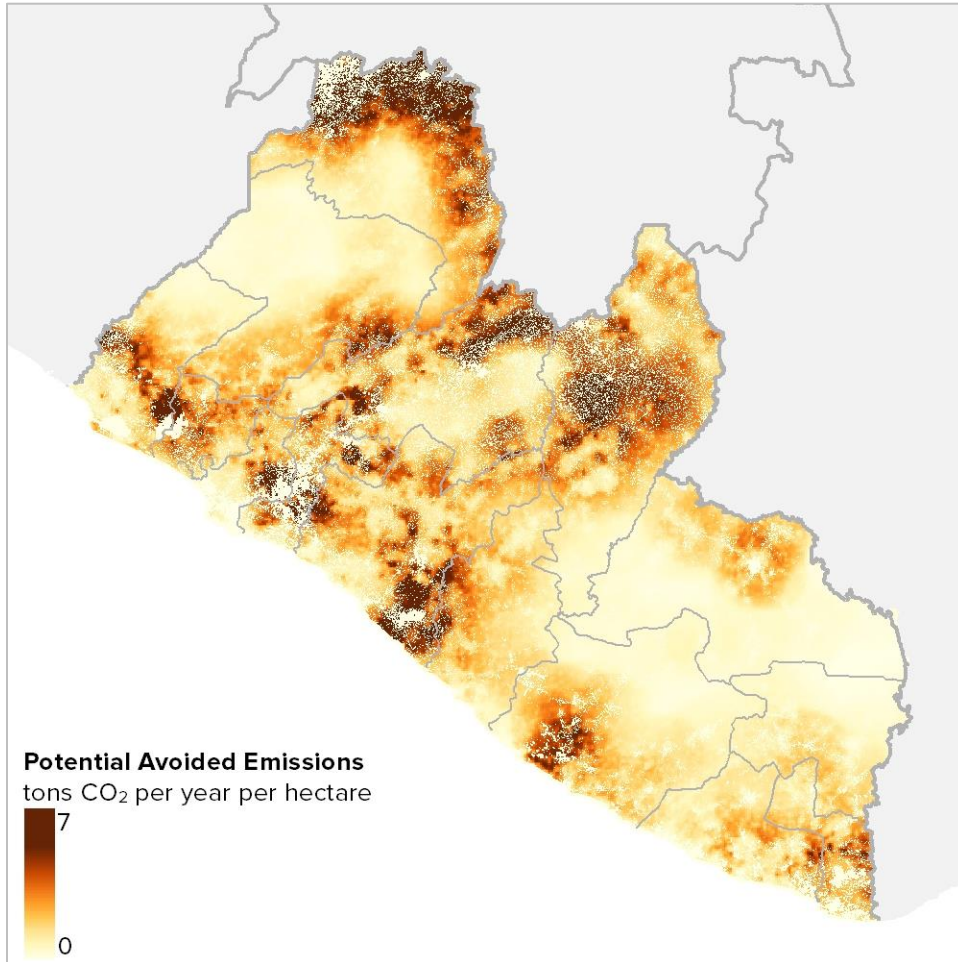


Figure 20. Potential emissions from tree cover loss represent the amount of CO₂ that could be released to the atmosphere based on the vulnerability to tree cover loss and forest carbon stock maps. Areas with high potential emissions are shown in brown, while areas with low potential emissions are in white.

Results: Forest cover change and carbon stock by land-use designation

Land-use designations provide a useful perspective for assessing the tree cover change and carbon stocks in Liberia. Relevant land use designations in Liberia include protected areas and concessions for palm oil, rubber, and timber (Figure 21).

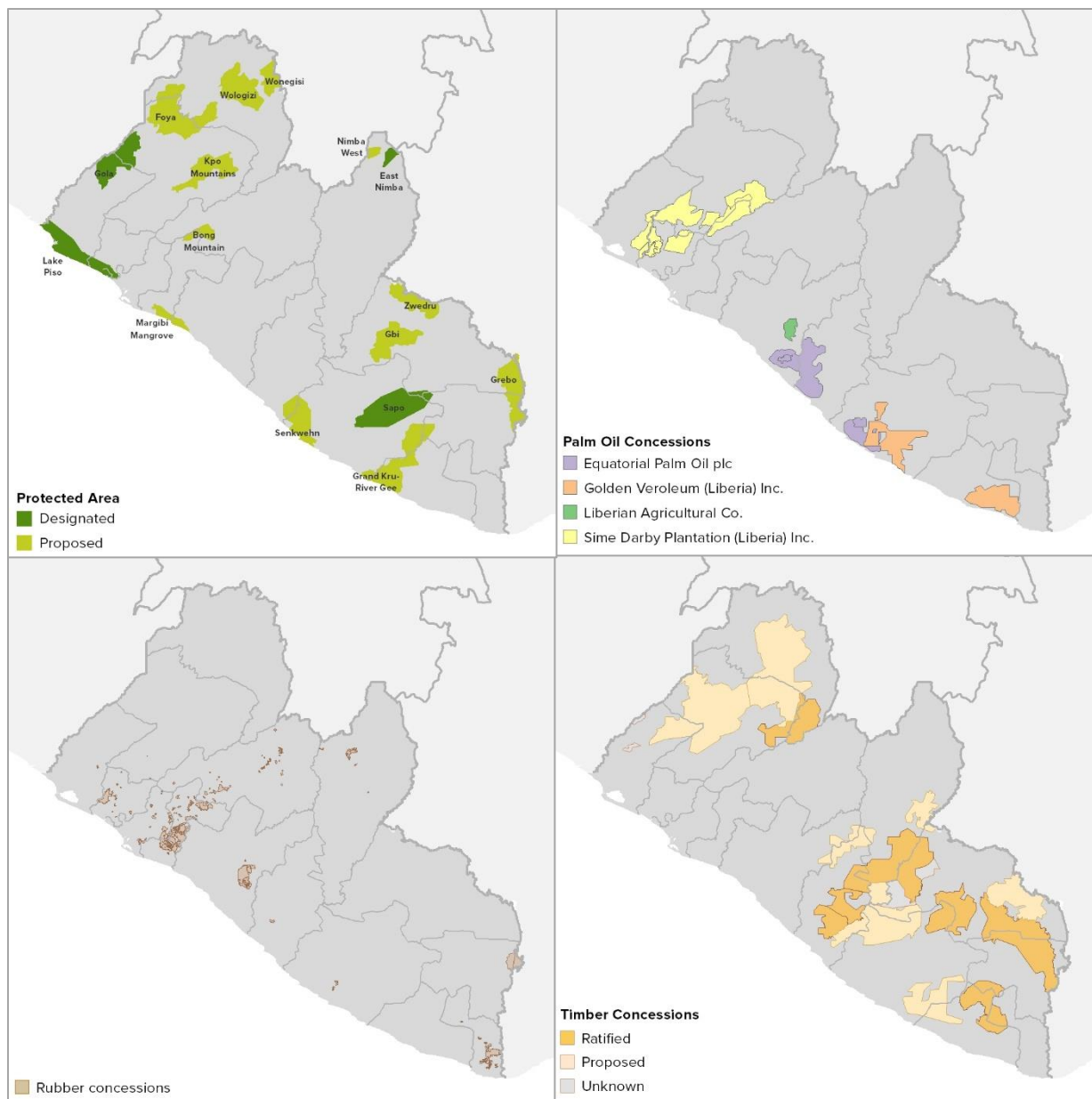


Figure 21. Liberia land-use designations including protected areas (designated and proposed), oil palm concessions (by company), rubber concession, and timber concessions (ratified and proposed).

Table 9 shows the change in forest cover in relation to land-use designations. Not surprisingly rubber plantations had the highest rate of tree cover loss from 2000-2015, likely reflecting established plantations with regular cultivation cycles. In oil palm plantations the annual tree cover loss rate between 2000-2015 (0.6%) was twice the national average loss rate (0.3%). Overall, tree cover loss in oil palm plantations accounted for almost 15% of the total tree cover loss over the observation period. This could be an indication that the oil palm plantations are less established than the rubber plantations, and are likely clearing forested land to plant palm oil, rather than exhibiting a regular cultivation cycle. Another interesting observation is that the tree cover loss rate in proposed protected areas was lower

than in designated protected areas. This may be because areas proposed for protection may not have many competing land-uses, which is not uncommon as it would reduce the opportunity cost for their creation. Still, almost the same proportion of the total tree cover loss occurred within proposed protected as in ratified timber concessions, highlighting the need for official designation of proposed protected areas to avoid future clearing.

The relationship between carbon stock and land-use designation is shown in Table 10. The trend that immediately jumps out is that the mean forest carbon stock is highest in the ratified and proposed timber concessions. This would suggest that high carbon stock forests are preferentially chosen for timber extraction. In terms of green growth this could prove problematic as many of the highest carbon stock forests in Liberia contain essential natural capital and ecosystem service benefits. Another troublesome trend is that the current protected area network captures less than 5% of the forest carbon in the country. On a positive note, if all the proposed protected areas were designated this number would rise to almost 18%. The final pattern that is worth highlighting is the much lower average carbon content in rubber plantations. This is likely because the rubber plantations are established under a rotating cultivation cycle, but it has large implications for their average biomass. If rubber and oil palm plantations expand in an unsustainable fashion, high carbon natural forest will increasingly be replaced by lower carbon forest crops, which will have broad implications for climate and biodiversity at a global scale.

Table 9. Forest cover change by land-use designation

	Forest 2000 (ha)	Proportion of forest 2000	Forest 2015 (ha)	Proportion of forest 2015	Forest loss 2000-2014 (ha)	Proportion of loss 00-14	Tree cover loss rate % yr-1
Liberia total	8,504,508.96	-	8,141,749.38	-	362,759.58	-	0.30%
Proposed protected area	867,034.62	10.19%	861,213.06	10.58%	5,821.56	1.60%	0.05%
Designated protected area	325,240.11	3.82%	322,043.94	3.96%	3,196.17	0.88%	0.07%
Ratified timber concession	984,586.77	11.58%	978,402.24	12.02%	6,184.53	1.70%	0.04%
Proposed timber concession	1,227,087.81	14.43%	1,216,625.40	14.94%	10,462.41	2.88%	0.06%
Oil Palm plantations	614,070.45	7.22%	560,822.13	6.89%	53,248.32	14.68%	0.62%
Rubber plantations	60,521.49	0.71%	40,352.31	0.50%	20,169.18	5.56%	2.38%

Table 10. Carbon stocks (2015) by land-use designation

	Area (ha)	Proportion of total area	MEAN (tC/ha)	Total forest Carbon 2015	Proportion of forest carbon
Liberia Total	9594063.72	-	158.594152	15215623958	-
Proposed protected area	909597.33	9.48%	218.734834	1989606210	13.08%
Designated protected area	362336.85	3.78%	180.147704	652741516.6	4.29%
Ratified timber concession	1007782.11	10.50%	223.653891	2298076166	15.10%
Proposed timber concession	1257945.84	13.11%	233.172847	2933188135	19.28%

Oil Palm plantations	696876.48	7.26%	119.753677	834535211.7	5.48%
Rubber plantations	94302.36	0.98%	30.580732	28838352.24	0.19%

Limitations and assumptions

Several assumptions were made while conducting this analysis and there are limitations to the ways that the results can be applied.

1. Calculations of carbon storage are based on a global dataset. There are multiple global forest biomass datasets and there is some level of disagreement between them, especially at the local level. Ideally, the data we used would be validated using ground-based sampling of biomass carbon stock.
2. Carbon stock is biotic carbon in above- and below-ground vegetation, but not soil carbon. Soil carbon values could be particularly important along the coastal mangroves; however, it is currently not considered in these analyses.
3. The model of vulnerability to tree cover loss is based solely on proximity to historical tree cover loss. While this assumption is reasonable, it is not necessarily true as future deforestation can occur in areas that have no historical tree cover loss, especially in cases where the drivers of deforestation change over time, such as if a new road is constructed or a new dam is installed.
4. The 20km radius used for the vulnerability to tree cover loss analysis is based on the literature and expert opinion, as it approximates a realistic distance that people would be willing to travel from roads and infrastructure to clear forest. It is assumed that areas within 20km of a given site will have similar land-use pressures to the site (whether the site is a managed unit or a raster-analysis cell) in question.
5. These indicators should not be interpreted as an estimate of a Reduced Emissions from Deforestation and Degradation (REDD+) reference level or of emissions reductions; those would require more complex and rigorous methodologies (e.g. Voluntary Carbon Standards) to enter the carbon market. Nonetheless, these analyses are adequate for use in ranking the appropriateness of sites for potential future REDD+ feasibility studies and activities.

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Mapping Essential Natural Capital for Freshwater Ecosystem Services

Compiled by Miroslav Honzák and Natalia Acero

INTRODUCTION

Liberia's climate is dominated by abundant rainfall – on average 2700 mm of water falls in a year and during the rainy season (May to October) an average monthly rainfall ranges from 150 mm-350 mm (Ndehedehe et al., 2016). There are six major rivers in Liberia, which drain approximately two-thirds of the country (UNEP, 2004; Figure 22). The Mano, Cestos and Cavalla are shared basins between Sierra Leone and Côte d'Ivoire respectively, while the Lofa, Saint John and Saint Paul drain part of Guinea (USAID, 2008). The major rivers flow in a northeast to southwest direction due to the topography, and empty into the Atlantic Ocean.

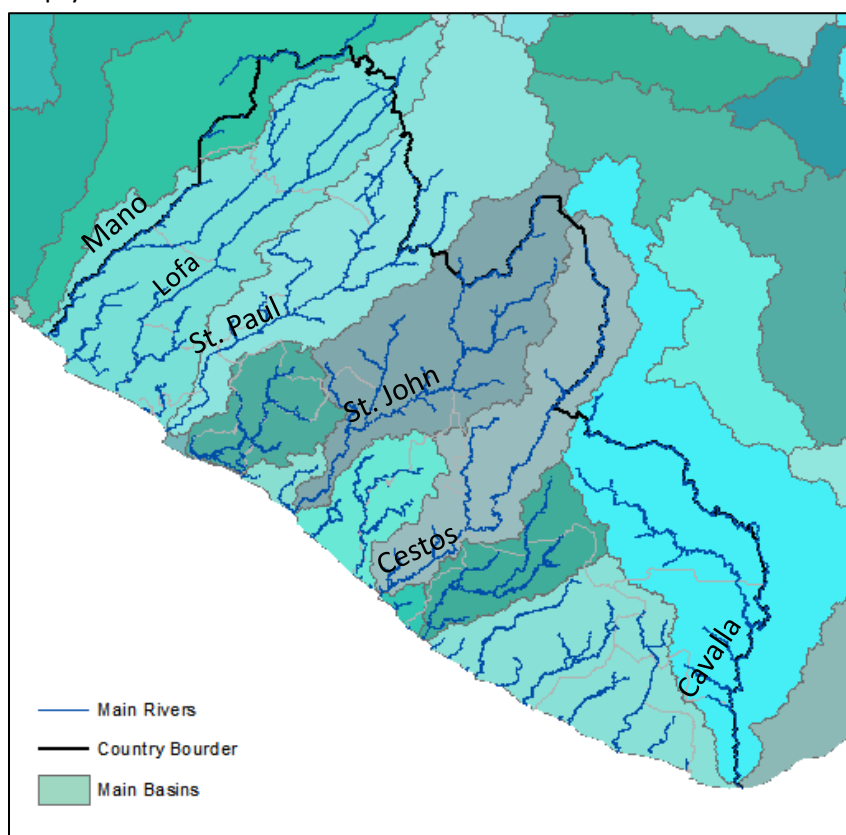


Figure 22. Major rivers in Liberia

Although fresh water is not a scarce resource in Liberia, it is vital resource important for people and the economy. Both rural and urban populations are primarily reliant upon groundwater resources for their water supply; only 62% of the Liberian population has access to protected water sources (MPEA, 2013), mainly from shallow and unregulated wells, or boreholes with hand pumps. Some communities draw water from surface water sources such as springs or harvested rainwater (UNDP, 2006). Prior to the civil conflict, 11 cities had piped water supplies including Monrovia, Gbarnga, Vojnjama, and Kakata, among others (UNDP, 2006; Figure 23). Most water systems, including the largest system in Monrovia,

were based on surface water collection and treatment (UNEP, 2004) with only four systems relying on groundwater sources (USAID, 2008).

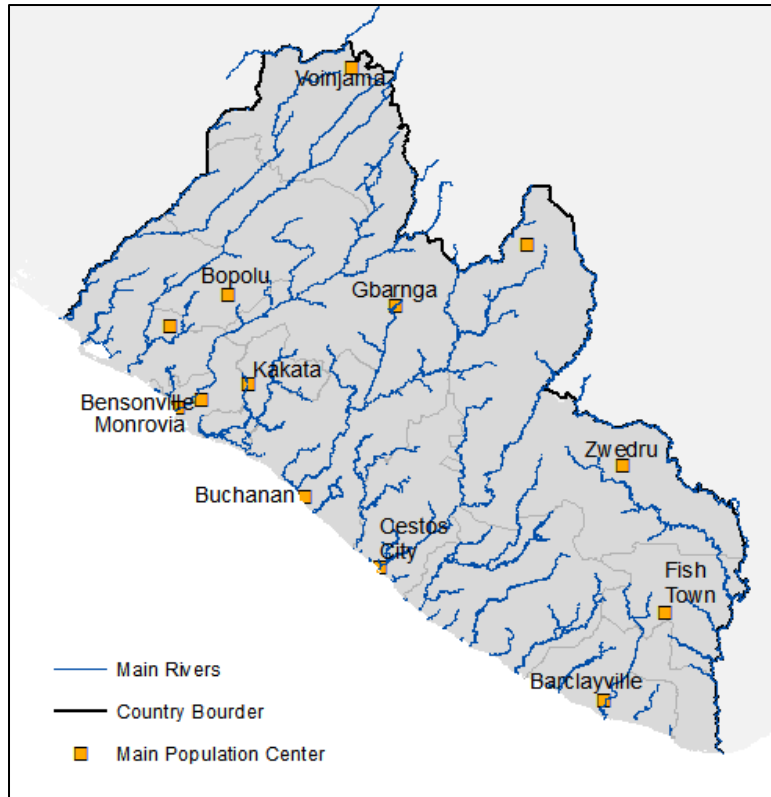


Figure 23. Human population centers in Liberia (Source: National Population and Housing Census 2008 (LISGIS, 2009))

Due to the civil conflict, Liberia’s infrastructure was completely destroyed and public services stopped their operation including water distribution (USAID, 2008). The rate of people without access to clean water is 61%, (MPEA, 2013). In the capital city, 64% of people get their water from one protected well, two primary bore holes and 250 shallow wells (AWF, 2007; USAID, 2008); and only 14.5% get their water from a water distribution system (GoL, 2013). The use of unsafe water sources and inadequate domestic and public sanitation facilities creates breeding grounds for mosquitoes, which in turn makes people vulnerable to malaria, one of the primary causes of mortality and morbidity in Liberia (Yarngo, 2011).

The rate of people without electricity is 95% (MPEA, 2013), which is the world’s lowest rate of access to public electricity. According to the Ministry of Lands, Mines and Energy (2013), the high cost and lack of reliable access to electricity remain key obstacles to the country’s stability and sustainable economic growth. Preliminary studies, based on the magnitude of the surface water flows in the country, indicate a high potential for hydroelectric power, up to 1,000 MW (MLME, 2013; Figure 24).

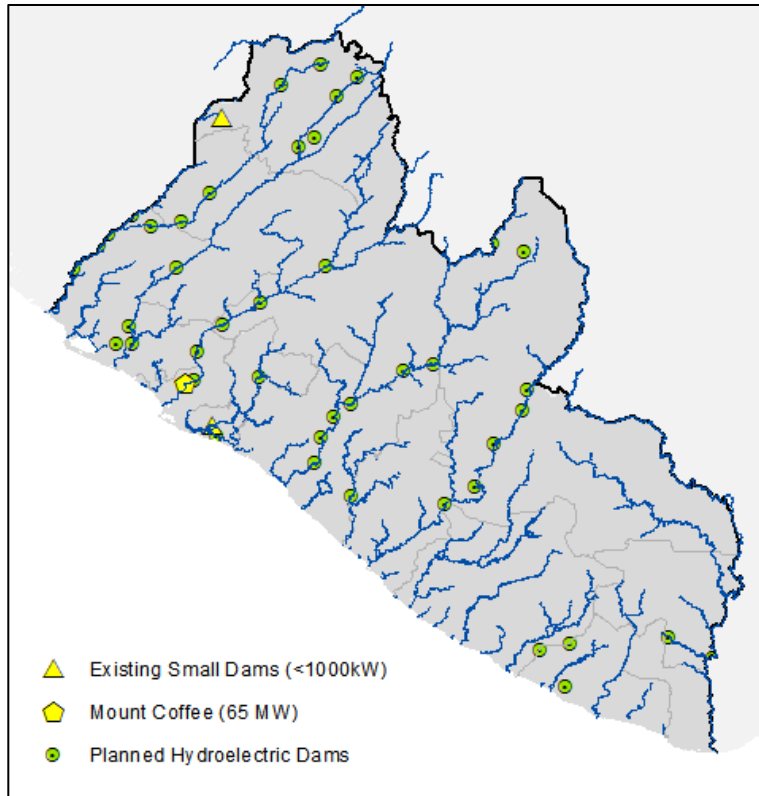


Figure 24. Planned and existing hydropower dams in Liberia. Source: Liberia Investment Plan for Renewable Energy (MLME, 2013)

In terms of agriculture, despite the abundance of land and water in Liberia, making multiple harvests per year feasible, less than 5% of the land is under permanent cultivation, and less than 1% is irrigated (MPEA, 2013).

How do ecosystems provide services to people?

Natural ecosystems such as forests, wetlands, and other aquatic ecosystems play a vital role in the hydrological cycle, as they regulate water flows in a landscape (TEEB, 2010). They capture sediment and recycle nutrients, improving water quality (TEEB, 2010). For example, cloud forests have the ability to intercept atmospheric water and through the process of evapotranspiration, return part of it back to the atmosphere. Soils containing abundant root systems, especially the root systems of trees, prevent soil erosion and exhibit a high infiltration rate that is important for groundwater recharge. Agricultural or industrial runoff that includes excess sediment and other harmful substances are retained and neutralized by wetlands and marshes. Wetlands and marshes also reduce the velocity of water flows, reducing flood and drought risk (Zedler and Kercher, 2005).

In Liberia, we defined *essential natural capital for the provision of freshwater ecosystem services* as natural ecosystems that provide surface water for human use and hydropower production (water

quantity), ecosystems that reduce erosion and regulate sediment (water quality), and ecosystems that attenuate floods (flow regulation).

In the following sections, we describe our mapping methods and quantify the relative importance of areas for the provision of: 1) *potential* ecosystem services – those provided by ecosystems regardless if they are used by humans, and 2) *realized* ecosystem services – those that provide a goods and benefits to beneficiaries, such as population centers, hydropower facilities, or other sectors that are depend on the provision of fresh water.

[Potential ecosystem services](#)

Areas important for sediment regulation – water quality

Methodology

First, we estimated the mean annual sediment erosion and deposition occurring under the current vegetation cover scenario (JV Metria/GeoVille and FDA 2016) using the Unit Stream Power Erosion and Deposition model (USPED; Mitasova et al., 1996). We then estimated the mean annual sediment erosion and deposition under a hypothetical scenario in which all vegetation cover is removed (bare soil). We assessed the sediment regulation function of vegetation by calculating the absolute difference between these two estimates. The resulting map (Figure 25) was generated by averaging the values over the Level 9 hydrological boundaries derived from the HydroBASINS dataset (Lehner, 2013).

Interpretation of results

The below map shows the average amount of sediment regulated (sediment erosion and retention) annually by a hectare of land within each level 9 watershed. Areas of higher values (darker blue) provide more potential sediment regulation services. In other words, these areas are important for sediment regulation, but those benefits are not necessarily used (“realized”) by anyone downstream.

Implications

The below map can be used to target conservation or restoration investments to reduce sediment loads in rivers. In other words, vegetation cover should be maintained or restored in the darker blue areas to reduce erosion and ensure that rivers downstream do not become clogged with sediment.

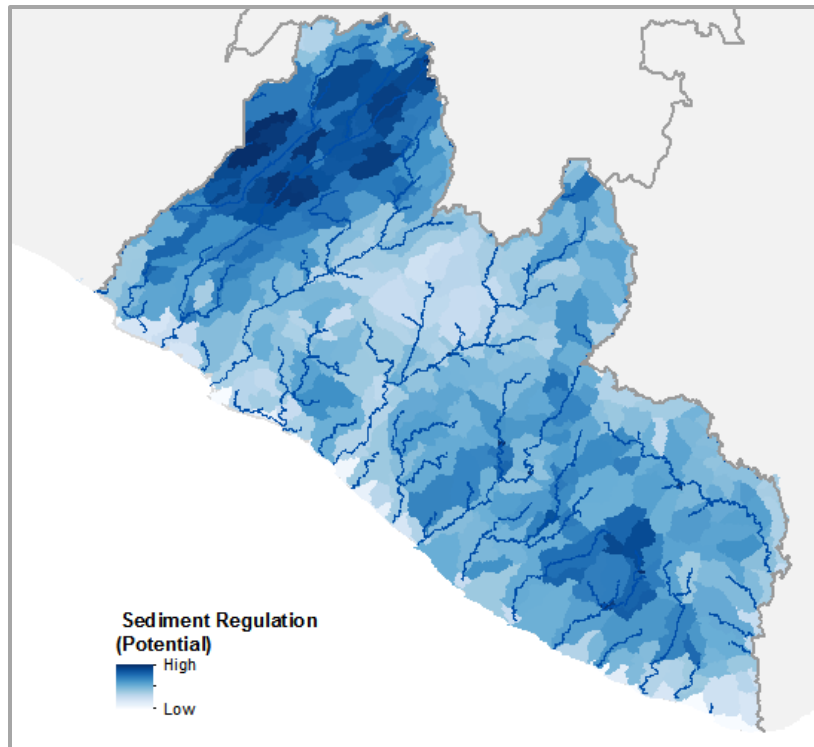


Figure 25. Important areas for Sediment Regulation (potential service).

Areas important for water quantity and flow regulation

Methodology

First, we estimated the mean annual water balance occurring under the current vegetation cover scenario using the WaterWorld hydrological model (Mulligan, 2013). Using the same model, we then estimated water balance occurring under a no vegetation cover (bare soil) scenario. We then assessed the water flow regulation function of vegetation (JV/Metria GeoVille and FDA, 2016) by calculating the difference between these two estimates. Similarly, we calculated the difference in the quantity of atmospheric water being intercepted (captured) by the current vegetation scenario compared to the bare soil scenario. In both cases, we ran the hydrological model using local precipitation data from the Liberian Hydrological Services (LHS 2016, <http://lhsliberia.com/>). The resulting maps (Figure 26) were generated by averaging the values over hydrological units, defined using the Level 9 hydrological boundaries derived from the HydroBASINS dataset (Lehner, 2013).

Interpretation of the results

The maps in Figure 26 show important areas for the provision of potential freshwater services related to: 1) water quantity (capture of atmospheric water) and 2) flow regulation (a steady predictable supply of water). Darker colors indicate higher importance for the service, as an average over each hydrological unit.

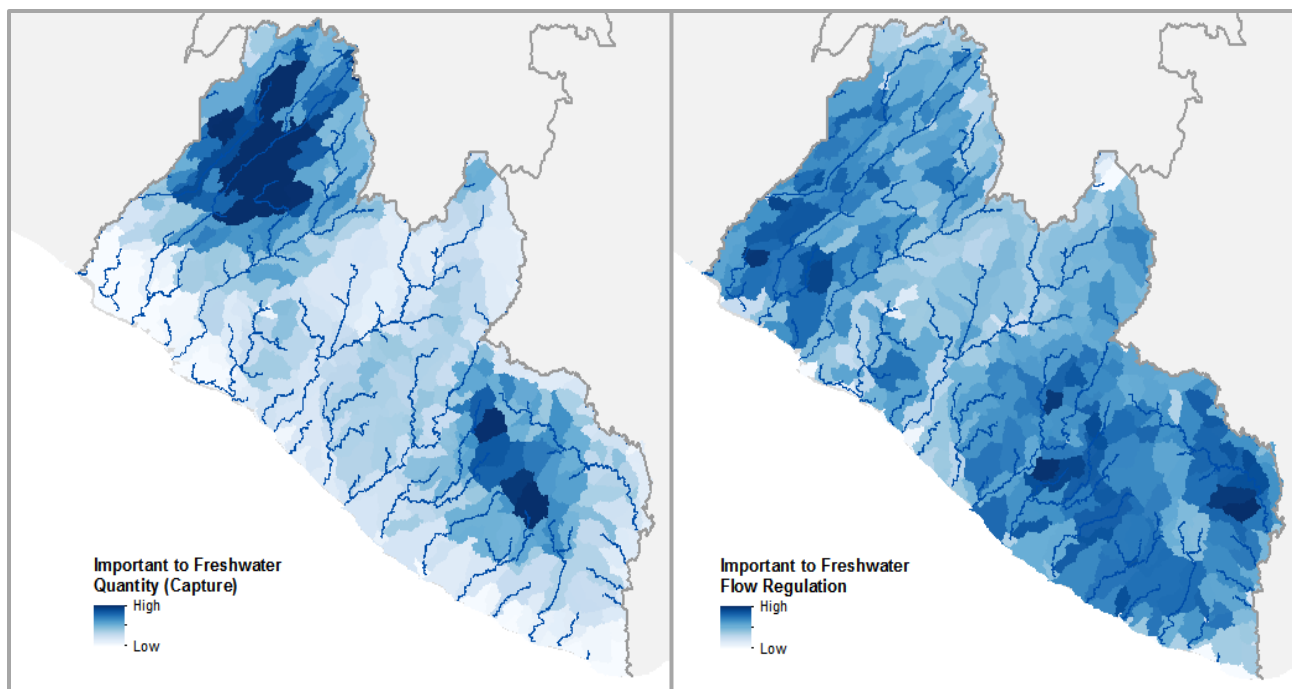


Figure 26. a) Important areas for water quantity (capture of atmospheric water (left)) and b) Important areas for flow regulation services (right).

Implications

The map can be used to target conservation or restoration investments to maintain and/or enhance the provision of water with a stable and predictable flow downstream.

Summary map of potential freshwater services

Methodology

The summary map (Figure 27) showing important areas for the provision of freshwater services (quantity, quality and flow regulation) was generated by averaging the values of the maps presented above (Figure 25 and Figure 26).

Interpretation of the results

The summary map in Figure 27 shows that the most important areas for potential freshwater services are in three key regions. The northern key region corresponds to the area of natural forest located around the Wologizi and Wonegizi Ranges. The southern two key regions are located around the Putu Range.

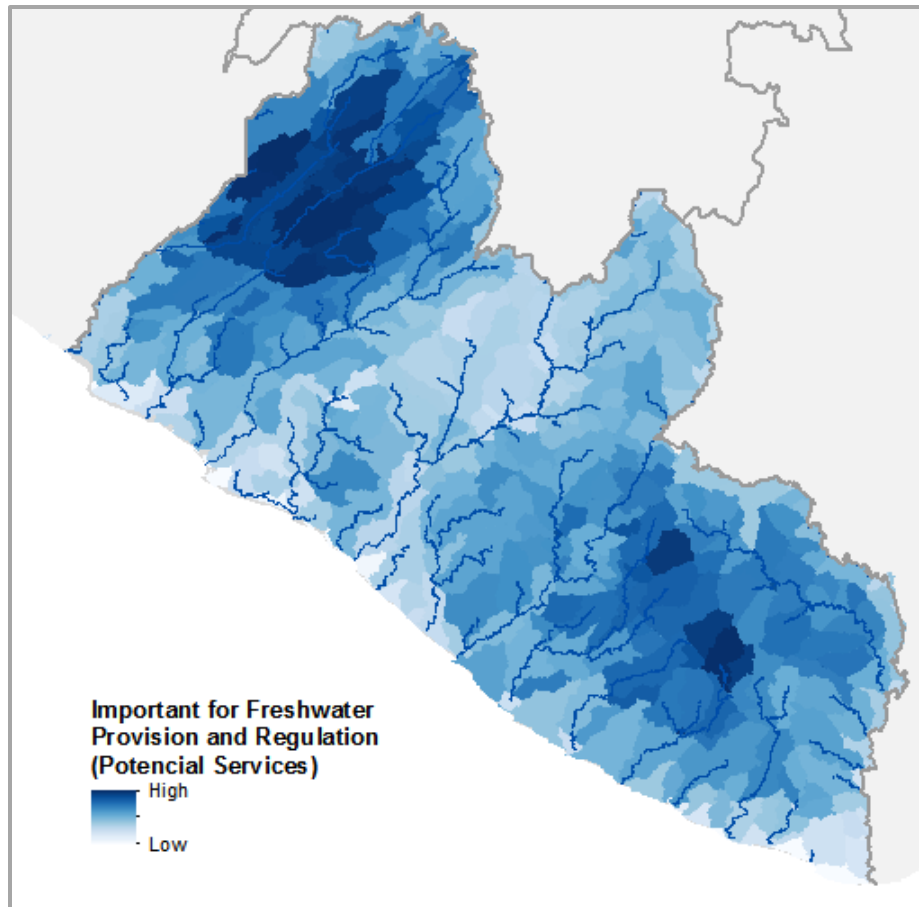


Figure 27. A summary map showing areas important for provision of potential freshwater services (quantity, quality, and flow regulation).

Realized ecosystem services

Areas important for water quality, quantity and flow regulation

The goal in this step was to identify important areas for water quality, quantity and flow regulation that are currently being used by beneficiaries.

Methodology

First, we identified the location of the two key beneficiaries of freshwater services in Liberia: 1) population centers and 2) hydropower dams. For locating population centers and their number of inhabitants, we used the National Population and Housing Census 2008 (LISGIS, 2009). We derived the locations and information about existing and planned dams from the Liberia Investment Plan for Renewable Energy (MLME, 2013). In the second step, we estimated water demand of each group of beneficiaries. The demand for domestic use in population centers was calculated using the number of people living in each population center, multiplied by the average estimated annual water use per person. This was based on an average global estimate of 120 liters per person per day (USGS, 2009). This rate is higher than the actual rate in Monrovia which is 25 liters per person per day (MLME, 2009), therefore demand for water for human consumption might have been over-estimated in our model.

However, other uses of water (e.g. for industrial use) was not included in this analysis. In the case of hydropower, the production capacity of each dam (in megawatts) was used as a proxy for the actual water demand. To obtain final maps of realized services, we weighted the potential services summary map (Figure 27, above) by the water demand of each group of beneficiaries and combined them to a single summary map (Figure 28, below).

Interpretation of results

The map in Figure 28 shows areas that provide freshwater services weighted by the level of demand of downstream beneficiaries (realized services). Areas of higher values (darker blue areas) provide higher levels of services and are located upstream of areas with higher demand for those services (e.g., larger population centers and larger hydropower dams.) The map is similar to the map of combined potential services (Figure 27), except the area upstream of Monrovia is now relatively more important due to the demand for water coming from this large population center and the Mount Coffee hydropower dam.

Implications

This map indicates that the area upstream of Monrovia should be targeted for conservation or restoration investments to maintain and enhance the provision of freshwater services for Monrovia and the Mount Coffee hydroelectric dam.

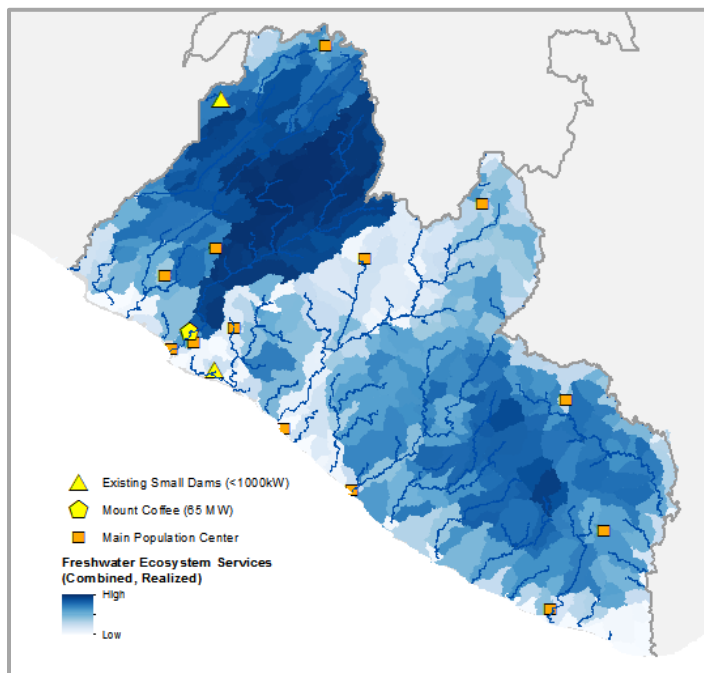


Figure 28. Important areas for freshwater services (quantity, quality, and flow regulation) located upstream of areas with water demand (larger population centers and existing hydropower dams.)

Areas Important for water quality for existing and planned hydropower dams

Methodology

First, we identified the locations of: 1) existing hydropower dams and 2) planned hydropower dams. The locations and information about existing and planned dams were derived from the Liberia Investment

Plan for Renewable Energy (MLME, 2013). The production capacity of each dam (in megawatts) was used as a proxy for the actual water demand. To obtain final maps of realized services, we weighted the sediment regulation map (Figure 25) by water demand of each group of beneficiaries and combined them to a single summary map (Figure 29).

Interpretation of results

Darker blue areas show areas that provide more sediment regulation services. These areas might be targeted for conservation or restoration of vegetation to benefit existing or future proposed hydroelectric dams. This map indicates the upper watershed of the St. Paul River in Lofa county, as well as the upper Cestos River watershed in Nimba county, should be targeted for conservation, to maintain the provision of freshwater ecosystem services for hydropower.

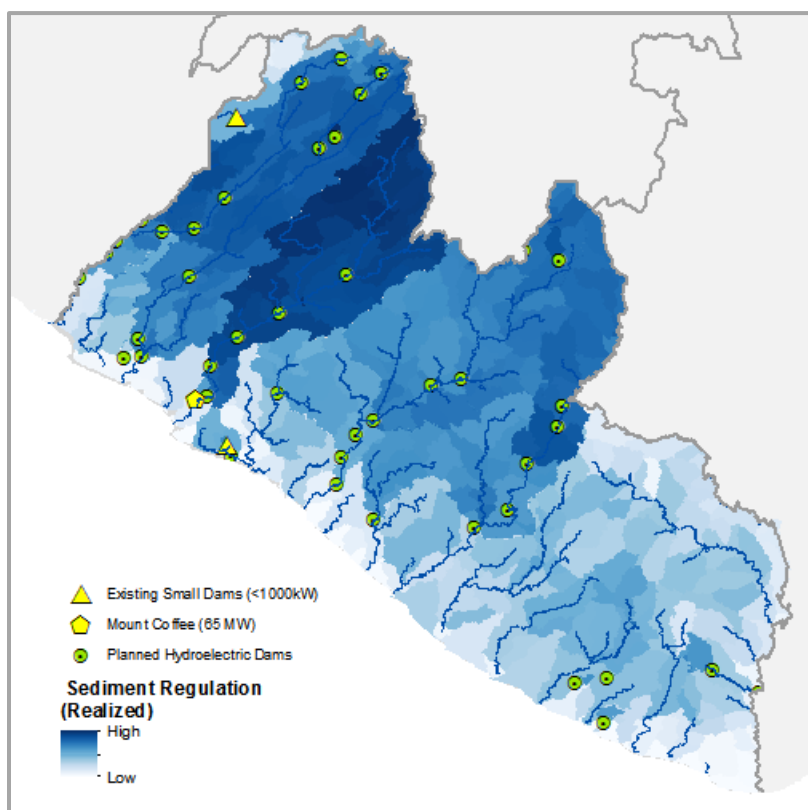


Figure 29. Sediment regulation services for existing and planned hydropower dams

Areas important for flood regulation

Methodology

The objective of this analysis was to identify areas that are important for reducing flood risk. First, we estimated the mean monthly water balance for the rainy season (May to October) occurring under the current vegetation cover scenario using the WaterWorld hydrological model (Mulligan, 2013). This was followed by estimating water balance occurring under a no vegetation cover (bare soil) scenario for the same period. The water flow regulation function of current vegetation (JV/Metria GeoVille and FDA,

2016) was assessed by calculating the difference between these two estimates. The definition of flood risk areas (Figure 30a) was based on the map produced for the Global Assessment Report on Risk Reduction (UNEP, 2009), which is a global dataset based on hydrological modeling, observed floods 1999-2007, and human population in 2009. The number of people living within 2.5 km of major rivers coinciding with the flood risk areas were hydrologically connected to upstream areas as a fraction of the water flow regulation function obtained in the previous step (Figure 30b). For the hydrological connection, we used water flow directions derived from the HydroSHEDS dataset (Lehner et al., 2008). For estimating the number of people in floodplains we used the LandScan 2007 dataset (Bright et al., 2008).

Interpretation of results

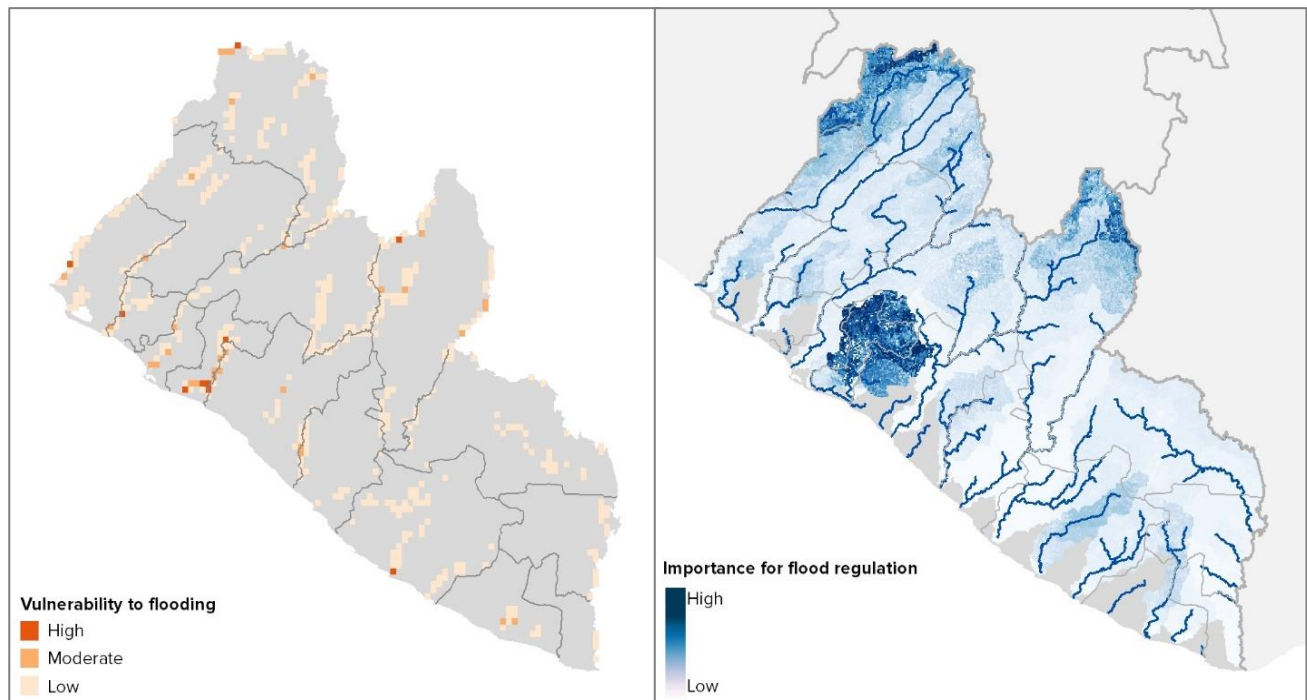


Figure 30. a) Human populations vulnerable to flooding (UNEP, 2009) (left). b) Areas important for flood regulation (right).

(UNEP 2009). The map on the right shows areas of natural capital (forest and herbaceous vegetation) that regulate water flows, weighted by the number of people downstream living in areas of increased flood risk. Areas of higher value (darker blue areas) have natural vegetation that regulates water flows, and provide flood regulation services for a greater number of people downstream. This map indicates that conserving vegetation cover in the watershed surrounding and immediately upstream of Monrovia is the most important area to reduce the risk of flooding for a large number of vulnerable people downstream.

Limitations and assumptions

There are several important assumptions and limitations that should be considered to better understand the maps:

- The location of beneficiaries determines the resulting maps of realized services. Therefore, other important beneficiaries in the country such as mining, and agriculture should be considered in future analyses.
- Water demand for provision of water for domestic use was estimated using data from other countries. Production capacity of hydropower dams in MW was used as a proxy for the actual water demand. Further analysis of actual water demand by people, dams, or other beneficiaries in Liberia should be the objective of future studies.
- The monthly seasonality of water availability was considered to identify areas important for one ecosystem service (flow regulation). A comprehensive analysis of seasonality impacts should be undertaken to determine the seasonal water availability important for the design of future hydropower facilities (including the area of upstream reservoirs, seasonal rainfall, etc.). Hydrological connectivity also should be the focus of future work, to determine the cumulative impacts of dams on river runoff and to mitigate effects on biodiversity and downstream fisheries.
- This analysis is not ecosystem-specific, therefore the analysis using only three landcover classes (forest, herbaceous vegetation, and bare soil) should be considered a first attempt to understand the role of ecosystems in the provision of freshwater services to people. Future analyses could investigate the role of more diverse ecosystem types (such as different forest types, savannas, wetlands, or other ecosystems) in the provision of ecosystem services.
- Due to a lack of data groundwater services are not included in this application. This variable should be addressed in future work, to have a better understanding of water resources, given the fact that people in Liberia in both rural and urban areas are primarily reliant upon groundwater resources for their water supply.
- This analysis does not address the potential impacts of proposed future hydropower dams throughout the country, which in some cases, are likely to have cumulative impacts on water availability downstream (i.e., several dams on the same river; this is the case of Cestos, Saint Johns and Saint Paul river). For this analysis, we are focusing on the role of ecosystems in supporting existing hydropower facilities; this analysis should not be interpreted as promoting the construction of new hydropower facilities. Impacts of hydropower dams go well beyond those analyzed here, including changes in sedimentation patterns and increase in CO₂ emissions from flooded forest, among others. For this reason, new hydropower dams need to be carefully considered before investments proceed.

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Mapping Essential Natural Capital for Food Security: Bushmeat and Non-Timber Forest Products

Compiled by Kellee Koenig and Rachel Neugarten

Introduction

Ultimately, all our food comes from nature. Natural capital (biodiversity and ecosystems) is important for providing numerous benefits that support food security, including game animals, fish, fruit, nuts, seeds, edible and medicinal plants, fuelwood used for cooking, and many others. Natural capital also provides ecosystem services including regulation of soil and water quality, climate regulation, pollination, and pest control, which allow us to grow crops and livestock. Therefore, essential natural capital for food security is defined in two ways:

Ecosystems that provide essential wild sources of food (bushmeat, fisheries, fuelwood and non-timber forest products) to vulnerable populations who are dependent upon them

-and-

Ecosystems that provide essential services to agriculture systems that produce crops and livestock for consumption (e.g. freshwater, soil fertility, pest and disease control, climate regulation, and/or pollination).

In Liberia, examples of essential natural capital for food security include:

- Forests or other natural habitats that provide edible plants, fruits, nuts, habitat for wildlife which is hunted for bushmeat or other wild sources of food, as well as firewood used for cooking
- Freshwater, marine, and coastal ecosystems providing fish and other food sources
- Forests, grasslands, wetlands, and other habitats that provide soil and water quality, climate regulation, pest control, pollination, or other ecosystem services that support agriculture

While natural ecosystems support food security in multiple ways in Liberia, including providing fisheries, hunting, collecting, cooking fuel, supporting agricultural production, and providing cash income, this analysis focuses specifically on bushmeat and non-timber forest products (NTFP).

In Liberia, forests and other natural habitats are critically important to the food security and livelihoods of many people, especially rural populations. About 70 percent of Liberia's rural population earn their living from forest and forest-related products, relying on firewood and charcoal as the main source of energy generation for cooking and heating (USAID 2009). In more remote areas, the figure is even higher: 90% of surveyed people in communities in Gola National Forest use the forest as a source of food, income, bushmeat, and medicine (Bulte et al. 2012). Furthermore, NTFPs frequently provide a "safety net," as they provide a critical source of dry season revenue when agricultural revenues are depleted.

Definitions

Bushmeat is defined as “all forest wildlife species, including threatened and endangered, used for meat including: elephant; gorilla; chimpanzee and other primates; forest antelope (duikers); crocodile; porcupine; bush pig; cane rat; pangolin; monitor lizard; guinea fowl; etc.”

(<http://www.bushmeat.org/sites/default/files/BCTFBRIE.pdf>).

According to the International Centre for Forestry Research (CIFOR), *non-timber forest products* (NTFPs) are any product or service other than timber that is produced in forests. They include fruits and nuts, vegetables, fish and game, medicinal plants, resins, essences and a range of barks and fibers such as bamboo, rattans, and a host of other palms and grasses.

For simplicity, in this section we use the acronym NTFP to refer to all food products harvested from forests and other natural habitats, including bushmeat.

Non-timber forest products

NTFPs are critically important to both food security and incomes in Liberia. A survey conducted by USAID in Nimba and Sinoe counties in Liberia calculated total revenues (those from all the actors in the areas of intervention and the traders that serve them) from non-timber forest products (defined as “plants, animals and fungi, or their products, that are gathered from forests, rather than hunted or fished animals”) (USAID 2009). According to the study, the NTFPs that seem to have the greatest impact on food security in these two counties are snails, bush yams, and wollar (*Beilschmiedia mannii*, a tree species). In terms of economic importance, they found the highest total revenues were from palm oil, bush pepper, country spice, and walnut with estimated total revenues of USD 50,990-147,283. This refers to palm oil collected from naturally occurring palm trees; this figure does not cultivated plantations. See Table 11 for other NTFP products in these two counties.

NTFPs also provide a source of livelihoods in many rural areas. In surveyed localities in Nimba and Sinoe counties, the number of people working with NTFPs amounts to an estimated 3,678 out of a total population of 31,213, or about 12% of people in these pilot sites (USAID 2009). If the family size in the surveyed areas was consistent with national averages, then this would mean that roughly one member of each family of seven is an NTFP producer nationwide.

Table 11. Non-timber forest products in Nimba and Sinoe counties, listed roughly in order of economic importance (USAID 2009). 1ry and 2ry forest means primary and secondary forest, respectively.

Product	Species name	Nature of product	Season	Forest type
Oil palm ^b	<i>Elaeis guineensis</i>	Oil from fruit	December to May	Fallow – 2ry forest
Country spice ^b	<i>Xylopia aethiopica</i>	Fruit	January – May	Fallow – 2ry forest
Bush pepper	<i>Piper Guineense</i>	Fruit	February – April	1ry forest
Walnut	<i>Cola edulis</i>	Fruit	Jan –March	1ry forest
Rattan	<i>Calamus spp.</i>	Vine	All year ^c	1ry forest
Bitter cola	<i>Garcinia cola</i>	Fruit	Dec- Feb	1ry forest
Chew sticks	Divers spp.	Root	All year	1ry forest
Wollar	<i>Beilschmieda manii</i>	Fruit	January – March	Fallow to 1ry forest
Bitter Root	<i>Cola affelii</i>	Apical bud	All year	2ry to
Palm wine	<i>Raphia vinifera</i>	Sap	December – May	2ry forest to 1ry forest
Brooms	<i>Raphia vinifera</i>	Branches	All year	2ry forest to 1ry forest
Bush yam	<i>Dioscorea spp.</i>	Tuber	June- August	2ry forest to 1ry forest
Snails	<i>Achatina</i>	Snail	December – April	2ry forest to 1ry forest
Thatch	<i>Begoniaceas spp</i> <i>Raphiapalm-pinus</i>	Branches	All year	2ry forest to 1ry forest
Monkey vine		Root	All year	1ry forest
African nut tree	<i>Ricinodendron heudelotii</i>	Fruit	July – September	2ry forest to 1ry forest
Grain of paradise	<i>Fromomum meleguetta</i>	Fruit	February – June	2ry forest to 1ry forest
Honey	<i>Apis spp.</i>	Honey	All year	2ry forest to 1ry forest

Bushmeat

Bushmeat provides a major source of protein in western Africa, and is particularly valuable in rural communities. It provides cash for the purchase of household supplies and school fees, and is essential to meeting protein needs, especially for those communities isolated from the coast or large waterways where fish is more available.

Three-quarters of the meat consumed in the Democratic Republic of Congo and Liberia comes from wild animals (Anstey 1991; Sale 1981; cited in Kaimowitz 2003). Bushmeat is also consumed in urban areas, however. Based on surveys in other African nations, wealthier households consume more bushmeat in settlements nearer urban areas, but the opposite pattern is observed in more isolated settlements (Brashares 2011). Wildlife hunting and consumption increase when alternative livelihoods collapse, but this safety net is an option only for those people living near harvestable wildlife (Brashares 2011).

In Liberia, there is a paucity of data related to harvest rates, but it is clear that the wildlife harvest is significant. Based on a 2002 survey, 96% of respondents report eating bushmeat (Hoyt and Groff 2002).

In 1991, each person in a rural forest area around Sapo National Park consumed a daily mean of 0.01752 whole animals (Stephens 1988, cited in Mayers 1991). Anstey (1991) estimated the volume of bushmeat harvested for both subsistence and commercial purposes in Liberia as 150,000 tonnes per year (Hoyt 2004), which is one of the highest per capita offtake rates in Africa (Tweh et al. 2014). Hunting has been reported as one of the main threats to wildlife, even near officially protected areas (Greengrass, 2011; Bene et al., 2013).

The civil conflict from 1989 to 2003, and the resulting collapse of the national economy, may have promoted the expansion of the wildlife harvest. During the height of the conflict, domestic meat availability declined and demand for bushmeat likely increased. Many county authorities reported an increase in commercial hunters over the last decade (Hoyt 2004).

Bushmeat is economically important in Liberia. The total estimated value of bushmeat trade adds up to USD 78 million/year (Hoyt and Groff 2002). (Another estimate is similar but slightly higher: bushmeat may represent 75% of Liberia's meat consumption, with an approximate replacement value of USD 100 million (Hoyt 2004).) Of this total, estimated urban sales of bushmeat equal USD 31.2 million/year while estimated rural/subsistence use of bushmeat equals USD 46.8 million/year (Hoyt and Groff 2002). Per capita, estimated expenditures for bushmeat are approximately USD 31.20/person/year in urban centers with assumed USD 2/week average bushmeat expenditure. Bushmeat surveys conducted in the capital city, Monrovia, estimated the total income generated from meat sales in the city at over USD 8 million in less than a year (CEEB 2003–2004, cited in Tweh et al. 2014).

Bushmeat also provides a key source of income in Liberia. Surveys of six localities around Mount Nimba found that bushmeat hunting was primarily for subsistence, specifically by farmers who were seeking protein and income for their own households and communities, but commercial bushmeat trade and sale also occurred between communities, from local communities to city markets further away, and across the border with nearby Guinea and Cote d'Ivoire (Bene et al. 2013). Anecdotal data also indicates substantial cross-border trade to Ivory Coast, which has much higher market prices, and therefore a considerable incentive for hunters and marketers to illegally transport their goods across the border. Based on one survey of twelve hunters (Hoyt 2004), the sale of bushmeat is estimated to represent an average income of USD 27 per hunter per month. In rural areas of extreme poverty, where the average villager makes less than USD 0.50/ day, bushmeat thus represents a significant source of cash income.

The trade in wild meat has been identified as among the greatest threats to the maintenance of biodiversity, second only to habitat destruction (Hoyt 2004). Monitoring of hunting activity indicated that rodents were the most commonly hunted animals (57%) followed by ungulates (20%), carnivores (13%), primates (5%) and Pholidota (3%) (Bene et al. 2013). Specific species encountered in markets include Maxwell's duiker (29%), Bay duiker (29%), Brush-tailed porcupine (6%), Common warthog (6%), Cane rat (5%), and Bushbuck (5%) (Table 1). Primate species included Mangabey (3%), Campbell's monkey (3%), Lesser spot-nose (1%), Baboon (1%), and Diana monkey (less than 1%).

A study of bushmeat hunting and trade was conducted in two villages (Sapo Town and Putu Town) around Sapo National Park (Greengrass 2011). In this study, duiker comprised the majority (84%) of biomass hunted at both sites. Gun hunters in Putu Town reported making on average USD 120/month

while those in Sapo Town reported making on average USD 93/month. Duiker, primates, and other ungulates comprised 96% of the total income generated across both sites. A list of species hunted near the national park are listed in Table 12.

Table 12. List of commonly hunted species near Sapo National Park, with their local and English names (Greengrass 2011).

Local name	English name
Blue ton (pronounced tongue)	Maxwell duiker
Kisseh (pronounced gizzeh)	Maxwell duiker
Porkapan / porker pound or variation	Porcupine
Black deer	Black duiker
Red ton (pronounced tongue)	Ogilby's duiker
Black -back	Bay duiker
Bush cat	Palm civet
Tree con (pronounced coon)	Palm civet
Water deer	Water chevrotain
Turtle	Terrapin
Mountain deer/marking deer	Zebra duiker
Ground hog	Cane rat
Golden cat	Golden cat
Black monkey	Black & white colobus
Red monkey	Red colobus
Jacko	Sooty mangabey
Diana monkey	Diana monkey
Handbag	Small porcupine (ground/tree)
White-nose monkey	Lesser white-nose monkey
Opossum	Pouched rat
Tabadu	Pouched rat
Red deer	Bushbuck
Olive monkey	Olive colobus
Bush dog	Tree hyrax?
Putu-putu or softly – softly*	Potto
Alligator	Nile crocodile or slender-snouted crocodile
Blue wing	Turaco

Note: "?" refers to species that remain unconfirmed. *The putu-putu was only positively identified as a potto after data analysis had been completed. From unclear descriptions given by the hunter at the time it was originally thought to be a honey badger. Data analysis therefore accounted it as being a carnivore rather than a primate. However, because only one individual was ever caught, data was not reanalyzed, as this error does not alter the results significantly.

Surveys were also conducted in two commercial hunting camps (Greengrass 2011). Significant harvest of species of conservation concern were recorded. Hunters each earned USD 1,000-2,000/month and each camp earned over USD 26,000 during the survey period of one month. The author of the study concluded that hunting at the rates recorded is unlikely to be sustainable for a number of species of conservation concern including elephant, pygmy hippo, chimpanzee, red colobus and other primate species. In particular, harvesting rates of chimpanzee indicate that the threat to this already endangered species from hunting is severe and that unless demand or supply is reduced, a viable population will not survive in a few years. The author recommended that the government consider closing all hunting camps located inside the national park and its boundaries, where hunting is mainly for sale to urban

centers, and provide a stronger law enforcement presence. Infrastructure development of the road network is likely to facilitate the existing bushmeat trade and possibly increase hunting pressure.

Methods

The objective of this analysis was to identify areas of Liberia that are likely providing sources of bushmeat and NTFPs, due to the presence of habitat (including grassland, open forest, closed forest, and other habitats) that are accessible to humans. We used a modelling approach developed for the Amazon basin by Manuel Peralvo for the Ecosystem Services for Poverty Alleviation (ESPA) group (Porro et al. 2008). While the model was developed for the Amazon, it is applicable to any forest-dominated region. It combines three primary inputs:

1. Natural ecosystems of known importance for hunting and collecting
2. Habitat quality (based on spatial data on known threats such as agriculture, roads, mining, and human settlements)
3. Accessibility to people

Each of those inputs is itself derived from other data, as described below. For our analysis, we excluded habitat quality as an input, as based on our literature review and discussions with local experts in Liberia, we learned that people hunt and collect NTFPs from modified (“low quality”) habitats, including fallow farm fields and secondary forests. Therefore we believe habitat quality is not a good predictor of habitat importance for NTFPs.

Natural Ecosystems

For a map of natural ecosystems we used a recent (2015) official government landcover product (JV Metria/Geoville and Forestry Development Authority 2016). The Geoville landcover product includes the following classes: forest (divided into three categories: >80%, 30-80%, and <30%); mangrove & swamps; settlements; surface water bodies; grassland; shrub; bare soil; ecosystem complex (rock & sand); clouds (unmapped) (Figure 31, Table 13). Based on our literature review, people in Liberia use multiple habitat types (e.g. fallow areas, secondary forest, and primary forest) for hunting and NTFP collection. Therefore, in our analysis all habitat types were considered equally valuable for potential NTFP benefits. Bare soil, ecosystem complex (rocks & sand) and settlements were excluded.

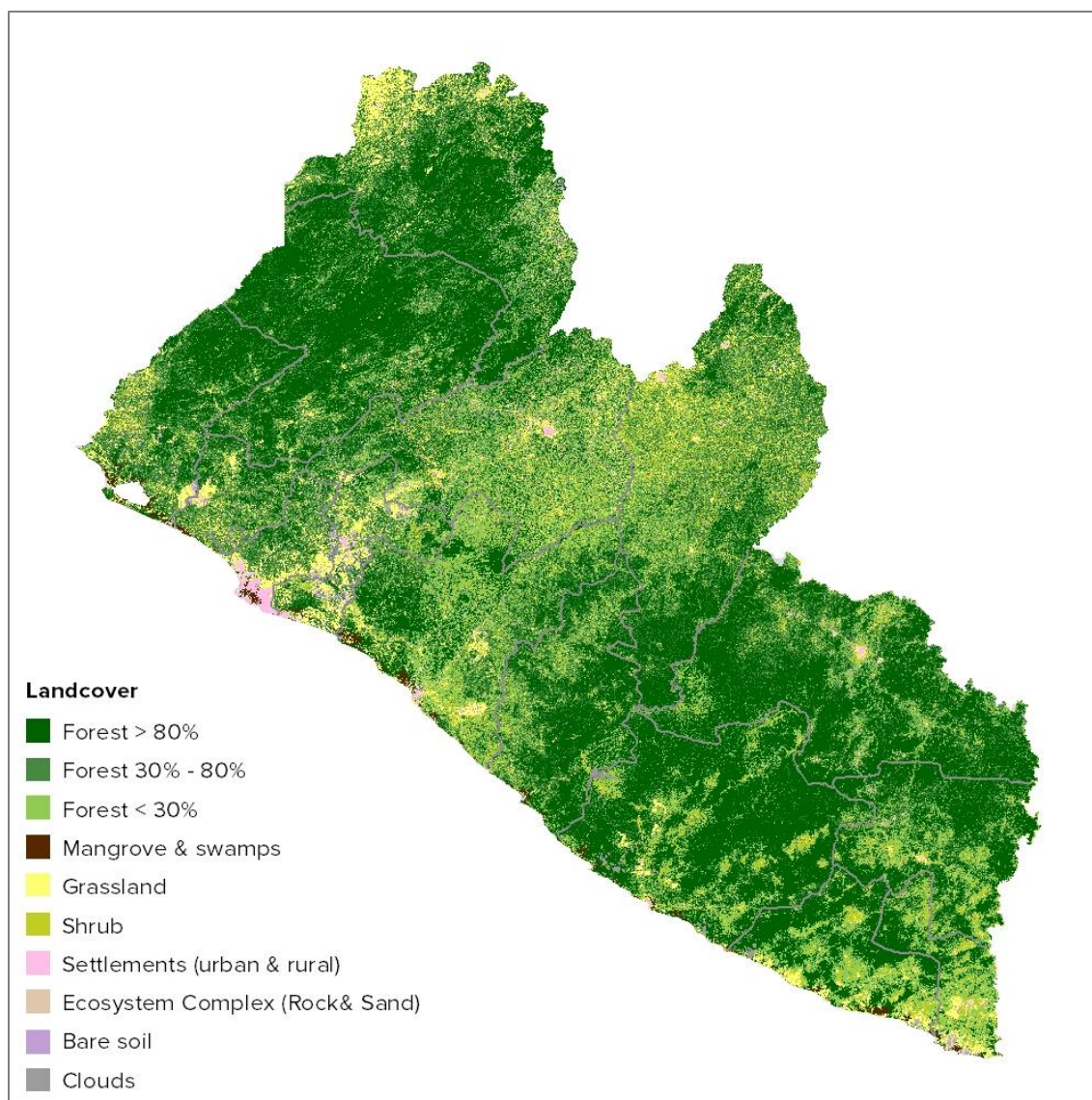


Figure 31. Geoville 2015 landcover map for Liberia (JV/Metria Geoville 2016).

Table 13. Landcover classes, their extent, and the percentage of total land area, based on the Geoville landcover product (JV/Metria Geoville and FDA 2016).

Landcover class	Hectares	% of mapped area
Forest >80%	4,389,270	45.50%
Forest 30 - 80 %	2,186,495	22.60%
Forest <30%	1,529,949	15.80%
Mangrove & Swamps	37,158	0.40%
Settlements	44,595	0.50%
Surface Water Bodies	60,374	0.60%
Grassland	625,332	6.50%
Shrub	606,928	6.30%
Bare Soil	173,690	1.80%

Landcover class	Hectares	% of mapped area
Ecosystem complex (rocks & sand)	2,271	0.02%
Clouds (unmapped)	14,336	0.15%
Total mapped area (land and inland water)	9,656,062	100.00%

Accessibility

The accessibility input was created by updating the ESPA model (Porro et al. 2008) in ArcGIS's Model Builder (Figure 32). This model uses spatial data on roads, existing land cover types, urban areas, and slope as all of these features influence travel time, an aspect of accessibility. Each spatial feature was converted to numeric values of travel time in kilometers per hour.

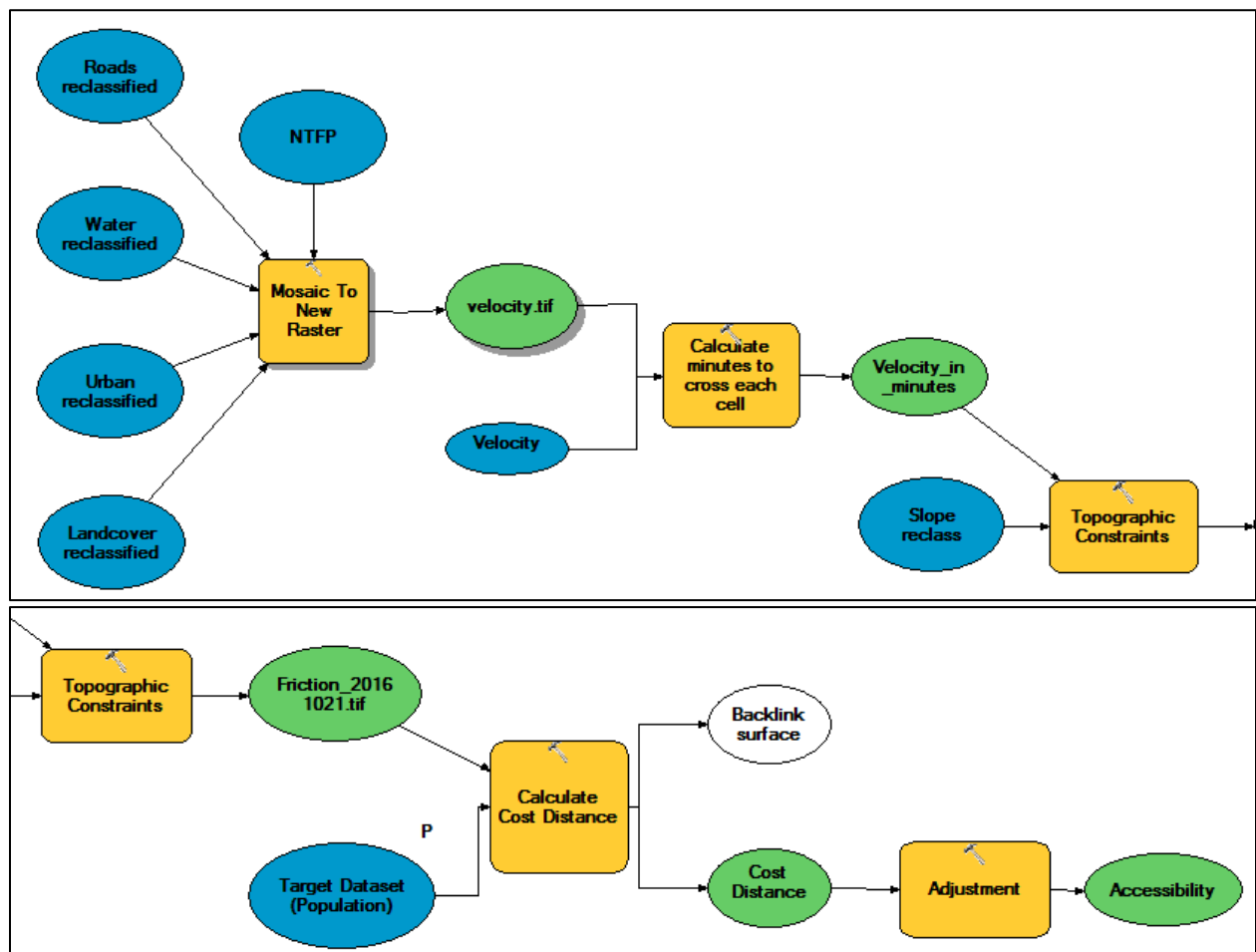


Figure 32. ArcMap Model Builder diagram of the Accessibility model (model provided by Manuel Peralvo, following Porro et al. 2008)

We used roads data from several government and non-governmental sources (see data sources listed at the end of this section). Each type of transportation and road type was assigned a travel velocity (based on input from local experts in Liberia and following Porro et al. 2008, see Table 14) and converted to a raster file. Following the guidance of local experts, the newer paved roads between Monrovia and Ganta, and Monrovia and Buchanan, were assigned higher velocity values (Figure 33).

Table 14. Road type and associated travel time (dry season)

Road Type (Dry Season)	NTFP model value (km/hr)
Newer roads (Monrovia-Ganta and Monrovia-Buchanan)	80
Paved	60
Unpaved	25
Tracks	5

The dataset of natural ecosystems (JV Metria/Geoville and FDA 2016) was dissolved into broad categories and reclassified based on travel velocities identified in Porro et al. 2008 (Table 15 and Figure 33). For example, travel time through human settlements was estimated as 5 km/hr (the average walking speed of an adult); while travel time through forest was estimated as 2 km/hr. Travel time over water was also estimated at 5 km/hr (a rough estimate based on self-propelled boat travel speed). Travel time through other habitat types fell somewhere between 2 and 5 km/hr.

Table 15. Land cover type and associated travel time

Land cover	NTFP value (km/hr)
No Data	-
Forest > 80%	2
Forest 30% - 80%	2
Forest < 30%	2
Mangrove & swamps	2
Settlements (urban & rural)	5
Surface water bodies	5
Grassland	3
Shrub	3
Bare soil	4
Ecosystem Complex (Rock& Sand)	4
Clouds (unknown land cover)	3

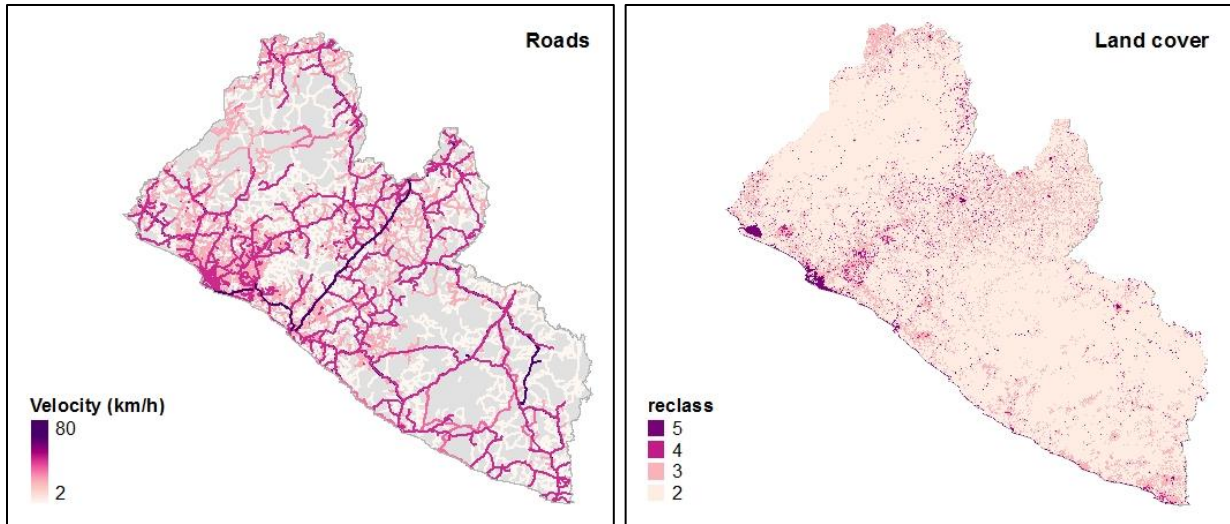


Figure 33. Roads symbolized by dry season travel time in kilometers per hour (road widths exaggerated for display purposes) (left). Land cover symbolized by travel time in kilometers per hour (right).

Urban areas were identified based on human settlement data from the Ministry of Planning and Economic Affairs (MPEA) (provided for this analysis by the Liberia Institute of Statistics and Geo-Information Services, LISGIS) and reclassified to a value of 25 km/hr (Figure 34). These layers (roads, landcover, and urban areas) were mosaicked together in ArcMap to yield a velocity surface, whose values were converted from units of km/hr to minutes of time required to cross a given grid cell (Figure 34).

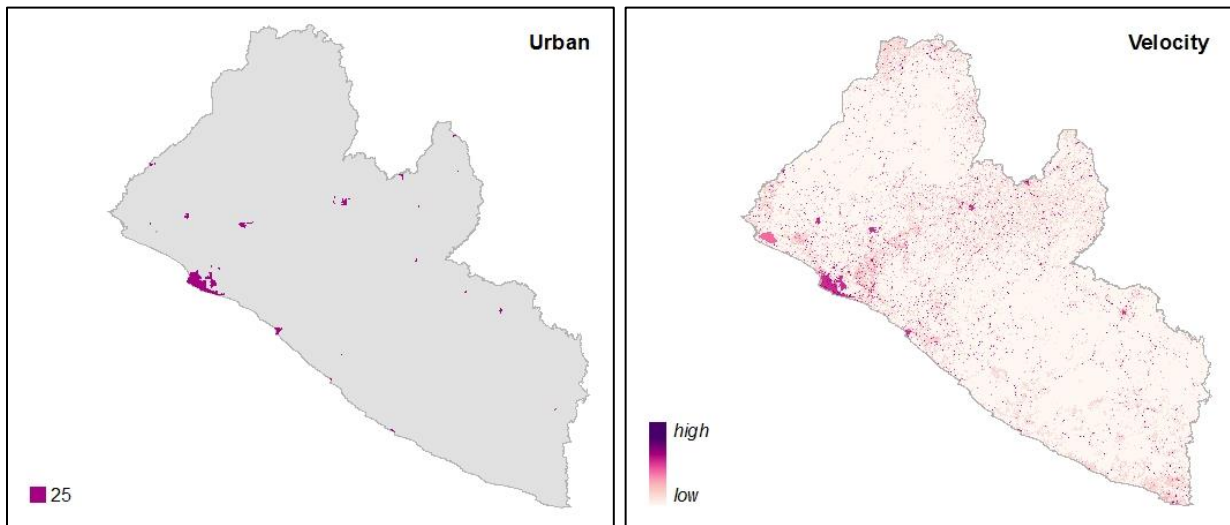


Figure 34. Urban areas symbolized by travel time in kilometers per hour (left). Velocity: roads, urban areas, and land cover symbolized by travel time with darker colors meaning higher velocity (right).

Topographic constraints are also important aspects of accessibility. Liberia is relatively low lying, with elevations ranging from 0 to 1,380 m (CIA World Factbook 2016, <http://www.ciaworldfactbook.us/africa/liberia.html>), therefore elevation was not considered a barrier to accessibility. Steep slopes, however, can reduce accessibility, no matter their elevation. For this, SRTM data (Jarvis et al. 2008) was modified to match the resolution of other model inputs, and analyzed

for slope. The output was reclassified into categories, with higher numbers indicating steeper slopes (Table 16).

Table 16. Slope categories

Degree	Reclassified to
0 - 5	1
5 - 10	2
10 - 100	3

The resulting Velocity and Slope layers were multiplied together to create a Friction Surface, with higher values indicating greater time is required to cross a pixel (Figure 35).

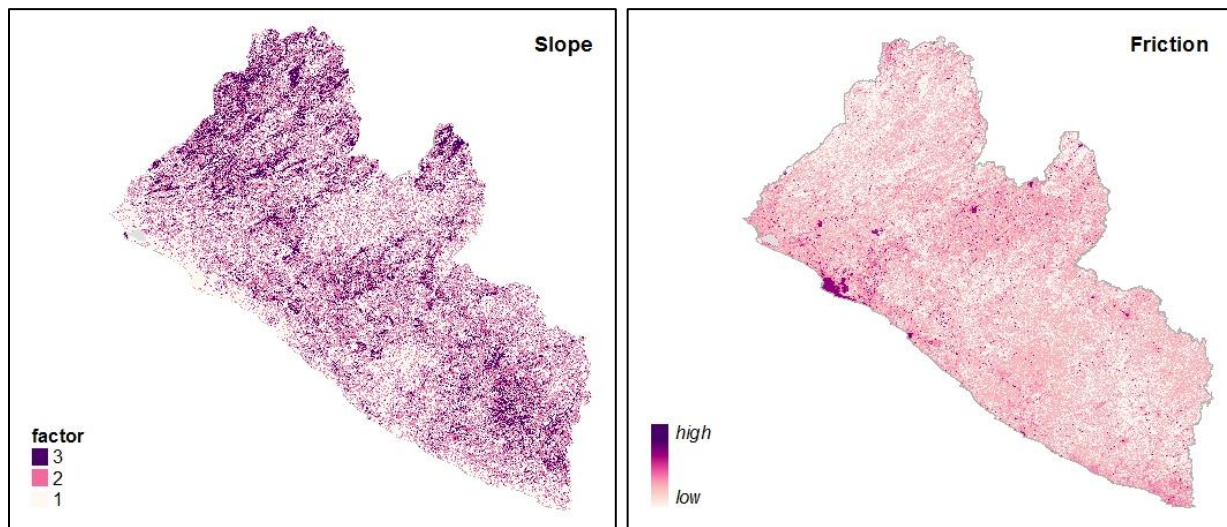


Figure 35. Slope factor (left). Higher numbers indicate reduced accessibility and are shown as darker colors. Friction surface (right). Darker colors indicate increased traverse time.

Next, we fed the Friction surface into the Cost Distance model (Porro et al. 2008), which calculated the least cumulative cost distance from each cell to the nearest population. We used 2014 population data from the Landscan global dataset (Bright et al. 2014), and only included areas with at least 50 persons/km² (Figure 36). This threshold was applied after experimenting with different thresholds and comparing their results; lower thresholds (e.g. 1 person/km²) showed virtually all of Liberia to be accessible (in other words, almost every location in the country is accessible to at least 1 person). Higher thresholds (e.g. 100 people/km²) showed very little of Liberia to be accessible. The arbitrarily selected threshold of 50 people/km² gave a result that showed a moderate area of the country as accessible. In the future, this threshold should be adjusted based on actual data on travel times (which was not available for this analysis) or using input from local people in different parts of the country, who could speak to whether or not the model appeared accurate for their area.

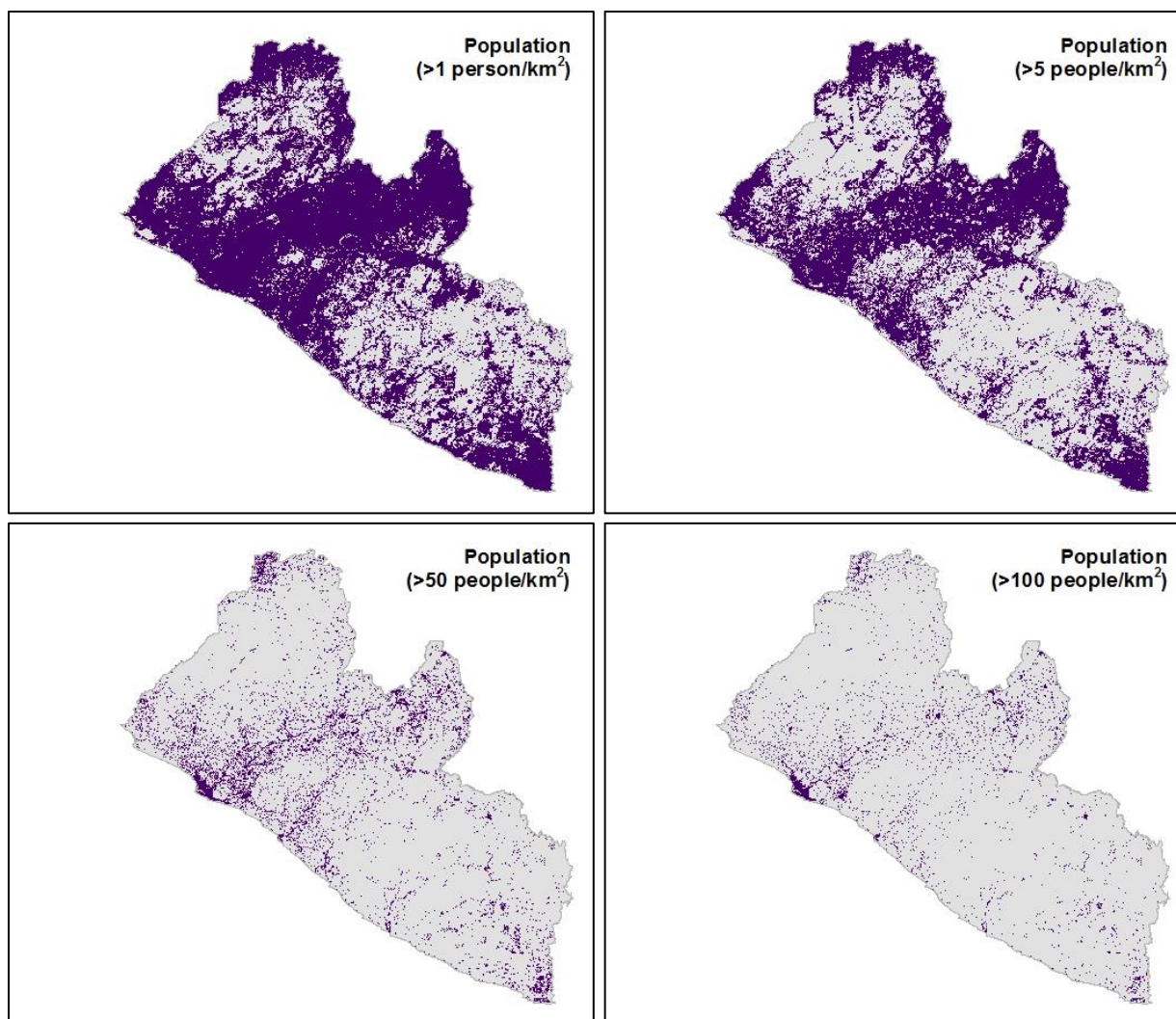


Figure 36. Populated areas in Liberia, shown in purple, using different thresholds (>1 person/km², >5 people/km², >50 people/km² and >100 people/km²). For this analysis, we used an arbitrary threshold of areas with >50 people/km² (lower left).

Results

Accessibility

The areas of greater accessibility and relative importance for NTFPs show strong spatial patterns, with concentrations in several regions. The greater Monrovia area has one of the largest regions of accessibility, with a wide swatch extending north along the road to Nimba and west towards Lake Piso and the border with Sierra Leone. This is unsurprising as the majority of Liberia's population is concentrated in the capital city, and the roads from the capital tend to be paved and better maintained. Another concentration is in the northern border of Lofa county near the borders with Sierra Leone and Guinea. This area appears to have relatively higher population when compared to other rural areas of the country. The areas surrounding Buchanan and Harper also have larger regions of importance. Conversely, the areas of relatively low accessibility are Gbarpolu county, southern Lofa county, and the majority of Grand Gedeh, Sinoe, River Gee, and Grand Kru counties.

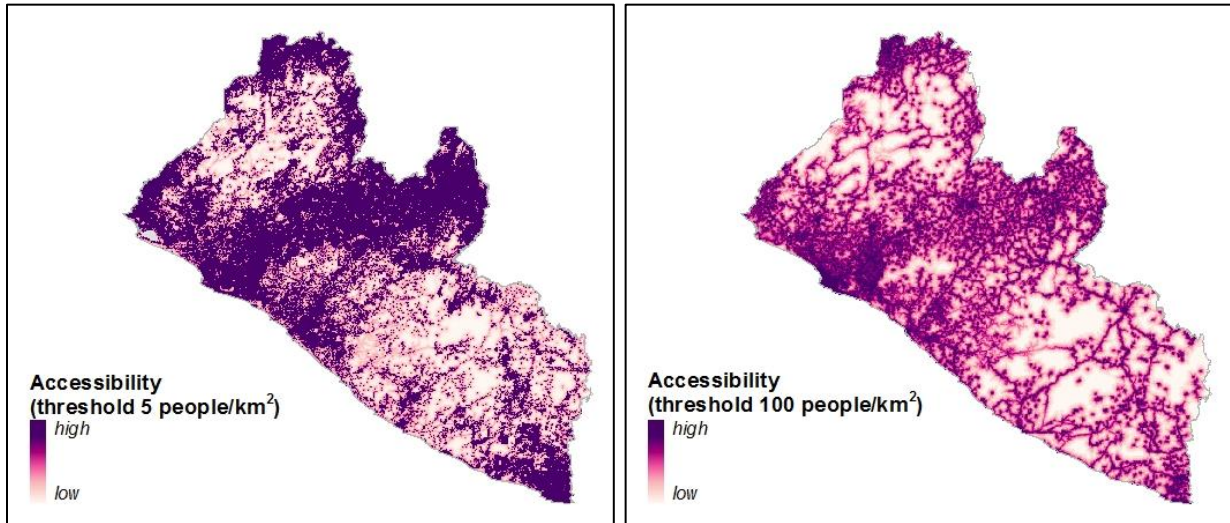


Figure 37. Accessibility, in hours (threshold for population input: 5 people/ km² and 100 people/ km².) Darker colors indicate increased accessibility, or reduced travel time.

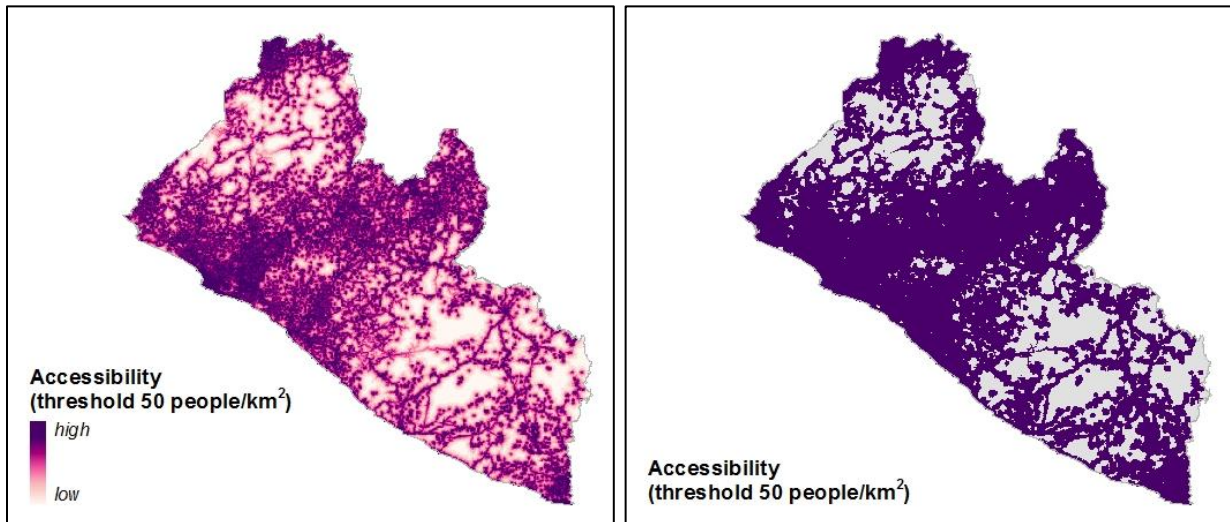


Figure 38. Accessibility, in hours (threshold for population input: 50 people/km²) (left). Darker colors indicate increased accessibility, or reduced travel time. Most accessible areas, based on modeling (all areas above the national mean value in terms of accessibility) (right).

All of these areas are accessible, and therefore are potentially more important in terms of the provision of bushmeat and NTFPs. This approach also allows us to identify the *most* accessible areas. Applying a threshold (in this case, we created a histogram of the data and used the mean value as the threshold) yields a map of the most accessible areas in the country (Figure 38). Note this threshold is arbitrary, due to lack of data we could not establish a meaningful threshold for Liberia.

In examining the results, it is clear that this modelling approach is heavily driven by roads and human population. Slope and land cover were relatively less influential to indicate areas important for NTFPs.

Given the lack of data from Liberia, it is not possible to tell whether this result is accurate; future data collection or consultation with local people could help validate the model results.

Essential natural capital for food security: natural ecosystems accessible to people

For our final map, we combined the map of areas accessible to people, based on the threshold described above, with the map of natural ecosystems (the Geoville landcover product). This resulted in a map of natural ecosystems (forests, grasslands, mangroves & swamps, and shrublands) that are accessible to people (Figure 39). We found that the most accessible natural habitats are located along the central part of Liberia, along the coast, and along roads. We define these areas as “essential natural capital for food security”, because we believe these areas are likely providing sources of bushmeat and NTFPs for people in Liberia. Because these are the “most” accessible areas, these areas are likely providing the highest level of food security benefits to people.

At the same time, however, these areas may be subjected to unsustainable levels of harvest, and therefore may already be over-harvested, or threatened with over-harvest in the future. Some species, such as certain NTFPs, may be abundant and their ongoing use may not significantly threaten future use. Others, such as rare or endangered species, may not be able to sustain even low levels of harvesting over time. Therefore, areas identified in this analysis could be priorities for further research to establish sustainable levels of harvesting for different species. These areas could also be prioritized for establishment of sustainable management regimes (such as community conservation agreements) to ensure that rare and endangered species are not over-harvested. Finally, these areas could be prioritized for monitoring and enforcement of existing regulations (e.g. for protected species.)

Limitations and assumptions

The modeling approach is based on the assumption that ecosystems more accessible to people are more important for NTFPs; however, it is known that people are sometimes willing to travel long distances for certain products (such as animals hunted for bushmeat). Also, more remote areas (such as Sapo National Park) might have larger populations of certain species. Thus, even more remote areas may be targeted for bushmeat and NTFPs. Also, the most accessible locations may already be over-harvested and therefore have low or no value for NTFPs. On the other hand, some NTFP species (such as palm) are often cultivated near people’s homes and farms. Thus the relationship between accessibility and importance for NTFPs is complex and varies depending on the product, the location, and the level of extraction.

Our analysis also assumes that all natural ecosystems are equally important for NTFPs; however it is known that certain habitats provide higher levels of certain products (see for example Table 11, above, which indicates which NTFPs come from fallow areas, primary, or secondary forests.) Again, depending on the product, some of the habitat types included in our map may be more important than others.

Our model also assumes that people depend on NTFPs uniformly. It is known, for example, that people in more rural areas are more dependent on NTFPs for livelihoods and food security than people in cities. However, due to the large population size of cities, the relatively high rates of food insecurity and

poverty in cities, and the high level of use of firewood, charcoal, and bushmeat even in urban areas, we still believe that natural habitat near Liberia's cities are likely being heavily used for NTFPs.

Lastly, the lack of spatially-explicit species data was a significant limitation in this analysis. While site-level studies were available, no nationwide information about the distribution of species important for NTFPs existed. Due to both lack of data and lack of time, we were therefore unable to validate the modeling result with species occurrence data. Ground truthing and/or consultations with local communities to gain a better understanding of which products are important, and where they are hunted and collected, would improve the quality of spatial information on NTFPs in Liberia.

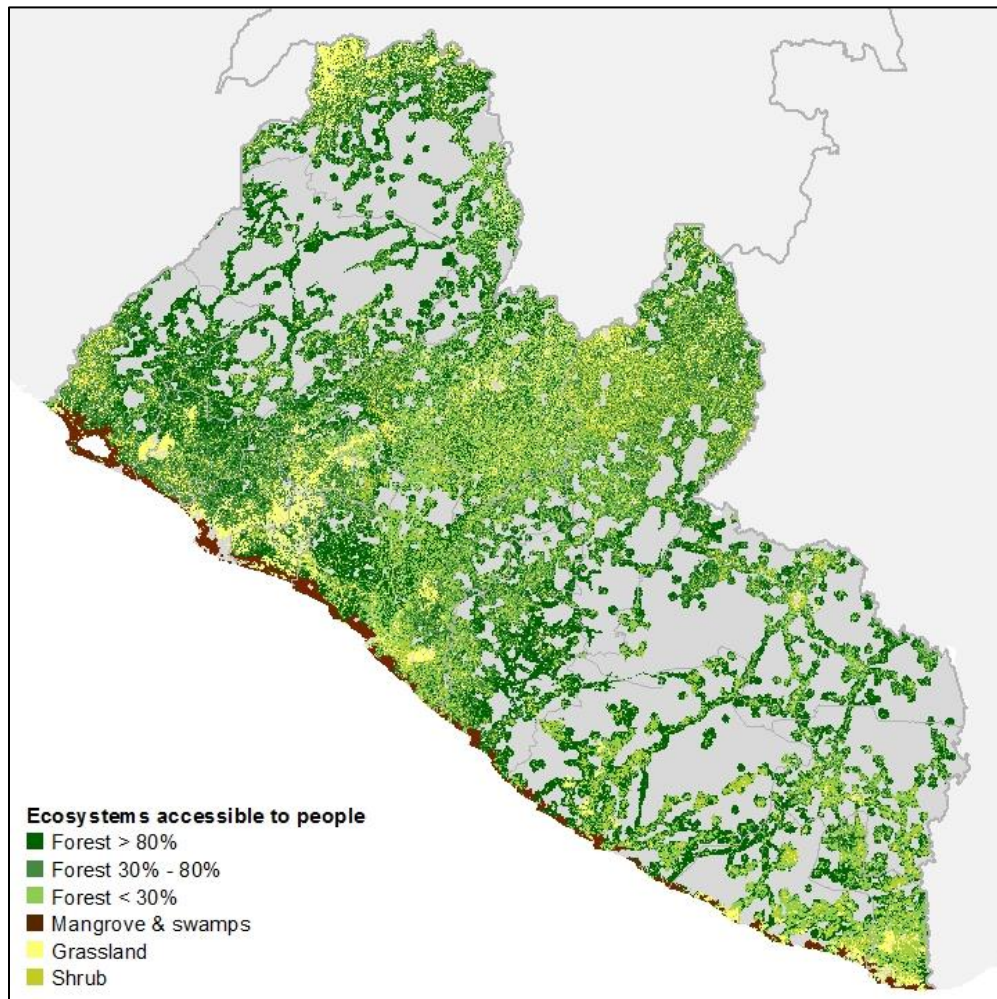


Figure 39. Essential natural capital for food security: natural ecosystems that are accessible to people.

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Landcover

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Non-timber forest products model: Provided by Manuel Peralvo, CONDESAN. Citation: Porro, R. et al. 2008. Challenges to Managing Ecosystems Sustainably for Poverty Alleviation: Securing Well-Being in the Andes/Amazon. Situation Analysis prepared for the ESPA Program. Amazon Initiative Consortium,. ESPA-AA, Belém, Brazil. Available from http://www.espa.ac.uk/files/espa/Final%20Report%20Amazon%20-%20main%20report_Part1.pdf

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LandScan 2014. Bright, E. A., P. R. Coleman, A. N. Rose, and M. L. Urban. 2012. LandScan 2014. Oak Ridge National Laboratory. Available from <http://web.ornl.gov/sci/landscan/>

Protected areas:

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Roads: Two datasets were used for this analysis, from the Liberia MPEA and the US NGA:

Liberia MPEA roads:

Ministry of Planning and Economic Affairs (MPEA), *Transportation* (dataset: mpea_nimac_gis_vector.mdb\transportion (classes of roads included for this analysis: current_roads, int_road, Liberia_trail_line, major_road), Provided for this analysis by the Liberia Institute of Statistics and Geo-Information Services, LISGIS (Thomas Davis, Director of Geo-Information Services, personal communication, April 2016: tomtdavis@yahoo.com.)

US NGA roads:

U.S. National Geospatial Intelligence Agency (NGA), 2014, dataset: LBR_Roads_NGA_20160708.shp. Source, S2, Content Management Office (SD), Geospatial Data Steward, NIPR: CMOServiceEnableTeam@nga.mil
https://services1.arcgis.com/cc7nIINtrZ67dyVJ/arcgis/rest/services/Liberia_Transportation_Lines/FeatureServer accessed July 2016.

Urban areas:

Ministry of Planning and Economic Affairs (MPEA), *Settlements* (dataset: mpea_nimac_gis_vector.mdb\settlement) Provided for this analysis by the Liberia Institute of Statistics and Geo-Information Services, LISGIS (Thomas Davis, Director of Geo-Information Services, personal communication, April 2016: tomtdavis@yahoo.com.)

Mapping Essential Natural Capital for Coastal Protection

Compiled by Kevin Moull and Rachel Neugarten, with contributions from Jess Silver

Introduction

Mangroves are "coastal forests that inhabit saline tidal areas along sheltered bays, estuaries, and inlets in the tropics and subtropics throughout the world" (Barbier et al. 2011). Liberia's mangroves are rich in biodiversity and provide habitat for numerous threatened species. Mangroves provide critical breeding grounds for many fish and shrimp species, and critical habitat for a variety of other coastal species, including mammals, reptiles, and birds (CEPF 2015). Liberia's mangroves also store significant quantities of carbon, particularly in their soils (Clark and Thompson 2015). By providing fish nursery habitat, mangroves support Liberia's fishing industry as well as food security and livelihoods of people who live along the coastline. Nearly 58% of Liberia's population lives along the coast, and the fishery sector provides about 65% of the population's protein needs (TEEB Liberia).

Mangroves also support coastal populations by providing direct sources of food and other provisioning services (Clark 2016). Documented human benefits from mangroves at five sites surveyed in Liberia (Lake Piso, Bomboja, Monrovia, Marshall, and Buchanan) include: erosion control, fish nursery area, fuelwood and charcoal production, setting baskets (to catch crabs, crawfish), collection of casemeat (hermit crabs), fishing (with nets and lines), and oyster collection (Clark 2016). Mangroves also provide wood (timber, poles, posts, fuelwood, charcoal) and non-wood (food, thatch, fodder, alcohol, sugar, medicine, and honey) services which supports local commerce (Clark and Thompson 2015). Threats to mangroves in Liberia include habitat loss and land degradation, exploitation, pollution and climate change; in some cases mangrove degradation and mangrove forest loss is higher than in Liberia's terrestrial forests (Clark and Thompson 2015).

Mangroves provide coastal protection along West Africa's coastlines, which have very high and rapidly growing population densities (USAID 2014). Modifications of the biological and physical environment of coastal habitats can affect mangroves' ability to provide coastal protection and can increase exposure to storm-induced erosion and flooding (inundation) (Sharp et al. 2016). Mangroves serve two key functions related to coastal protection: 1) they are natural coastal storm barriers to periodic wind and wave or storm surge events and 2) they have the ability to stabilize sediment and retain soil in their root structure which reduces shoreline erosion and degradation (Barbier et al. 2011).

Coastal erosion is defined as "the permanent loss of sand from the beach-dune system" and depends on numerous factors related to the coast, including exposure, wave conditions, surge levels, sediment composition, and beach slope (Van Rijn 2011). The loss of mangroves increases 1) the vulnerability of coastal human communities to storm surge events and 2) the vulnerability to coastal erosion (Badola and Hussain 2005).

Unfortunately there is no data on the quantity or spatial distribution of most ecosystem services provided by mangroves in Liberia and therefore this analysis will focus only on coastal protection provided by mangroves, which can be modeled using available data.

Methods

The InVEST Coastal Vulnerability model was used to produce a qualitative estimate of coastal exposure in terms of a Vulnerability Index, which differentiates areas with relatively high or low exposure to erosion and inundation during storms (Sharp et al. 2016). By coupling these results with population information from a global dataset (LandScan, Bright et al. 2014), the model shows areas along Liberia's coastline where humans are most vulnerable to storm waves and surge (Sharp et al. 2016). Lastly, the model evaluates the role of natural habitat, such as mangrove ecosystems, in reducing human vulnerability along coastlines. Model inputs, which serve as proxies for various complex shoreline processes that influence exposure to erosion and inundation, include:

- 1) A polyline with attributes about local coastal geomorphology along the shoreline: the shoreline of Liberia was traced using ESRI's World Imagery Basemap satellite imagery (ESRI et al. 2016). The following ranks were assigned (based on Sharp et al. 2016) (see Table 17 and Figure 40 below):

Table 17. Exposure ranks for the InVEST model, from least (1) to most (5) exposed

Type of geomorphology	Exposure rank
Rock (harbour break)	1
Rocky	3
Sand/mangroves	3
Unknowns (unidentifiable, e.g. settlements, haze)	3
Beach with mangrove behind	4
Beach with settlement behind	5
Mud	5
Sandy banks	5

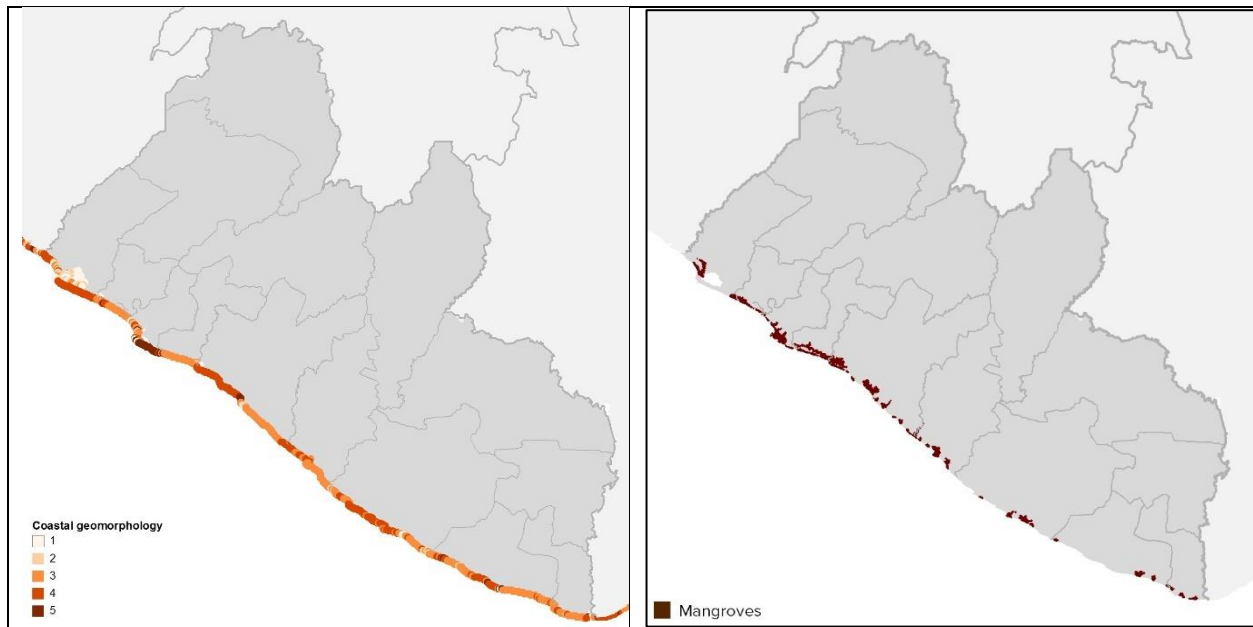


Figure 40. Coastal geomorphology ("geomorphology") from the InVEST model and mangroves in Liberia (right). Mangrove areas were exaggerated for visibility at this scale.

- 2) Polygons representing the location of mangroves: Liberia's national mangrove GIS layer (Barry Clark) was used (Figure 40). A rank of 1 (based on Sharp et al. 2016) and a protection distance of 1000m were used (Barbier et al. 2008);
- 3) Rates of (observed) net sea-level change: no data available.
- 4) A depth contour that can be used as an indicator for surge level (the default contour is the edge of the continental shelf): continentalShelf.shp, the default continental shelf layer was used;
- 5) A digital elevation model (DEM) representing the topography and the bathymetry of the coastal area: the default global DEM layer was used;
- 6) A point shapefile containing values of observed storm wind speed and wave power: The default Climate_forcing_WaveWatchIII_Liberia.shp was used (Tolman et al. 2009) (Figure 41);
- 7) A raster representing population distribution: LandScan (Bright et al. 2014) (Figure 41).

All default values suggested by Sharp et al. 2016 were used, except for the 'exposure proportion', which was calibrated to 0.65 (from a default value of 0.8) in order to improve the shoreline exposure output.

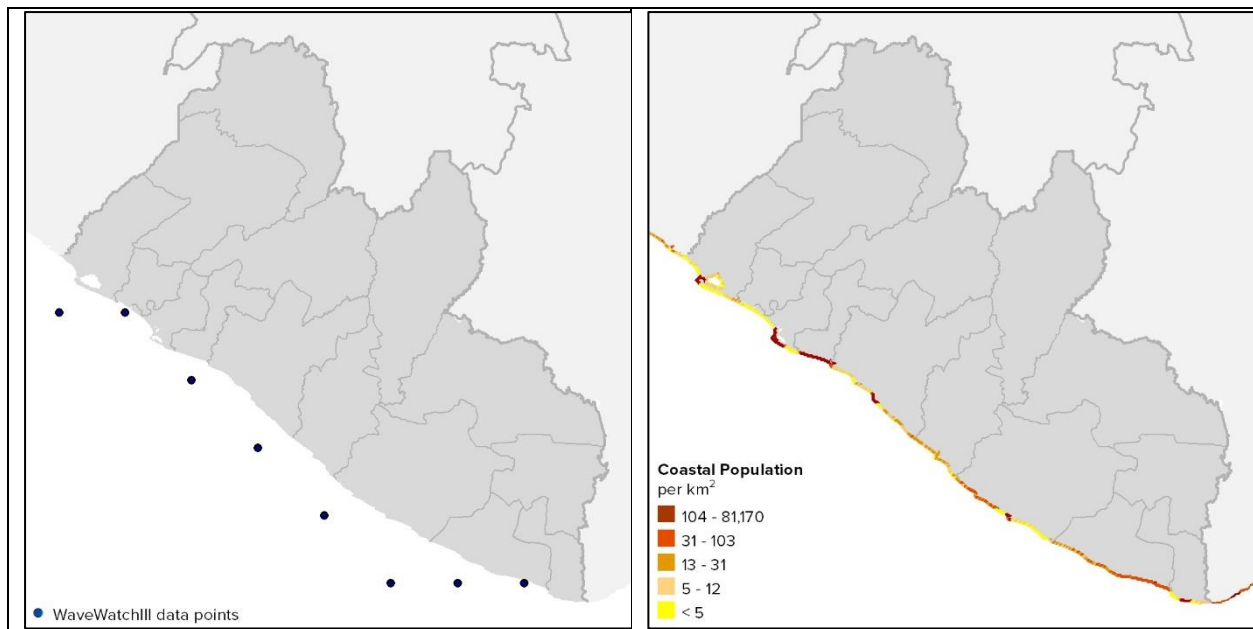


Figure 41. WaveWatchIII data points off the coast of Liberia. WaveWatchIII data provided with the InVEST model (Tolman et al. 2009) (left). Coastal population, based on LandScan population data provided with the InVEST model (right).

Results

The Coastal Vulnerability model produces a qualitative index of coastal exposure to erosion and inundation as well as a map of the location and size of human settlements (Sharp et al. 2016). The model ranks sites as having a relatively low, moderate or high risk of erosion and inundation (Sharp et al. 2016).

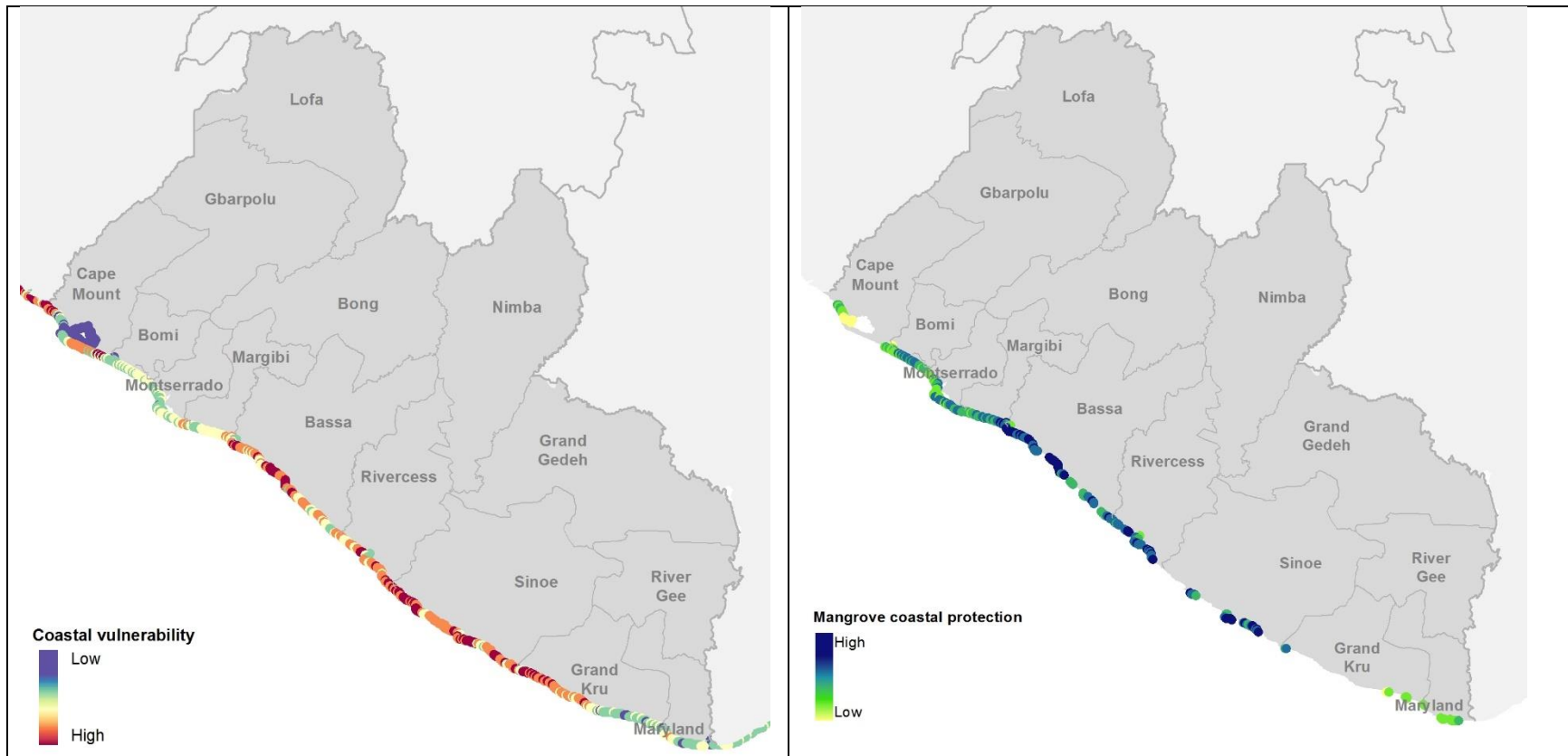


Figure 42. Coastal vulnerability (“exposure index”) from the InVEST model. Red areas are more vulnerable, blue areas are less vulnerable (left). Coastal protection provided by mangroves (“habitat role”) provided by InVEST model. Darker blue areas indicate where mangroves provide more protection; yellow areas are where mangroves provide less protection (right).

These results indicate that the most vulnerable coastal areas to erosion are in Bassa, Rivercess, Sinoe, and Grand Kru counties (Figure 42, left). Coastal protection provided by mangroves is relatively high in Bassa and Rivercess counties, and to a lesser extent in Sinoe county (Figure 42, right), indicating that these mangroves should be conserved to ensure they continue providing this valuable benefit to people along the coast. In Sinoe county, if environmental conditions are conducive to mangroves, then mangrove restoration or planting might help protect Liberia’s coastline where large areas of the coastline are not currently protected by mangroves. Moderately vulnerable areas include Grand Bassa and Grand Kru counties. In Grand Bassa county, the coastal protection provided by mangroves is relatively low and mangrove conservation and/or restoration might better help protect Liberia’s coastline. In Grand Kru county, mangroves are very scarce and mangrove planting, if the appropriate conditions exist, might help protect Liberia’s coastline in this region.

Currently the only protected area that includes mangrove areas is located near Lake Piso (Figure 43); therefore most mangroves in Liberia are currently unprotected and may be threatened with loss or conversion in the future. Specifically, the mangroves that may be providing the most benefits in terms of coastal protection, according to our model, are currently unprotected. If the Margibi Mangrove proposed protected area was to be designated, it would contribute to the level of mangrove and coastal protection in Liberia.

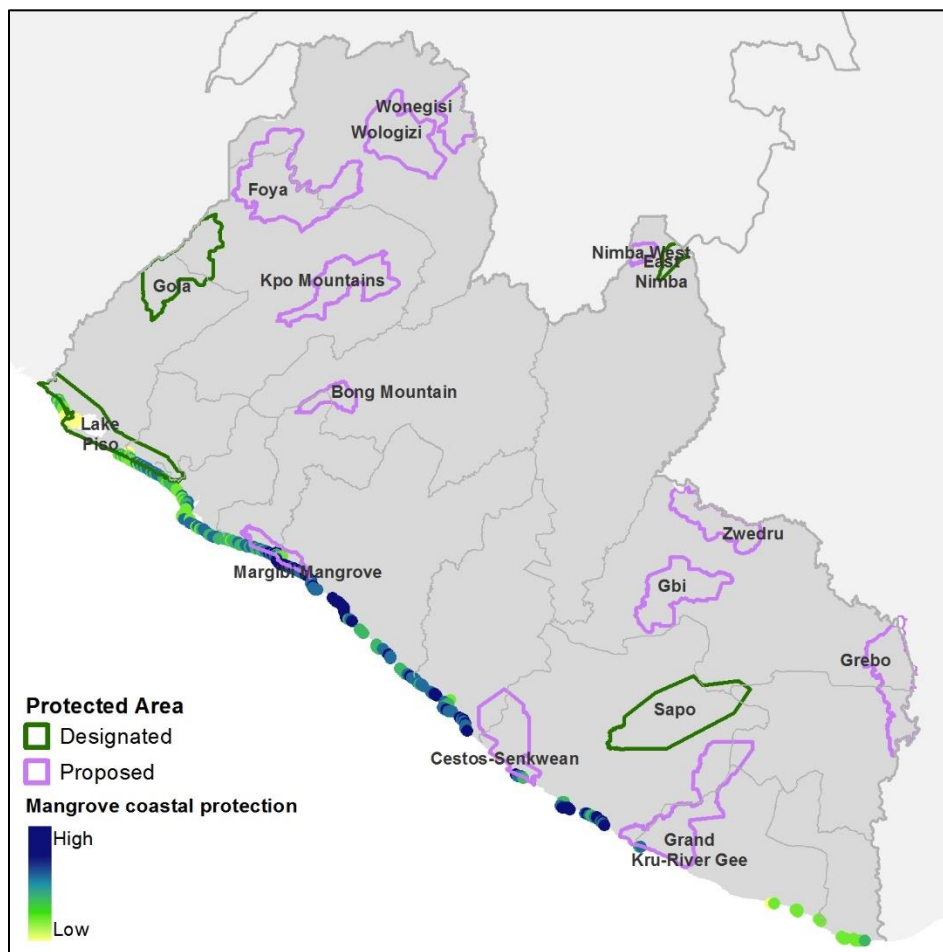


Figure 43. Coastal protection from mangroves, as modeled by InVEST, combined with designated and proposed protected areas. The areas where mangroves are providing the most protection (dark blue) fall outside of protected areas.

Limitations & assumptions

Aside from the mangrove data, this model relies exclusively on global datasets which may not be very accurate for Liberia. Furthermore, the InVEST model was designed to show areas along a coastline where humans are most vulnerable to coastal storm waves and surge. However, for Liberia the issue is primarily a combination of slow erosion, sea level rise, and flooding in coastal areas near river mouths due to inland rain events, which the model may not accurately take into account. However, given there is no data on coastal erosion in Liberia, nor specific data on the role of mangroves in reducing it, we nonetheless hoped that this model would provide some useful indicative results.

While the results provide an indication of where mangroves might be helping to protect Liberia's coastlines, additional research (including field data collection) is needed to gain a better understanding of the actual roles of mangroves in stabilizing Liberia's coastline and reducing the vulnerability of coastal populations.

The technical and theoretical limitations of the model are provided below (taken from Sharp et al. 2016): "Beyond technical limitations, the exposure index also has theoretical limitations. One of the main limitations is that the dynamic interactions of complex coastal processes occurring in a region are overly simplified into the geometric mean of seven variables and exposure categories. We do not model storm surge or wave field in nearshore regions. More importantly, the model does not take into account the amount and quality of habitats, and it does not quantify the role of habitats are reducing coastal hazards. Also, the model does not consider any hydrodynamic or sediment transport processes: it has been assumed that regions that belong to the same broad geomorphic exposure class behave in a similar way. Additionally, the scoring of exposure is the same everywhere in the region of interest; the model does not take into account any interactions between the different variables. For example, the relative exposure to waves and wind will have the same weight whether the site under consideration is a sand beach or a rocky cliff. Also, when the final exposure index is computed, the effect of biogenic habitats fronting regions that have a low geomorphic ranking are still taken into account. In other words, we assume that natural habitats provide protection to regions that are protected against erosion independent of their geomorphology classification (i.e. rocky cliffs). This limitation artificially deflates the relative vulnerability of these regions, and inflates the relative vulnerability of regions that have a high geomorphic index.

The other type of model limitations is associated with the computation of the wind and wave exposure. Because our intent is to provide default data for users in most regions of the world, we had to simplify the type of input required to compute wind and wave exposure. For example, we computed storm wind speeds in the WW3 wind database that we provide by taking the average of winds speeds above the 90th percentile value, instead of using the full time series of wind speeds. Thus we do not represent fully the impacts of extreme events. Also, we estimate the exposure to oceanic waves by assigning to a coastal segment the waves statistics of the closest WW3 grid point. This approach neglects any 2D processes that might take place in nearshore regions and that might change the exposure of a region. Similarly, we compute exposure in sheltered region by combining the average depth near a particular segment to the wind speed and direction in a sector, instead of modeling the growth and evolution of wind waves near that segment.

Consequently, model outputs cannot be used to quantify the exposure to erosion and inundation of a specific coastal location; the model produces qualitative outputs and is designed to be used at a

relatively large scale. More importantly, the model does not predict the response of a region to specific storms or wave field and does not take into account any large-scale sediment transport pathways that may exist in a region of interest."

Aside from the mangrove data, this model relies exclusively on global datasets for population, bathymetry, elevation, wind and wave data due to lack of data availability for Liberia. Furthermore, no data was found for sea level rise.

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Mapping Essential Natural Capital: Combined maps

Compiled by Rachel Neugarten

As defined above, *natural capital* is the stock of biodiversity and ecosystems that provides a flow of benefits (ecosystem services) that support human well-being and economic activity. *Essential natural capital* is the sub-set of all natural capital that provides benefits that cannot be substituted or replaced. But how do we define what is “essential” natural capital in Liberia?

Ideally, we would have information on the amount of natural capital that is needed to support Liberia’s people and economy, sustainably, now and in the future. For example, we would like to be able to say, “we need this many hectares of intact, healthy forest ecosystem in order to provide timber, fuelwood, and forest products to sustainably support the food security and income needs of Liberia’s people now and in the future.”

Unfortunately, these data are currently lacking in most countries, including Liberia. It is not known how much forest is needed to meet the food security and economic needs of Liberia’s population in a sustainable way. However, based on the above analyses, we can try to identify the “most important” places for certain types of natural capital. We can do this by looking at each map and identifying the areas that have the highest importance, relative to other parts of the country.

For example, for forest carbon, it is possible to identify the places that have the highest forest carbon stocks. The map on the left, below, shows all forest carbon stock, and the map on the right is the same map stratified to show areas with different levels of carbon (Figure 44). The FDA has a goal of conserving 30% of Liberia’s forest. We used this goal to identify a threshold (233 tC/ha) that would allow us to identify the 30% of Liberia’s forest with the highest biomass carbon stocks. For the purposes of this analysis, we define these areas as “essential natural capital for forest carbon.”

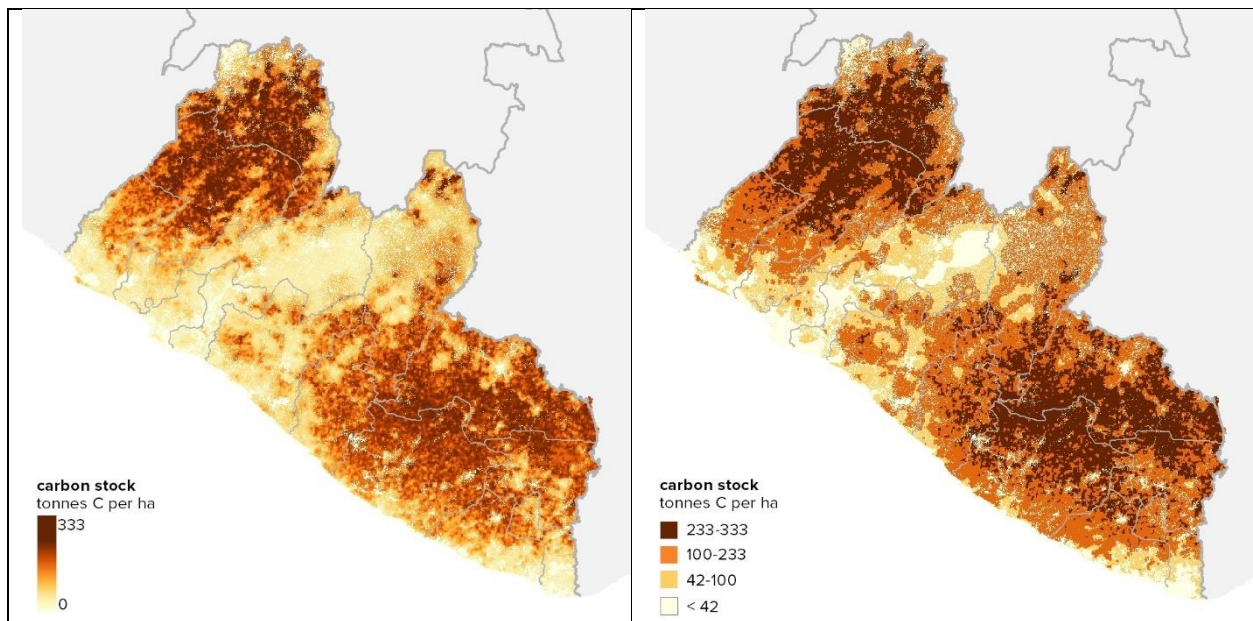


Figure 44. Forest biomass carbon stock values (left) and forest carbon stock values stratified (right).

Similar analyses can be conducted for the other types of natural capital mapped in the sections above. For biodiversity, the conservation priority areas identified by Junker et al. 2015 already incorporate such targets (30% of forested areas containing >25% of chimpanzees, other large mammals and tree species; as well as other targets). Therefore, we can directly adopt these conservation priority sites as “essential natural capital for biodiversity.” For freshwater, we identified the top 30% of watersheds providing ecosystem services to population centers and existing hydropower facilities (Figure 45). For coastal protection, we identified the top 30% of mangroves that protect Liberia’s vulnerable coastal populations (Figure 46).

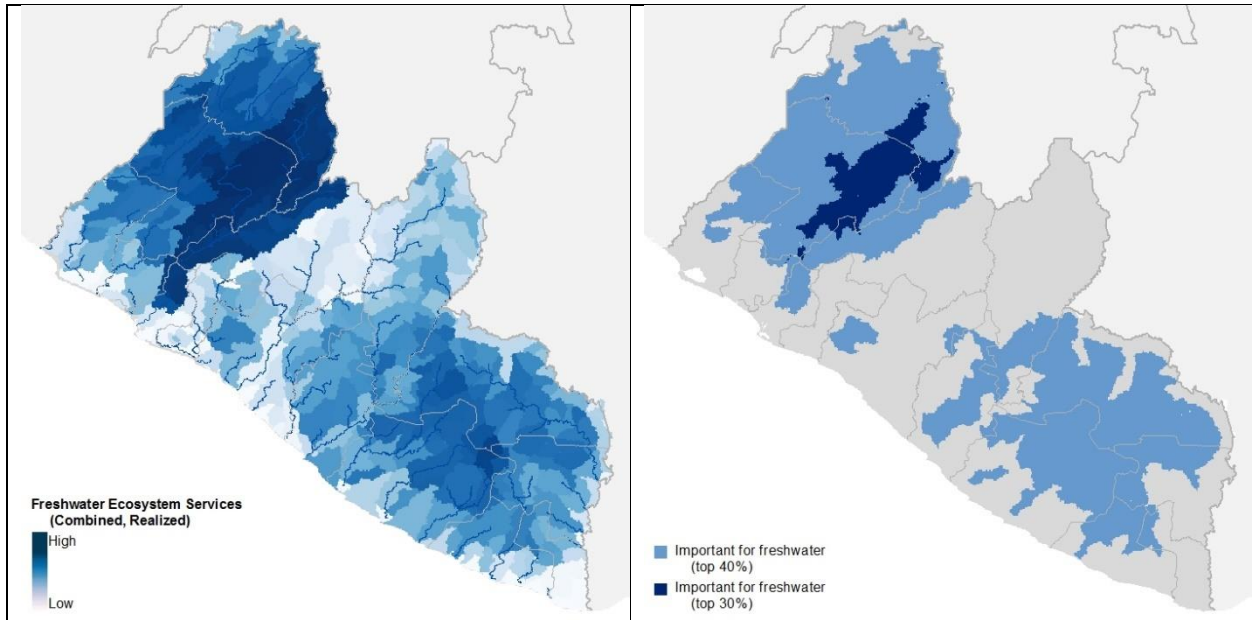


Figure 45. Combined, realized freshwater ecosystem services (left) with thresholds to identify the top 40% and 30% of watersheds supplying services (right). Note freshwater services are not normally distributed, so identifying the top 30% of watersheds in terms of their importance results in an area that is smaller than 30% of Liberia’s land area. (The watersheds upstream of Monrovia are highlighted due to the large population and presence of the Mount Coffee dam downstream.)

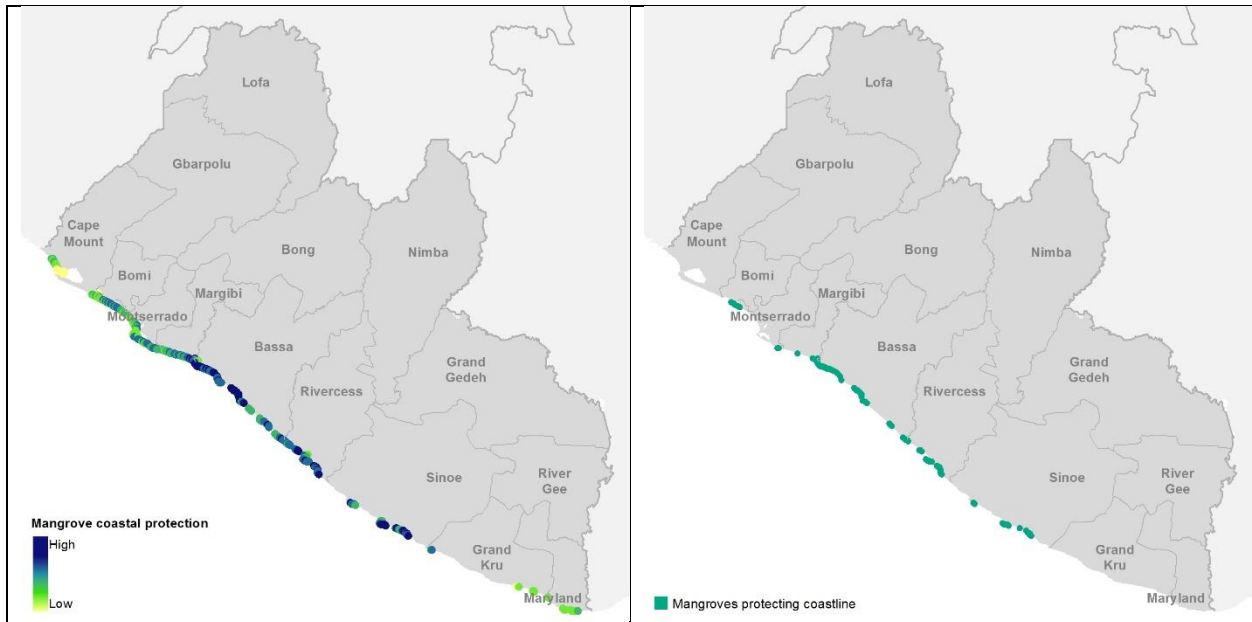


Figure 46. Mangroves protecting Liberia's vulnerable coastal populations (left) and the top 30% of mangroves in terms of their importance (right). Note: mangrove extent was exaggerated on this map to be visible at this scale.

We combined these areas in a single map of “essential natural capital” which can then be converted into a single map layer (Figure 47). These areas, which are concentrated in the intact forested landscapes in the northwest and the southeast, should be targeted for conservation, either through protection or through community-based conservation or other measures, as they represent the most essential of Liberia’s natural capital.

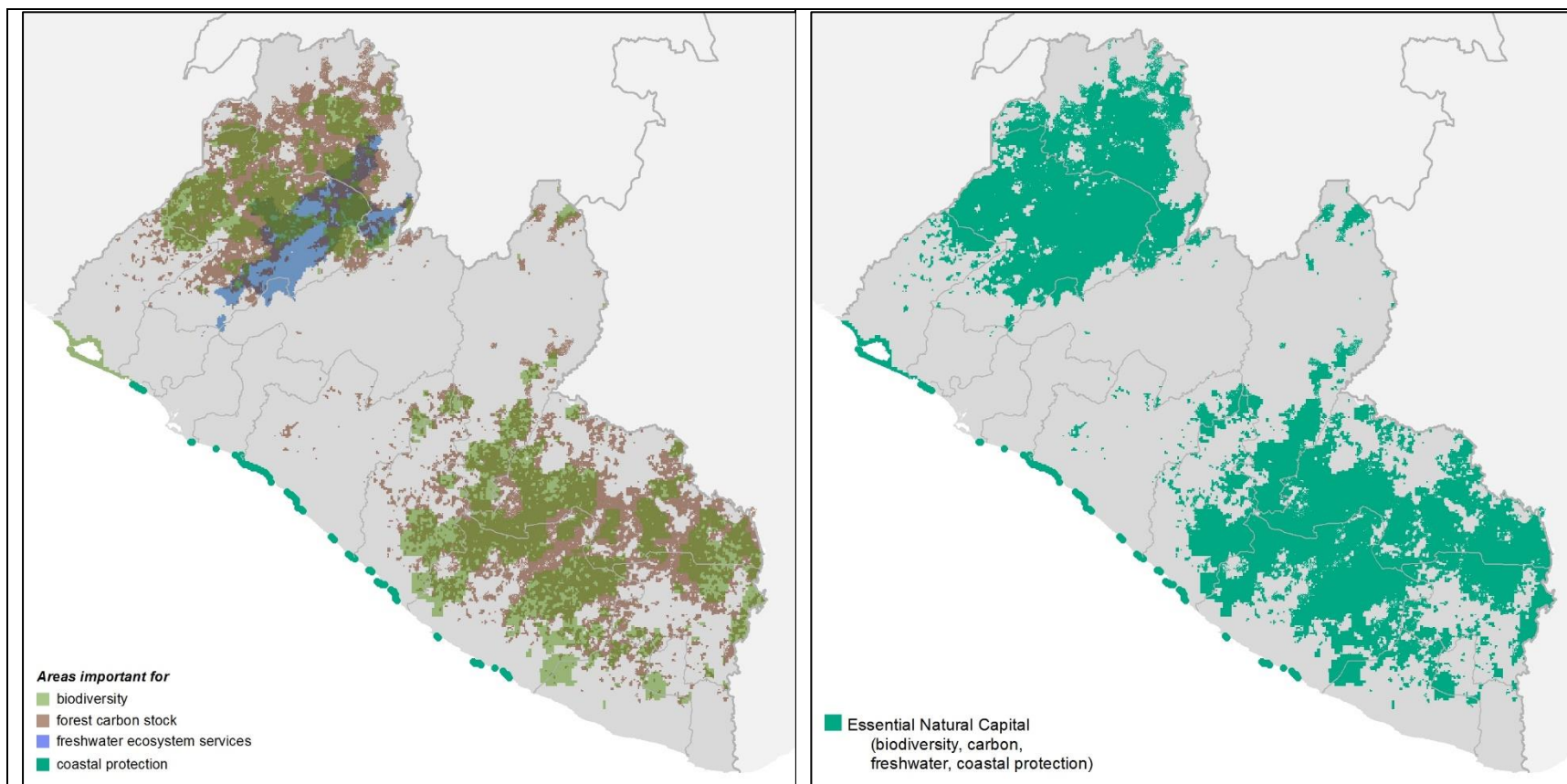


Figure 47. Essential natural capital for biodiversity, forest carbon, freshwater ecosystem services, and coastal protection (left) and all combined essential natural capital (right). Note: mangrove extent was exaggerated on this map to be visible at this scale.

Natural Capital being Used by People

In addition to the most essential areas for biodiversity, carbon, freshwater ecosystem services, and coastal protection, we might consider areas that are essential for people’s food security and livelihoods, such as areas important for hunting and forest products. These were mapped in the section above on bushmeat and non-timber forest products and are shown again below (*Figure 48*). These ecosystems are “essential natural capital” in that they are providing critically important sources of food and income to people.

Due to their accessibility, these ecosystems are also likely threatened with over-hunting and over-harvesting. Therefore, this map can be considered both a map of essential natural capital but also a map of threatened ecosystems. Unlike the areas above, which should be targeted for protection, these areas could be targeted for community-based conservation or sustainable management, such as sustainable agriculture and agroforestry, to ensure they continue to provide a sustainable level of firewood, food, and forest products into the future.

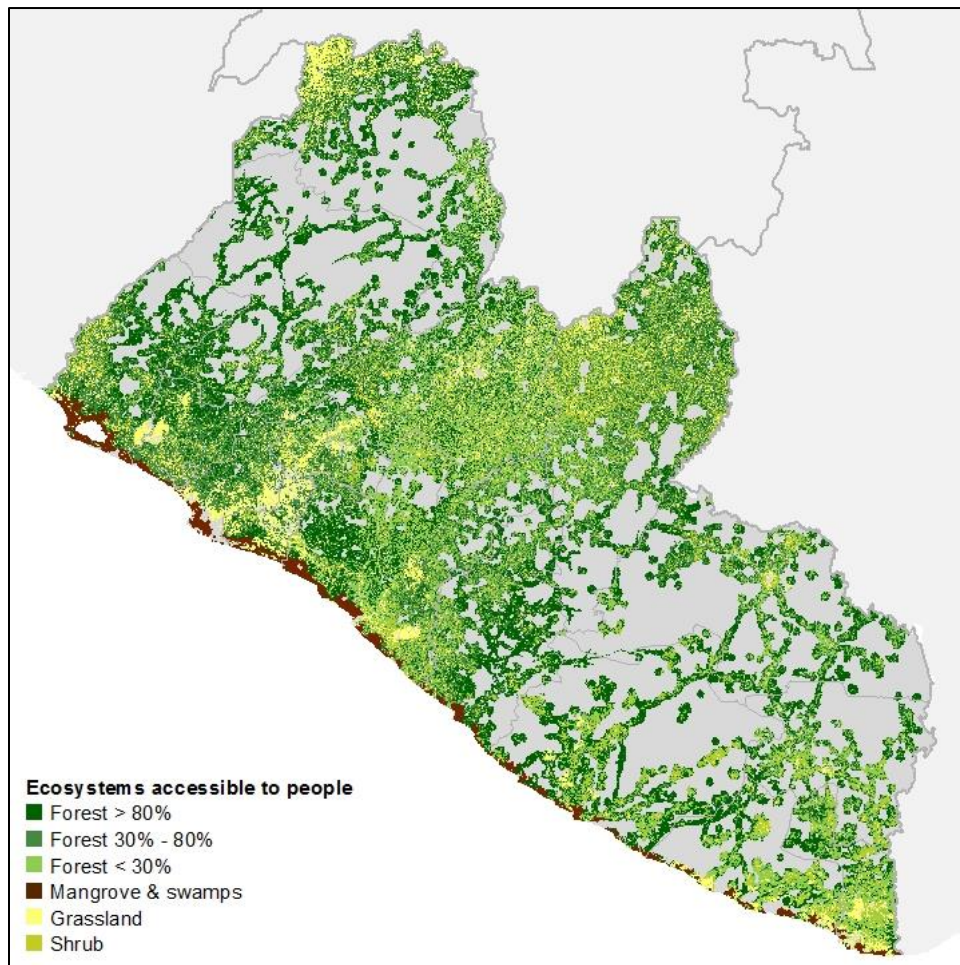


Figure 48. Natural capital being used by people: ecosystems accessible to people.

Protected Natural Capital

Now that we have maps of essential natural capital, we can ask questions such as, “how much of Liberia’s natural capital is protected?” By overlaying the map of essential natural capital with the map

designated and proposed protected areas, we can see that designated protected areas do capture 7% of Liberia’s essential natural capital, and if proposed protected areas were to be established, they would capture an additional 19%, for a total of 26% (Table 18, Figure 49). However, currently, 93% of Liberia’s essential natural capital is unprotected, and the majority (74%) of Liberia’s essential natural capital will remain unprotected, even if all proposed protected areas are established.

Table 18. Essential natural capital within designated and proposed protected areas

Category	Area (km ²)	Percentage
Essential Natural Capital (designated protected areas)	2545.5	7%
Essential Natural Capital (proposed protected areas)	6652.9	19%
Essential Natural Capital (unprotected)	26761.3	74%
Total Essential Natural Capital	35959.7	100%

Threatened Natural Capital

We can also ask, “how much of Liberia’s essential natural capital is threatened?” By overlaying the map of essential natural capital with other data, such as concession areas, vulnerability to tree cover loss, and accessibility to people, we can get a sense of which factors might be threats to Liberia’s essential natural capital now and in the future (Figure 50).

These maps indicate that Liberia’s essential natural capital is not very vulnerable to tree cover loss, and is relatively inaccessible to people – likely because essential natural capital tends to be located in relatively remote areas. This is good news, as it means these areas are probably less threatened with clearing and over-harvesting. The exception are the mangrove ecosystems along the coastline, which are relatively accessible to people. Also, it is known that some remote areas are still targeted for hunting, especially for high value species such as primates, which means that they are likely already subject to unsustainable levels of hunting for certain species. Most of Liberia’s rubber and mining concession areas do not overlap with Liberia’s essential natural capital. Some palm oil concessions, particularly in the north, do overlap with some areas of essential natural capital. Timber concessions also overlap with Liberia’s essential natural capital. Special attention should be paid to these areas to ensure they are sustainably managed.

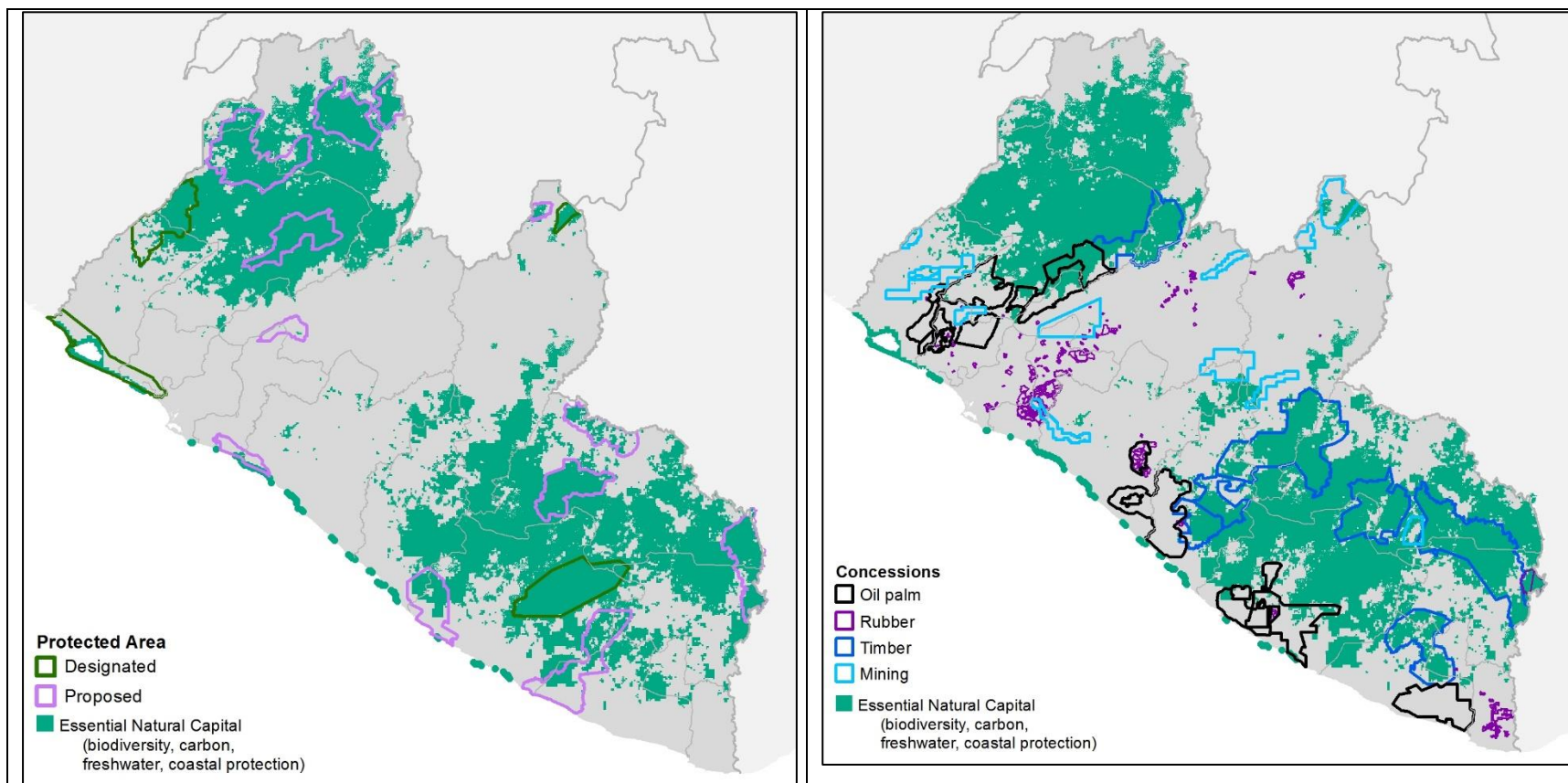


Figure 49. Essential natural capital overlaid with designated and proposed protected areas (left) and concessions (right). Note: mangrove extent was exaggerated on this map to be visible at this scale.

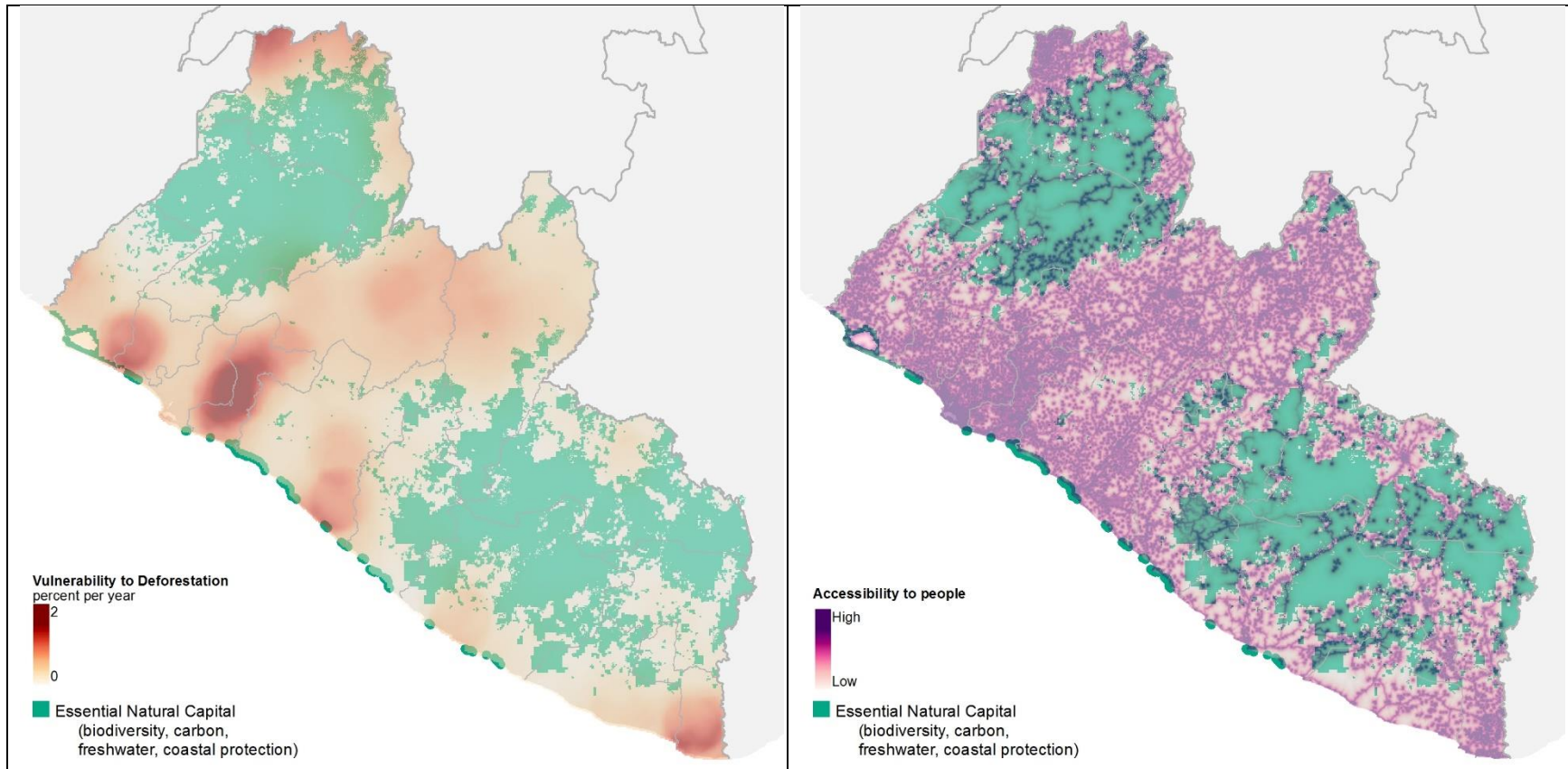


Figure 50. Essential natural capital overlaid with vulnerability to tree cover loss (left) and accessibility to people (right). Note: mangrove extent was exaggerated on this map to be visible at this scale.

Limitations

This study has many limitations, including a lack of data on several important ecosystem services in Liberia, such as fisheries and cultural ecosystem services. For the ecosystem services we included, we were often hindered by a lack of nationally representative data, which meant we had to use global data, which may not be accurate at local scales. We also had limited data on the level of human demand for ecosystem services, which means that we were not able to identify the most “essential natural capital” based on actual levels of human needs; instead, we used a thresholding approach to try to identify the top 30% of important areas for several kinds of natural capital. However, this 30% goal is arbitrary, not based on what is actually needed by people or for Liberia’s economy. Future research should attempt to identify the spatial extent of natural capital needed to support human well-being and sustainable development in Liberia. Many of our analyses were based on assumptions; for example, our model of bushmeat and non-timber forest products assumed that ecosystems in close proximity to people are more likely to be providing benefits than those which are more remote. However, we know this is not an accurate assumption for certain high-value species, for which people are willing to travel to more remote areas. This analysis was conducted over approximately 10 months, requiring approximately a total of 269 person-days, and had a budget of approximately USD 400,00 which included salary, international travel (seven total trips from US to Liberia), two workshops, and overhead costs. While this may seem a substantial amount, there was insufficient time and funding for field validation of our modeling results, or a more extensive stakeholder engagement process. Both of these would be desirable for future analyses of Liberia’s ecosystem services. Furthermore, while these maps of essential natural capital are useful for spatial planning, they should be combined with other spatial information (such as maps of agricultural suitability and maps of community resource use) for truly integrated spatial planning in Liberia. Finally, these maps are useful for identifying coarse national-scale priorities, but finer scale data is needed for local level planning.

Conclusion

In conclusion, these maps and accompanying analyses and interpretations, aim to identify the nature that people depend on for food security, livelihoods, and climate resilience, as well as Liberia’s globally significant biodiversity and carbon stocks. The most essential natural capital for biodiversity, carbon, and freshwater ecosystem services in Liberia is still intact. Nonetheless, a significant amount of Liberia’s essential natural capital is unprotected. Some species are already threatened with over-harvesting, and in the future, may become threatened by large-scale clearing for palm oil or other commodities. A multitude of management strategies such as community forestry, Payments for Ecosystem Services (PES) schemes, REDD+, or other creative solutions are needed to ensure the flow of benefits from natural capital is sustained.