



CONSERVATION
INTERNATIONAL



Conservation and sustainable use of Liberia's coastal natural capital - Natural Capital Accounting in coastal ecosystems

ANALYTICAL FRAMEWORK (DRAFT OF APRIL 2021)

ABOUT THIS REPORT

This report describes the analytical framework for the implementation of the GEF-led project Conservation and Sustainable Use of Liberia's coastal natural capital, specifically as it refers the implementation of complete set of SEEA Ecosystem Accounts (Component 1. Natural Capital Accounting (NCA) in coastal ecosystems). We start by providing a general introduction to the SEEA EA, describing key concepts and terminology, synthesizing the methodological approaches for the implementation of individual accounts. This report is the result of numerous discussions among the technical team and intended as an initial documentation of chosen measurements, to be refined as the analysis evolves, based on consultation and input from Technical Advisory Committee, other Liberian experts and supporting partners.

Technical team: Rosimeiry Portela (overall project lead); Mahbubul Alam (project technical lead/Ecosystem services flows and asset accounts); Miroslav Honzak (Extent accounts); Timothy Wright (Condition accounts); Trond Larsen (Thematic accounts).

ACRONYMS

EAA:	Ecosystem Accounting Area
NCA:	Natural Capital Accounting
SEEA:	System of Environmental Economic Accounting Ecosystem Accounting
ECT:	Ecosystem Condition Typology
EEZ:	Exclusive Economic Zone
EO:	Earth Observation
GIS:	Geographic Information System
SNA:	System of National Accounts
PPG:	Project Preparatory Grant
TAC:	Technical Advisory Committee
GEO:	Group on Earth Observation
SCC:	Social Cost of Carbon
ETS:	European Trading Scheme
RUSLE:	Revised Universal Soil Loss Equation
TCM:	Travel Cost Method
NWFP:	Non-Wood Forest Product

GLOSSARY

Coastal Baseline is usually the low-water line along the coast as marked on large-scale charts officially recognized by the coastal state. Straight baselines can be defined as connecting fringing islands along a coast, across the mouths of rivers, or with certain restrictions across the mouths of bays.

Ecosystem Accounting Area (EAA) is the geographical territory for which an ecosystem account is compiled. An EAA may be defined by, for example, the boundary of a country, a sub-national administrative area, a water catchment, or a protected area.

Exclusive Economic Zone (EEZ) is an area beyond and adjacent to the territorial sea, extending seaward to a distance of no more than 200 nautical miles (370 kilometers) out from its coastal baseline. It is an area of the sea in which a sovereign state has special rights regarding the exploration and use of marine resources, including energy production from water and wind.

Ecosystem Assets are contiguous spaces of a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions.

Geographic Information System (GIS) is a framework for gathering, managing, and analyzing data. Rooted in the science of geography, GIS integrates many types of data. It analyzes spatial location and organizes layers of information into visualizations using maps and 3D scenes.

Global Ecosystem Typology (Keith et al., 2020) is a systematic typology that encompasses all of Earth's ecosystems. It is a hierarchical classification system that, in its upper levels, defines ecosystems by their convergent ecological functions and, in its lower levels, distinguishes ecosystems with contrasting assemblages of species engaged in those functions.

Natural Capital Accounting is the measurement of stocks of natural resources (both renewable and non-renewable) and the flows of benefits they provide.

Social Cost of Carbon is an estimate of the monetary value of the damages that would result from an additional ton of greenhouse gas emissions into the atmosphere.

SEEA Central Framework is an international statistical standard for measuring the environment and its relationship with the economy covering three areas: environmental flows, stocks of assets, economic activity related to the environment.

SEEA Ecosystem Accounting is a spatially-explicit statistical framework for measuring and organizing information about ecosystems and ecosystem services in biophysical and monetary terms and linking this information to economic and human activities

Ecosystem enhancement is the increase in the value of an ecosystem asset over an accounting period that is associated with an improvement in the condition of the ecosystem asset during that accounting period.

Ecosystem degradation is the decrease in the value of an ecosystem asset over an accounting period that is associated with a decline in the condition of an ecosystem asset during that accounting period.

Ecosystem conversions refer to situations in which, for a given location, there is a change in ecosystem type involving a distinct and persistent change in the ecological structure, composition and function which, in turn, is reflected in the supply of a different set of ecosystem services and different expected future returns.

Other changes in the volume are changes in the value of an ecosystem asset, other than (i) those due to ecosystem enhancement, ecosystem degradation and ecosystem conversion, and (ii) those that are solely the result of changes in unit prices of ecosystem services.

Revaluations are changes in the value of ecosystem assets over an accounting period that are due solely to movements in the unit prices of ecosystem services which underpin the derivation of the net present value of ecosystem assets

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INTRODUCTION

In February of 2020, the Liberia Environmental Protection Agency, in partnership with many governmental agencies, and with support from Conservation International, started implementing the GEF-funding project **Conservation and sustainable use of Liberia's coastal natural capital** (the GEF NCA Liberia). The project objective is to improve conservation and sustainable use of Liberia's coastal natural capital by mainstreaming the value of nature into Liberia's development trajectory.

The GEF NCA Liberia demonstrates the recognition of the government of the importance of coastal ecosystems in the country, and mangroves in particular, for biodiversity as well as for its numerous benefits to livelihoods and economics. The project seeks to advance understanding of the value of those benefits, identify opportunities to finance the long-term maintenance and sustainable use of coastal natural capital, while institutionalizing benefit-sharing mechanisms that provide incentives at the local level. This three-tiered approach is further described on project components/activities as below.

- **Natural Capital Accounting in coastal ecosystems:** Entailing a complete set of System of Environmental Economic Accounting Ecosystem Accounts (SEEA EA) to underscore the value of mangrove benefits, including, e.g., protection and storm surge, erosion prevention, regulation of coastal water quality, habitat provision for numerous commercially important and endangered marine species, and food security for coastal communities. The ultimate goal of this component is to incorporate those benefits into national decision-making while building the foundation for a comprehensive set of natural capital accounts.
- **Innovative financing schemes for conserving coastal natural capital:** Entailing the increasing and diversification of resource flows for management and restoration of mangrove and coastal ecosystems, through financing mechanisms such as tourism-related taxes and fees, debt-for-nature swaps, conservation trust funds, and payments for environmental services (PES). By supporting the identification and operationalization financing opportunities, e.g., from beneficiaries of ecosystem services, this component will ultimately enable the long-term sustainability of measures seeking to reward stewardship of coastal natural resources.
- **Community incentives to conserve and sustainably manage natural capital in coastal ecosystems:** Relying on conservation finance mechanisms (e.g., bioprospecting, tourism-based revenues, and carbon finance) this

component will entail improved management and conservation of natural capital by local communities through mechanisms such as payments for ecosystem services (PES) that can, ultimately benefitting local communities, who are often the stewards of important conservation areas.

This report describes the analytical framework for the implementation of Component 1, specifically as it refers the implementation of complete set of SEEA Ecosystem Accounts. We start by providing a general introduction to the SEEA EA, describing key concepts and terminology, synthesizing the methodological approaches for the implementation of individual accounts. This report is the result of numerous discussions among the technical team and intended as an initial documentation of chosen measurements, to be refined as the analysis evolves, based on consultation and input from Technical Advisory Committee, other Liberian experts and supporting partners.

The System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA)

Natural Capital Accounting (NCA) refers to the measurement of stocks of natural resources (both renewable and non-renewable) and the flows of benefits they provide. NCA efforts in the public sector are the domain of the United Nations' System of Environmental-Economic Accounts (SEEA), an internationally accepted framework for incorporating nature into national accounting systems. SEEA includes the Central Framework (CF) and Ecosystem Accounting (EA). While the CF focuses primarily on the provision of nature's goods to the economy, EA expands SEEA's measurements to include regulating and cultural functions of ecosystems, other natural flows of benefits often overlooked. EA involves more comprehensive spatial identification and mapping, resulting in a more complete picture of ecosystems and the benefits they provide to various parts of an economy.

The SEEA EA is a spatially-explicit statistical framework for measuring and organizing information about ecosystems and ecosystem services in biophysical and monetary terms and linking this information to economic and human activities (UNSD, 2021). SEEA EA is built on five core accounts (Figure 1) as well as several supplementary thematic accounts. Extent is the first account developed and used as inputs into both condition and ecosystem services flow account. The biophysical supply of a service (e.g., m³ of water) from ecosystems by different

users and beneficiaries (e.g., m³/ha water used for irrigation purpose) is used to quantify the value of that service in monetary terms (e.g., US\$/ha of irrigated agriculture). These individual values are finally combined in the asset account to derive the combined monetary value of all benefits (Figure 1).

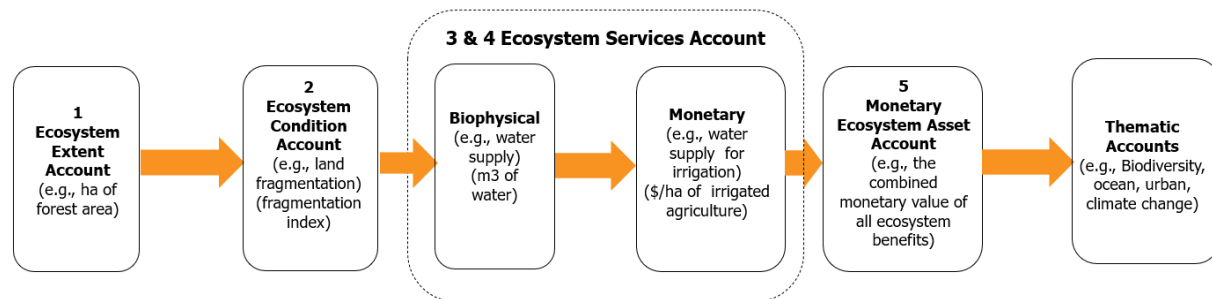


Figure 1 Components and steps of ecosystem accounting

The *Extent Account* summarizes information on the extent of different ecosystem types within an ecosystem accounting area and change in extent over an account period. The entries in extent account include the opening and closing extent as well as additions to and reductions in extent. Furthermore, the ecosystem type change matrix is compiled from the opening and closing extent to show conversion of one ecosystem type into another during the accounting period (i.e., the increases and/or decreases in the area according to the ecosystem type). Extent account is foundational to other accounts as it provides the underlying infrastructure and spatial data needed for the implementation of ecosystem condition and measurement and modeling of ecosystem services flows.

The *Condition Account* complements the extent account by recording information on biotic, abiotic and landscape features that describe the characteristics of ecosystem assets and their change. Information generated from the condition accounts is also used in the measurement of the capacity of ecosystem assets to supply ecosystem services sustainably now and into the future.

The *Ecosystem Services Flow Account* (biophysical) records ecosystem services flows in biophysical terms (such as m³ of water) as contributions of ecosystems to the benefits used in different economic units (e.g., households, enterprises, government) and other human activity. The information from this account is presented in a supply-use table where final services are recorded as flows between ecosystems and economic units. The supply use tables also support the recording of inter-ecosystem flows (i.e., intermediate services) between ecosystem assets.

The *Ecosystem Services Flow Account* (monetary) records the estimates of monetary value of the services supplied by ecosystems and used by economic units. Typically, a unit monetary value is determined for an individual service using various market and non-market approaches and this unit value is used to quantify the monetary value of that service for different beneficiaries. Similar to the biophysical accounts, monetary accounts are also presented in a supply-use table. An additional utility of monetary account is its use in deriving useful economic statistics (e.g., % share of the value of timber) useful for policy discussions.

The *Monetary Asset Account* records the monetary values of all ecosystem assets within the EAA and reports as opening and closing stocks within the accounting period. They are primarily designed to record stocks and change in stocks as a result of ecosystem degradation, conversion, enhancements and revaluation etc. Monetary asset account takes the monetary value of individual services and use them to estimate a net present value (NPV) using a predetermined interest rate and an asset life.

In addition to the five core accounts, *Thematic Accounts* are developed to organize data around specific environmental themes such as biodiversity, climate change, ocean and urban areas. These thematic accounts are derived using the same SEEA EA general principles and designed for a specific policy interest.

Information needed to compile those thematic accounts can be sourced from Ecosystem Accounts as well as SEEA Central Framework and SNA.

Coastal ecosystems are critical to maintaining human well-being and biodiversity globally. Liberia is no exception, mangroves and other coastal ecosystems provide numerous benefits and services, including protection from storm surge and sea level rise, erosion prevention, nursery habitat provision for commercially important fisheries and food security for coastal communities. Despite such importance, the coastal ecosystems in Liberia, and mangroves ecosystems in particular, are under tremendous threat due to over-exploitation, urbanization and transport infrastructure development. Such degradation of ecosystems is often overlooked in development decisions due to the lack of information on the value of keeping the ecosystems intact. The SEEA EA generated information in this project seeks to support the conservation and sustainable use of Liberia's coastal natural capital by mainstreaming the value of nature into Liberia's development trajectory.

Ecosystem Accounting Area (EAA)

The Ecosystem Accounting Area (EAA) is the geographical territory for which an ecosystem account is compiled. An EAA may be defined by, for example, the boundary of a country, a sub-national administrative area, a water catchment or a protected area (UNSD, 2021). According to the SEEA EA standards, the EAA should include all relevant ecological realms, i.e., terrestrial, freshwater, and marine ecosystems up to the boundary of an Exclusive Economic Zone (EEZ; UN, 1984). The set of included ecosystem assets should allow for an EAA to be fully tessellated, i.e., filled, including, e.g., built environments.

For this project, we propose to define an EAA using a combination of existing terrestrial and marine boundaries. On the terrestrial side, the boundary will be defined by the districts that are -the closest to the Liberian Coastal Baseline, as defined by the internationally recognized EEZ boundary or containing important ecosystems associated with the coastal area of Liberia. On the marine side, we propose to use the contiguous zone boundary – an EEZ-defined boundary, that extends 24 nautical from the Liberian coastal baseline (Figure 2).

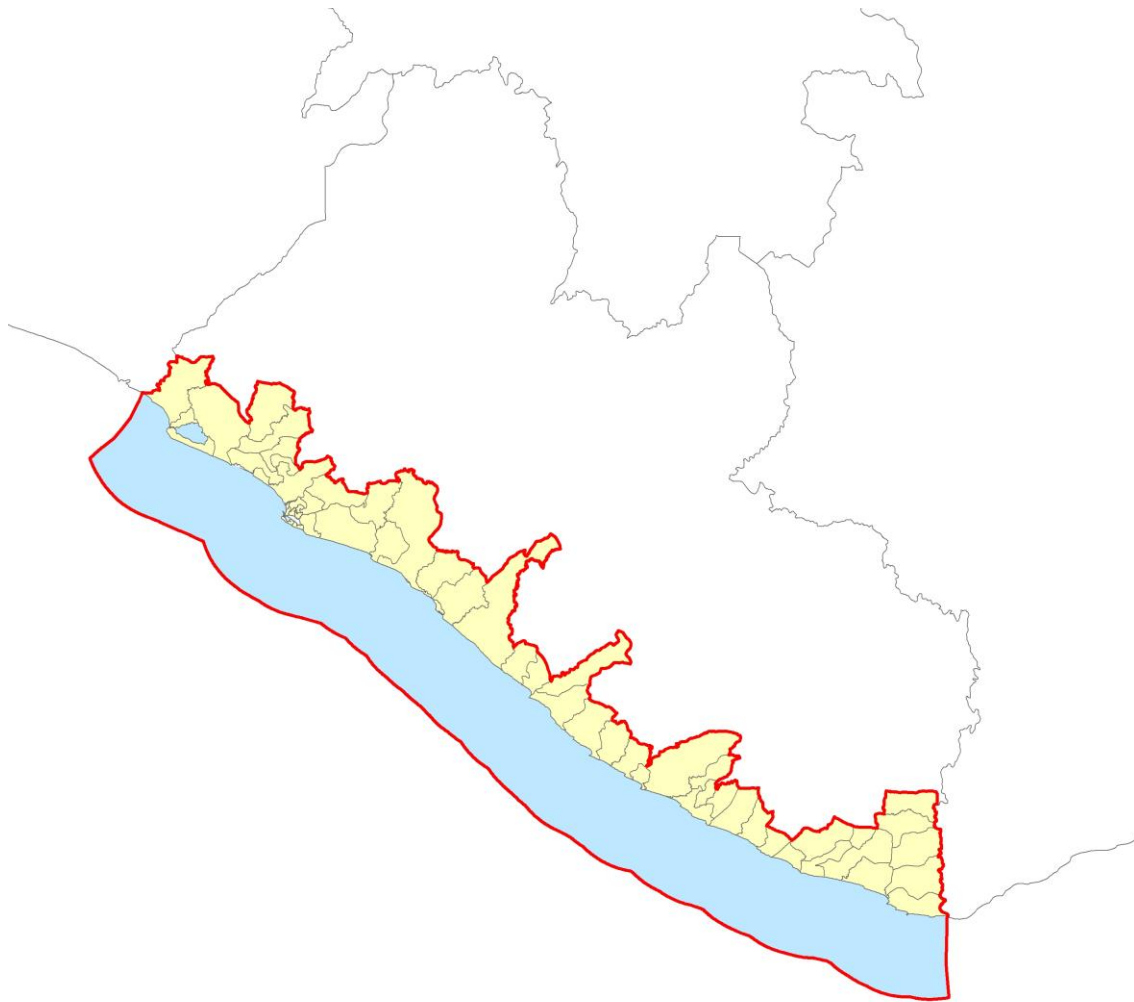


Figure 2 depicts the proposed EAA boundary (red). It is a combination of district and contiguous zone boundaries depicted in yellow and blue, respectively (see main text for details). Grey lines represent district and national boundaries.

The choice for this selected boundary was based on available information about the structure of governance of the coastal area (i.e., relevant administrative coastal districts) and presence of coastal ecosystems that provide important

ecosystem services (i.e., mangroves, fishing grounds). Furthermore, using established administrative boundaries not only facilitate scaling of ecosystem accounting to the national level, but are more relevant for district level policies and planning. Note, the proposed EAA boundary is subject to change based on new information or needs unforeseen at this stage of the project.

Mapping Ecosystem Assets

Ecosystem Assets are contiguous spaces of a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions. Mapping these assets within an EAA and their change over time is one of the necessary requisites for compiling a set of ecosystem extent accounts. The SEEA EA framework recommends that ecosystem assets should be delineated based on various ecosystem characteristics such as physical structure and type, species composition, ecological processes, climate, hydrology, soil characteristics, topography, and depth in case of water bodies. The mapping should be guided by existing national or sub-national ecosystem maps and encompass ecosystem types classified at that level and occurring across the terrestrial, freshwater, marine, and subterranean realms. If this information is not available, the mapping should be guided by the IUCN's Global Ecosystem Typology (Keith et al., 2020) – a systematic typology that classifies all of Earth's ecosystems hierarchically to several levels, representing the diversity of both ecosystem function and biodiversity. Specifically, in its upper levels (Levels 1-3), it defines ecosystems by their convergent ecological functions and, in its lower levels (Level 4-6), distinguishes ecosystems with contrasting assemblages of species engaged in those functions. The SEEA EA framework recommends the Level 3 (ecosystem functional groups) to be used at the regional level of mapping, and more ecologically explicit Levels 4-6, are recommended to be used at the national to sub-national scales. Comparably, classification of land use types within anthropogenic biomes should follow an existing national land use classification scheme. In the absence of such a scheme, the SEEA Central Framework Land Use Classification (UN, 2014) should be used instead. The SEEA EA framework recommends that the 3-digit fine-level description of land use (e.g.,

what type of crops is grown) to be used to assist the preparation of statistics and clarify the treatment of some specific flows and stocks.

In our approach, the initial selection of ecosystem types for the coastal area of Liberia was guided by the above-described recommendations and document review. We propose to develop an initial map based on existing global and national information and maps that we will be able to compile. The central source for this will be the Ecosystem Extent Maps of Liberia, developed through an initiative between the Liberian Environmental Protection Agency, US National Aeronautics and Space Administration (NASA), and Conservation International (Figure 3). As more data is collected during the project, we will refine this map. We propose that the initial map will include 28 ecosystem types as listed in Table 1 in the column labeled as "Liberia-Specific Ecosystems (Level 4)". Note, the last column contains data/method that will be used for mapping those classes.

Figure 3 presents an overview of the methodology used to produce annual land cover and ecosystem extent maps from 2000-2018. Numbers and letters represent the order of each process: (1) Annual temporal composite images were produced using the LandTrendr methodology (Kennedy et al., 2018). (2) The LandTrendr 2015 image was matched to the 2015 base map of land cover types (de Sousa et al., 2020). (3) Stratified samples for 11 classes were selected from the 2015 base map. Spectral information was extracted from the 2015 LandTrendr composite images at the location of each sample. (4) The training sample set was used to train a random decision forest classifier. (5) The temporal composite images were classified using the trained random decision forest model. (6) Output timeseries of land cover maps (LCM stack). (A) Species presence were extracted from BIEN dataset (Enquist et al., 2016), bioclimatic and soil data were used in generalized dissimilarity modelling (GDM; Ferrier et al., 2007) (B), to produce a modelled ecosystem types map. (C) The modelled ecosystem types map and land cover maps were merged to produce final ecosystem extent maps.

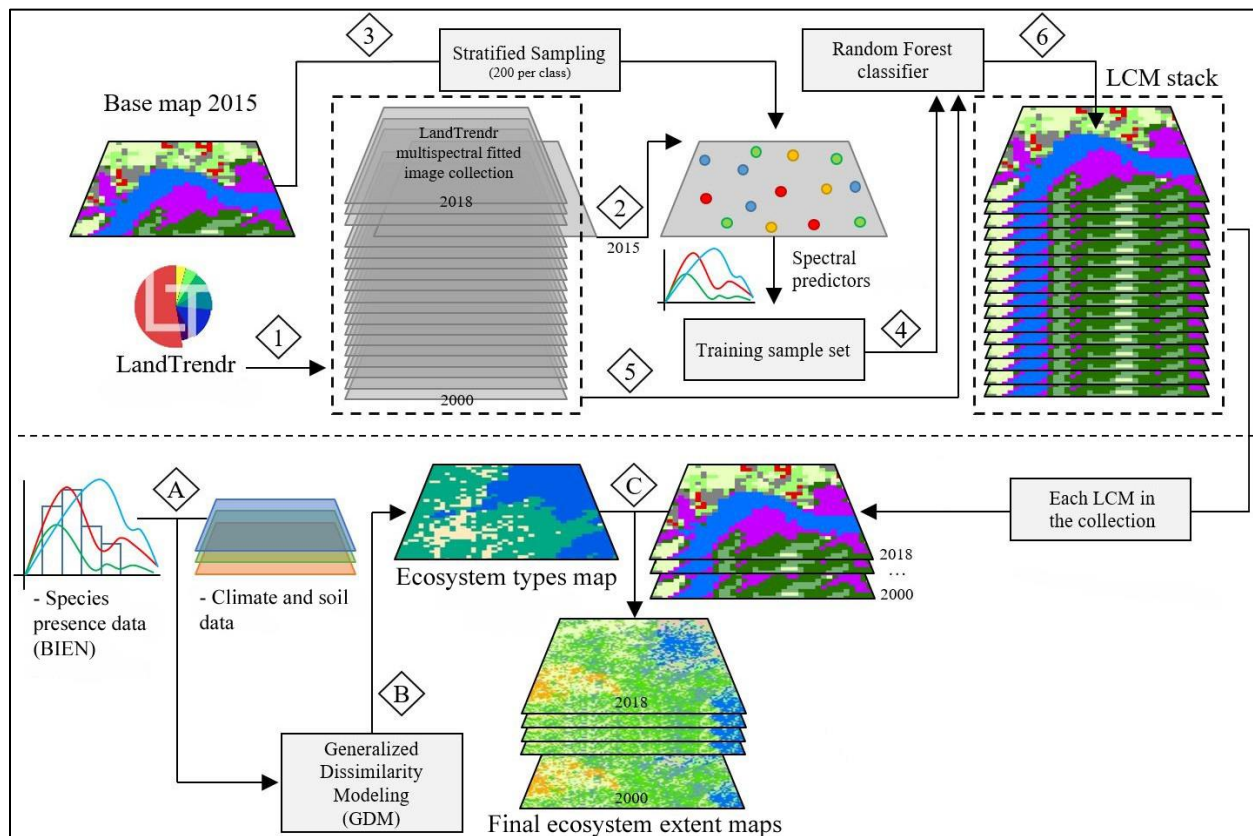


Table 1 shows proposed ecosystem types that will be included in the initial ecosystem extent map.

Realm (Level 1)	Biome (Level 2)	Ecosystem Functional Group (Level 3)	Liberia-Specific Ecosystems (Level 4)	Source Data/Method
Terrestrial	T1 Tropical-subtropical forests	T1.1 Tropical-subtropical lowland rainforest	Mature Tropical Lowland Annual Rainforest	Ecosystem Extent Maps of Liberia
			Mature Tropical Lowland Biannual Rainforest	Ecosystem Extent Maps of Liberia
	T7 Intensive land-use	T7.3 Plantations	Plantation	Ecosystem Extent Maps of Liberia
		T7.4 Urban and industrial ecosystems	Build-up Area	Ecosystem Extent Maps of Liberia
			Barren Land	Ecosystem Extent Maps of Liberia
Freshwater	F1 Rivers and streams	F1.2 Permanent lowland rivers	Rivers	Ecosystem Extent Maps of Liberia/global data
	F2 Lakes	F1.2 Large permanent freshwater lakes	Lakes	Ecosystem Extent Maps of Liberia/global data
	F3 Artificial fresh waters	F3.1 Large reservoirs	Reservoirs	Ecosystem Extent Maps of Liberia/global data
Freshwater-Terrestrial	TF1 Palustrine wetlands	TF1.3 Permanent marshes	Freshwater Marsh	Ecosystem Extent Maps of Liberia/height data/GIS analysis
Freshwater-Marine	FM1 Semi-confined transitional waters	FM1.1 Deep water coastal inlets	Inlets	GIS analysis
		FM1.2 Permanently open riverine estuaries and bays	Estuaries	GIS analysis
		FM1.3 Intermittently closed and open lakes and lagoons	Lagoons	GIS analysis
Marine	MT1 Marine shelves	M1.1 Seagrass meadows	Seagrass	Global data
		M1.3 Photic coral reefs	Reefs	bathymetry maps/global data
		M1.6 Subtidal rocky reefs	Rocks	bathymetry maps/global data
	M2 Pelagic ocean waters	M2.1 Epipelagic ocean waters	Neritic waters	bathymetry maps
		M2.2 Mesopelagic ocean waters	Oceanic waters	bathymetry maps
	M4 Anthropogenic marine systems	M4.1 Submerged artificial structures	Wrecks	bathymetry maps
		M4.2 Marine aquafarms	Shrimp farm	high resolution imagery
Marine-Terrestrial	MT1 Shoreline systems	MT1.1 Rocky shorelines	Rocky shorelines	global data
		MT1.2 Muddy shorelines	Muddy shorelines	global data
		MT1.3 Sandy shorelines	Sandy shorelines	global data
	MT2 Supralittoral coastal systems	MT2.1 Coastal shrublands and grasslands	Coastal shrublands	Ecosystem Extent Maps of Liberia/GIS analysis
			Coastal grasslands	Ecosystem Extent Maps of Liberia/GIS analysis
	MT3 Anthropogenic shorelines	MT3.1 Artificial shorelines	Artificial shorelines	high resolution imagery

Marine-Freshwater-Terrestrial	MFT1 Brackish tidal	MFT1.1 Coastal river deltas	River deltas	GIS analysis
		MFT1.2 Intertidal forests and shrublands	Mangrove	Ecosystem Extent Maps of Liberia/height data/GIS analysis
		MFT1.3 Coastal saltmarshes and reedbeds	Saltmarsh	Ecosystem Extent Maps of Liberia/height data/GIS analysis

While this table also includes terrestrial and freshwater ecosystems, this project's focus will be on coastal ecosystems that are providing important ecosystem services.

Compiling Ecosystem Extent Account

The key purpose of an ecosystem extent account is to record the size and changes in size of ecosystem assets over time. It comprises - two tables: 1) Ecosystem Extent, and 2) Ecosystem Type Change Matrix. These tables record the information in units of area (e.g., hectares of lowland rainforest, square kilometers of grassland) and/or lengths of linear features (e.g., kilometers of rivers, miles of shoreline). We propose to use information derived from the Ecosystem Extent Maps of Liberia to compile these two tables for those ecosystems for which temporal information exists, i.e., mangroves (Figure 4). Accounting for other coastal ecosystems, such as inlets, estuaries, lagoons, seagrasses, reefs, neritic waters, shrublands, grasslands, river deltas, and saltmarshes, will depend on the availability of spatial and temporal information, which will become apparent after we finish the mapping phase which is described in the previous section.

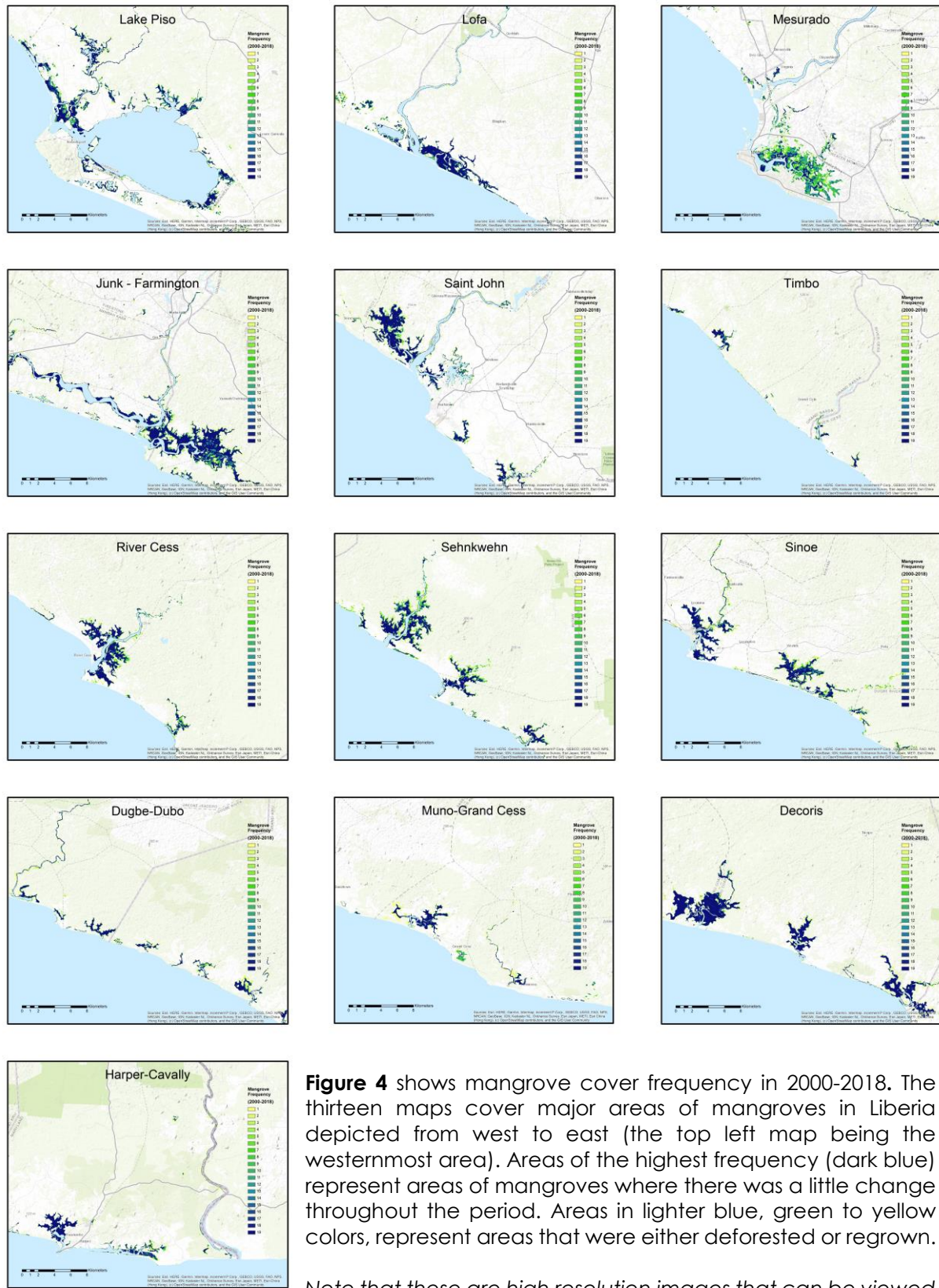


Figure 4 shows mangrove cover frequency in 2000-2018. The thirteen maps cover major areas of mangroves in Liberia depicted from west to east (the top left map being the westernmost area). Areas of the highest frequency (dark blue) represent areas of mangroves where there was a little change throughout the period. Areas in lighter blue, green to yellow colors, represent areas that were either deforested or regrown.

Note that these are high resolution images that can be viewed in detail by zooming in when on an electronic device.

ECOSYSTEM CONDITION ACCOUNT

Ecosystem condition accounts are a structured approach to record and aggregate data describing the characteristics of ecosystem assets and how they have changed over time. Ecosystem condition is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics. Condition is assessed with respect to an ecosystem's composition, structure, and function, which in turn, underpin the ecological integrity of the ecosystem, and support its capacity to supply ecosystem services on an ongoing basis (UNSD, 2021). There are three primary outputs associated with ecosystem condition accounts: the condition variables account, the condition indicators account, and derived condition indices.

Ecosystem condition is represented by the abiotic and biotic characteristics of the ecosystems. "Ecosystem characteristics are the system properties of the ecosystem and its major abiotic and biotic components (water, soil, topography, vegetation, biomass, habitat and species) with examples of characteristics including vegetation type, water quality and soil type" (UNSD, 2021). To systematically organize the information of condition characteristics the SEEA uses the ecosystem condition typology (ECT). The ECT is a hierarchical typology for organizing data on the ecosystem condition characteristics based on their abiotic, biotic, and landscape-level characteristics. Below is an overview of the ECT groups and classes:

Table 2: ECT groups and classes

SEEA ECT groups and classes
Group A: Abiotic ecosystem characteristics
Class A1. Physical state characteristics: physical descriptors of the abiotic components of the ecosystem (e.g., soil structure, water availability)
Class A2. Chemical state characteristics: chemical composition of abiotic ecosystem compartments (e.g., soil nutrient levels, water quality, air pollutant concentrations)
Group B: Biotic ecosystem characteristics
Class B1. Compositional state characteristics: composition / diversity of ecological communities at a given location and time (e.g., presence / abundance of key species, diversity of relevant species groups)
Class B2. Structural state characteristics: aggregate properties (e.g., mass, density) of the whole ecosystem or its main biotic components (e.g., total biomass, canopy coverage, annual maximum NDVI)
Class B3. Functional state characteristics: summary statistics (e.g., frequency, intensity) of the biological, chemical, and physical interactions between the main ecosystem compartments (e.g., primary productivity, community age, disturbance frequency)
Group C: Landscape level characteristics
Class C1. Landscape and seascape characteristics: metrics describing mosaics of ecosystem types at coarse (landscape, seascape) spatial scales (e.g., landscape diversity, connectivity, fragmentation)

An ECT is developed for each ecosystem type in the ecosystem account. The same characteristics may be applicable for multiple ecosystems, such as vegetation productivity or species composition, while others may be specific for an individual ecosystem. ECT for each coastal ecosystem of interest are outlined in Annex 3.1.

Condition variable accounts

The condition variables account is based on the ecosystem characteristics identified in the ECT. Condition variables str quantitative metrics describing individual characteristics of an ecosystem asset. A single characteristic can have several associated variables, which may be complementary or overlapping (UNSD, 2021). Variables differ from characteristics in that they are quantifiable, clearly defined, dynamic, and directional.

The selection of ecosystem variables should prioritize variables that reflect ecological processes that contribute to overall ecosystem integrity. Condition variables represent stocks rather than flows of ecosystem processes. Condition variables should also be sensitive to change over time, especially due to human pressure or intervention. Variable can be derived from field measures or remotely sensed data sources but need to be measured over time to develop the condition variable account.

For each ECT a set of variables is selected to represent the ecosystem characteristic. ECT for select coastal ecosystems and associated variable are shown in Table 3.1.

The condition variable account represents the starting and ending stock of select condition variables for an ecosystem type, group based on the ECT. Ecosystem condition variable can be tracked over time and the change can be recorded; however, variables cannot be compared with each other since each is measured in different units. To make condition variables comparable they need to be transformed into indicators based on a reference condition.

Reference condition

A reference condition is the condition against which past, present, and future ecosystem condition is compared to measure the relative change over time. It also allows the condition of an ecosystem against a desired ecosystem state. Reference condition is used to set the reference levels for ecosystem condition variables. There are multiple methods for determining reference condition and the same method does not necessarily need to be applied for all ecosystems. For example, in primarily natural systems the reference condition could be based on an intact or undisturbed state, however, in more couple human-natural systems, such as agroforestry, an ecological equilibrium or sustainable yield approach might be more appropriate.

In the case on the Liberia coastal accounts, we are primarily focused on natural ecosystems and do not have a long-term ecological dataset to draw from. Therefore, we will apply a method that sets the reference condition based on undisturbed or minimally disturbed ecosystems. To identify ecosystems with minimal disturbance we will use a timeseries of land-cover information and direct observations of EO sensors. First, we will identify large landcover patches that have not experienced change in the past 20 years (2000-2020). Then we will also look at the spectral reflectance of these patches over the Landsat archive using tools such as LandTrendr (<https://emapr.github.io/LT-GEE/>) to further refine the delineation of reference sites.

After the reference sites have been identified we will calculate the reference levels for the EO-derived condition variables for each ecosystem of interest. Based on the variance of the EO-derived variables, we will stratify the ecosystems of interest and collect field data for a subset of sites that represent the full spectrum of ecosystem conditions.

Ecosystem Condition Indicator accounts

Ecosystem condition indicators are rescaled versions of ecosystem condition variables. The variables are normalized based on the reference levels derived from the reference condition. Therefore, each condition indicator is scaled from 0 – 1 with 1 representing the reference condition. In order to calculate the

condition indicators the top value (1) and bottom value (0) for an ecosystem variable need to be identified. Then a linear rescale can be applied to the variable using the formula below:

$$I = (V - V_L) / (V_H - V_L)$$

Where I is in the value of the indicator, V is the value of the variable, V_L is the low condition score and V_H is the high condition score.

It is important to note that variables may need to be transformed before the equation should be applied. For example, in cases where low values are more desirable, like pollutions or invasive species. It is important to clearly document and justify these choices in the condition account.

The advantage to rescaling all the condition variable to a common range is that they can be more readily compared with each other, changes in the relative condition of an ecosystem can be tracked over time, and the condition indicators can be combined to create indices.

Condition Indices

Ecosystem condition indices and sub-indices are composite indicators that are aggregated from the combination of individual ecosystem condition indicators recorded in the ecosystem condition indicator account. There are many advantages to creating condition indices; they can provide high-level information on the state of ecosystems or they can be created to address a particular policy target or commitment. The process of developing indices is hierarchical, meaning that often sub-indices are first created, based on the ECT, and then the sub-indices are aggregated to create indices.

Indices can be aggregated primarily in two different ways: thematically and spatially. Thematic aggregation is often applied within ecosystem types. For example, multiple condition indicators for a single ecosystem asset may be aggregated to better understand the overall condition of that ecosystem. Spatial aggregation looks at multiple ecosystem types for an area of interest. For example, if you have multiple ecosystems in an accounting area and you would

like an overall condition index for the accounting area, then spatial aggregation would be appropriate. There are multiple methods for spatial allocation, such as normalizing by area, that need to be considered.

There is also overlap between method of thematic and spatial aggregation. In many cases both methods will need to be applied. Figure 5 below is a diagram that outlines the application of aggregation techniques:

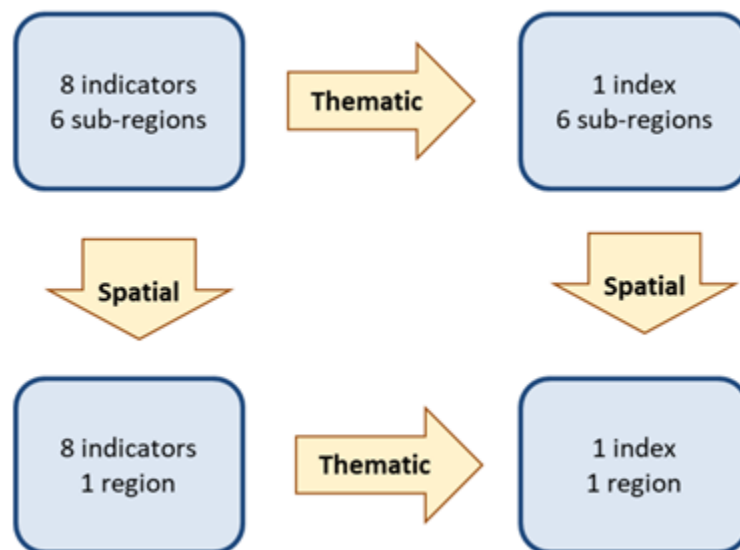


Figure 5: Application of the aggregation techniques (UNSD, 2021)

For the coastal accounts in Liberia, we will apply thematic aggregation within ecosystem types to provide a single index of condition of that ecosystem, based on the sub-indices, and we will provide a spatial aggregation of all ecosystem types based on the thematic aggregation for the entire accounting area. We will also work with stakeholders in the Liberian government to identify other policy priorities and will work with them to develop appropriate indices to track progress.

Table 3.1

3.1.1 – Mangrove ecosystems

Mangrove ecosystem condition typology:

ECT Group	ECT Classes	Ecosystem Characteristics
Abiotic Characteristics	Physical state	Sedimentation rate, Plastics
	Chemical state	Salinity, Heavy metals, Soil organic carbon
Biotic Characteristics	Compositional state	Biodiversity, Species composition
	Structural state	Canopy height, NDVI, Age diversity
	Functional state	n/a based on most recent guidance from SEEA
Landscape Characteristics	Landscape characteristics	Migration potential, Patch size, Fragmentation

Mangrove condition variables:

Ecosystem Variables	Data type
mm of sediment accumulated per year	Field survey
oz plastics per ha	Field Survey
Parts per thousand of dissolved salt	Field survey
Parts per million of lead and mercury	Field survey
Tonnes per hectare of carbon	Field survey
Abundance of indicator species (mollusks, crabs, coastal birds...)	Field survey
Species richness (vegetation, marine)	Field survey
Canopy height (m)	Remote sensing
Maximum annual NDVI	Remote sensing
Annual difference NDVI	Remote sensing
Vertical structure complexity (unit unknown)	Remote sensing
Age profiles	Field survey
tons per hectare of carbon	Field survey
Meters of migration potential without obstruction	Remote sensing
Patch size (ha)	Remote sensing
Fragstats (Clumpy, edge-perimeter ratio, others...)	Remote sensing

ECOSYSTEM SERVICES ACCOUNT

In SEEA EA ecosystem services are defined as “the contributions of ecosystems to the benefits that are used in economic and other human activity” (UNSD, 2021). The term “benefits” is used here more broadly than the SNA conceptualization and includes goods and services that are ultimately used and enjoyed by people and society. Furthermore, the term “use” in the definition incorporates not only the direct physical consumption of materials but any passive receipt of the services as well.

Ecosystem services account constitutes a central part in ecosystem accounting, connecting ecosystem assets with beneficiaries/end users. The primary purpose of this account is to measure the role of ecosystems in producing benefits through ecological production functions and to record the contributions to people and economy, more specifically, how those benefits are distributed across different sectors of the economy. According to the EA framework, an ecosystem asset is the supplier of one or more ecosystem services and these services are recorded as flows between the asset and economic units (e.g., households, businesses and governments). These flows are recorded both in biophysical and, where appropriate, economic terms and are then aggregated by different ecosystem types for the entire EAA. The aggregated information has two primary uses: a) reporting on the non-SNA contribution of ecosystem as a separate sector of the economy and b) using the statistical information to make policy decisions.

The spatial focus of ecosystem accounting in Liberia is coastal areas. Some ecosystem services generated are exclusive to coastal areas (e.g., coastal protection) and many others are common to terrestrial ecosystems as well (e.g., food provision, erosion control). Keeping that in mind, the modeling framework is

being set up in a way that is replicable in other ecosystems and scalable nationally. Two ecosystem services accounts to be developed in Liberia are:

- a) Ecosystem services flows measured in **biophysical terms**, which will record flows of benefits in biophysical units such as m³ water during an accounting period.
- b) Ecosystem services flows measured in **monetary terms**, which will record flows of benefits in monetary terms such as US\$ worth of firewood supplied by ecosystems

Ecosystem services selected

In the SEEA EA methodological guidance, the ecosystem services are grouped into (i) provisioning services, (ii) regulating and maintenance services and (iii) cultural services (UNSD, 2021). We used this as a reference list and evaluated each service for coastal areas in Liberia. This evaluation was done primarily based on three criteria: relevance, data availability and technical feasibility. The services that do not have explicit connection/relevance to coastal ecosystems were excluded in this accounting exercise (e.g., water supply services). Similarly, the services that are relevant for the coastal areas, but data availability is uncertain were also excluded (e.g., pollination services). To finalize the list of services, complementary literature review and stakeholder consultation were conducted as follows:

- discussions held during the stakeholder workshop in the Project Preparatory Grant (PPG) phase
- feedback received from the Technical Advisory Committee (TAC)¹ meeting

¹ TAC is a committee of representatives from different government agencies formed to provide technical advice and recommendations for the project

- review of mangroves literature on ecosystem services provided by coastal ecosystems globally.
- evaluation of services mapped under the Mapping and Accounting Essential Natural Capital (MENC)² project in Liberia
- review of documentation of scoping workshop conducted under TEEB-Liberia, which generated a list of services provided by mangrove species: provision of food, regulation of extreme events, cultural values and C sequestration and storage.

Based on the above, the following services (Table 4) were initially selected for modeling (note: this list may change and/or expanded during technical implementation of the accounts):

Table 4: An initial list of ecosystem services for measurements and modeling

Ecosystem Services	Specific description
Crop provisioning services	Rice production
Wood provisioning services	Firewood for cooking Charcoal* for smoking fish
Wild fish and other natural aquatic biomass provisioning services	Commercial fisheries Subsistence fish catch
Global climate regulation services	Carbon sequestration and storage
Soil erosion control services	Reduction in coastal erosion
Coastal protection services	Storm surge mitigation
Recreation-related services	Tourism

* Note: Charcoal is the primary source of energy for cooking in Liberia and in fact, 70% urban and 5% rural use charcoal (GoL, 2008). It is estimated that the national demand for charcoal is 337,000 t/year with a retail value of US\$ 46 million (World Bank, 2019). More than 75% of this demand is in just 3 counties around Monrovia – Montserrado, Margibi and Bong. Although this large charcoal demand is in urban centers in coastal areas,

² See Conservation International (2017)

the supply of charcoals originates further inland (as far as 150 km from Monrovia). Coastal ecosystems, particularly mangroves are not a large supplier of charcoal products and in fact 75% of charcoal is produced from matured rubber trees. As a result, charcoal production will not be part of coastal accounts. However, there are anecdotal evidence of charcoal being used in smoking fish in coastal villages. Quantitative information on charcoal use for such activities will be collected during the household surveys.

In addition to the list of services presented above, a number of beneficiaries have also been identified during the PPG phase of the project (Table 5). This beneficiary list will be revised during technical implementation and serve as an essential input in the modeling and valuation process.

Table 5: A preliminary list of beneficiaries of ecosystem services

List of beneficiaries for coastal ecosystem services in Liberia		
<ul style="list-style-type: none"> • Households • Industries • Fishermen • Farmers • Dealers • Communities • Tourist visitors • Development partners • Researchers • Liberia water and sewer corporation 	<ul style="list-style-type: none"> • Clinics • Hospitals • Animals (food) • Plants (water supply) • Businesses • Aquaculturists • Spiritualists • Indigenous communities • Government • Traditional doctors • Pharmacies 	<ul style="list-style-type: none"> • Academics • Miners • Transportation providers • Tourist guides • Hunter

Biophysical measurements/modeling and monetary valuation of individual services

This section described biophysical measurements/modeling as well as monetary valuation approaches applied to different individual services based on the supply of services from the ecosystems and demand of those services by different economic units. The term *supply* here refers “the capacity of a particular area to provide a specific bundle of ecosystem goods and services within a given time period”, where as *demand* refers to the “sum of all ecosystem goods and services currently consumed or used in a particular area over a given time period” (Burkhard et al., 2012). Biophysical and monetary measurements/modeling quantifies the services that are supplied by ecosystems but also has a specific beneficiary. In other words, only the services that are used beneficiaries (i.e., realized services) are quantified in biophysical/monetary terms and added to the accounts.

Crop provisioning

Crop provision as an ecosystem service refers to the growth of cultivated plants (e.g., agricultural commodities used by economic units). In biophysical terms crop provisioning service will be measured in tons of crop production attributable to inputs from natural ecosystems.

Agricultural crop production depends on both natural and human inputs. The natural inputs include water for irrigation, pollination, erosion control, rainfall etc. while anthropogenic inputs are fertilizers, land, labor, seeds, pesticides etc. The purpose of modeling crop provisioning in ecosystem accounting is to distinguish and quantify natural inputs.

For biophysical modeling, the share of agricultural yield that is attributable to ecosystems ($EcoCon_{crops}$) will be quantified using the following equation (Vallecillo et al., 2019):

$$EcoCon_{crops} = \frac{Natural\ inputs}{(Natural\ inputs + Human\ Inputs)} \quad (1)$$

The value of $EcoCon_{crops}$ is in a range of 0 to 1. If the production is entirely produced by human inputs the value takes 0 and in the other spectrum, if the production is entirely through natural inputs the value takes 1. We will use average values for different crops (see Vallecillo et al., 2019, 17p) as a reference point but will subjectively modify for Liberia based on known knowledge and stakeholder inputs.

The actual biophysical flow of crop provisioning will be determined based upon total production of a particular crop (i) produced in coastal areas in Liberia.

$$Biophysical\ flow_i = Production_i * EcoCon_{crops[i]} \quad (2)$$

The monetary flow will take biophysical flow and multiply with market price of per unit crops sold.

$$Monetary\ flow_i = Biophysical\ flow_i * Unit\ market\ price_i \quad (3)$$

Firewood supply

Firewood supply as an ecosystem service refers ecosystem contributions to the growth of biomass that is used by households primarily as a source of energy. Firewood supply will be measured in terms of m³ of wood biomass harvested from coastal ecosystems. A spatial allocation model will be used for modeling firewood demand and supply. This spatial model will take inputs from measurements and data from field survey and allocate demands cross different ecosystems. Below is the methodological process involved in calculation of demand and the development of a spatial allocation model for firewood supply and in coastal areas.

Measuring demand

- Firewood demand will be estimated based on per capita firewood use in rural areas, household size and total number of households in the study area. The demand will be adjusted for population living in urban centers around Monrovia, since urban households primarily use charcoal for cooking activities.
- This total demand will be used to determine the supply sources through a spatial allocation model using proximity from villages, accessibility through roads and degradation
- Villages will be identified using remote sensing techniques. A regression model will be developed to estimate number of households in each village cluster based on density.
- Both proximity and accessibility will determine how far people travel from their households, assuming people would prefer to travel to the nearest ecosystems
- Forest loss and ecosystem degradation serves as an important indicator for firewood supply and will be used in the spatial allocation model
- Based on the above a firewood suitability surface will be created

Data for demand calculation:

- Estimates of firewood use (household surveys)
- Travel time required for firewood collection (household surveys)
- Biomass of smoked fish (household surveys)
- Firewood needed per unit fish biomass for smoking (household surveys)

Data for spatial allocation model:

- Location of villages along the coast (data available through MENC project but check for an updated version)

- Roads network (data available through MENC project but check for an updated version)
- Mangroves loss (data available in-house analysis of mangrove forest cover loss through extent accounts)
- Population (data available in-house but check with LISGIS if they have updated version. Also check UN map of population settlements).
- Degradation map (data available in-house though condition accounts)

Climate Regulation

Both the stock and change in stock of carbon (i.e., sequestration and emission) represent measures of global climate regulation services. The measurement of physical carbon stock will include the opening and closing stocks of carbon stored in the above and below ground biomass (in tons of CO₂e), whereas, the change in stock will measure removal of atmospheric carbon (i.e., sequestration) and release/loss of carbon from existing stocks (i.e., emission) through ecosystem degradation and enhancement (UNSD, 2021). As such, all those measures will be used in coastal accounts in Liberia using methods as follows:

- *Carbon stock assessment:* Above and below ground carbon stored in different ecosystems. C storage will be determined following IPCC Tier 1 approach by creating a look-up table for each ecosystem class derived from CI-NASA ecosystem extent map.
- *Carbon sequestration:* Sequestration refers to uptake of CO₂ by terrestrial vegetation. The rate of sequestration depends largely on the type of vegetation, growth rate and stages of maturity. Sequestration rates by different ecosystem types are unknown in Liberia, however, a lookup table

will be developed for each ecosystem types based on global data and use the table in conjunction with ecosystem extent information.

- *Carbon emission:* The area covered by coastal ecosystems will be derived based on annual land cover/use maps. From these land cover change data, CO₂ emission will be calculated using the IPCC Tier 1 approach. For mangrove ecosystems, two possible cases of land cover change: (1) conversion of mangroves to degraded land (e.g., deforestation) and (2) draining of mangrove areas (e.g., conversion to agriculture).
- *Monetary valuation:* Several techniques are used for monetary valuation of climate regulation services. Social Cost of Carbon (SCC) is the most robust and uniform technique used in most valuation. Market price is also used in places where C is traded through existing market mechanisms (e.g., Emission Trading Schemes, ETS) or REDD+. For ecosystem accounting in Liberia an appropriate SCC will be derived based on Nordhaus (2017).

Soil Erosion Control

Soil erosion control refer to the ecosystem contributions to the stabilising effects of vegetation, that reduce the loss of soil (and sediment) and support use of the environment, such as agricultural activity. A methodological framework for measuring erosion control services has been developed and tested following SEEA EA guidance in Pursat Basin (Cardamom Mountains) in Cambodia (Rawlins et al., 2020). This method estimated the total amount of sediment yield for each landcover/ecosystem type using the SWAT model for each hydrological unit. These values were further averaged over time to produce average annual sediment yield rates per land cover type (in tons/ha/year). A similar framework

will be applied in Liberia by making necessary adjustments in model inputs as follows:

- For modeling soil erosion control services provided by coastal ecosystems, the Revised Universal Soil Loss Equation (RUSLE) model will be calibrated for Liberia to obtain R (rainfall), K (soil erosivity), C (land cover) and P (conservation management) factors.
- To measure ecosystems' contribution to erosion control and sediment trapping, we will run the model twice and obtain the difference in output in current cover and bare soil.
- For monetary valuation, specific beneficiaries impacted by soil erosion will be identified (e.g., hydropower, coastal infrastructure damage). The economic damage done by per unit soil erosion will then be calculated.

Cultural Services

Cultural services are experiential and non-material connections between people and ecosystems. For accounting purposes, the cultural services are identified in two ways – first, by determining the relevant set of benefits and second, by representing contribution of ecosystems to those benefits (UNSD, 2021).

In the SEEA EA reference list, four cultural services were listed – recreation-related services; visual amenity services; education, scientific and research services; and spiritual, artistic and symbolic services. In Liberia, we propose to use ecotourism to represent recreation-related services provided by coastal ecosystems. The following steps will be followed for assessment of ecotourism:

- Identify and locate nature-based tourist spots along coastal areas (including sea beaches);
- Survey existing studies and databases to extract information on number of tourist visits in each site;

- Review available expenditure data on tourism activities;
- Multiply number of visits with per capita expenditure for each site.

Biophysical assessment will be done using longitudinal data of various tourist visit indicators such as the number of visitors (foreign and domestic), their length of stays, and hotel occupation rate. For monetary valuation, the conventional travel cost method (TCM) will be used to develop initial estimates which then will be used to calculate a “resource rent” to derive a value that is attributable to ecosystems.

Additional considerations for monetary valuation:

The general principle for monetary valuation is to view ecosystem as an asset and consider ecosystem services as rents generated by that asset – analogous to monetary benefit generated by a physical asset. This conceptualization allows for valuation of services following SNA principles by first calculating the gross value and then subtracting any intermediate costs. However, this conceptualization often cannot be applied to many ecosystem services because of their unique ecological production function. With that in mind and following SEEA EA technical recommendations, the following rules will be applied for selecting valuation methods (also see table below):

- If prices are directly observable in the market, use market price
- If prices are obtained from markets for similar goods and services, use shadow price
- If prices (and associated values) are embodied in market transactions, select methods: resource rent, residual value, change in productivity, hedonic pricing
- If prices are based on revealed expenditures (costs) in related goods and services, use methods: travel cost, averting behavior

- If prices are based on hypothetical expenditures or markets, use the following: replacement cost, avoided damage cost, simulated exchange value

Table 6: Based on the evaluation of available data and the general principle described above, the following methods have been identified as applicable in Liberia.

Ecosystem services		Economic valuation		
		Method	Model	Data
PROVISIONING SERVICES				
Biomass provisioning services	<i>Crop provisioning services</i>	Calculate ag rent/ha, multiply total area	Resource rent	Total yield (from bio analysis), product price, input costs
	<i>Timber provisioning services</i>	Calculate resource rent per concession types, multiply by timber volume	Resource rent	Harvest volume, sales price, input costs
	<i>Fish and other aquatic products provisioning services</i>	multiply total catch by unit price of fisheries products	Market price	total fish harvest, market price, cost of catch
REGULATING SERVICES				
Global climate regulation services		Decide on unit price of carbon for Liberia and apply it to C sequestration and CO2 emission separately	Social Cost of Carbon	tCO2/ecosystem class (sequestration & emission), SCC
Soil erosion control services (includes also sediment retention services and landslide mitigation)		multiply change in productivity with applicable cost of erosion to farmers/hydroenergy etc.	Replacement cost	tons/ha soil erosion or retention, soil nutrients, crop yield/ha, crop price/ton
Storm mitigation services		Estimates of properties protected, value of properties	Avoided damage	Population, infrastructure, property values
CULTURAL SERVICES				

Recreation-related services		Estimate per capital expenditure, multiply visitor numbers, quantify ecosystem contribution	Travel cost	Hotel occupancy, restaurants, tourist expenditure
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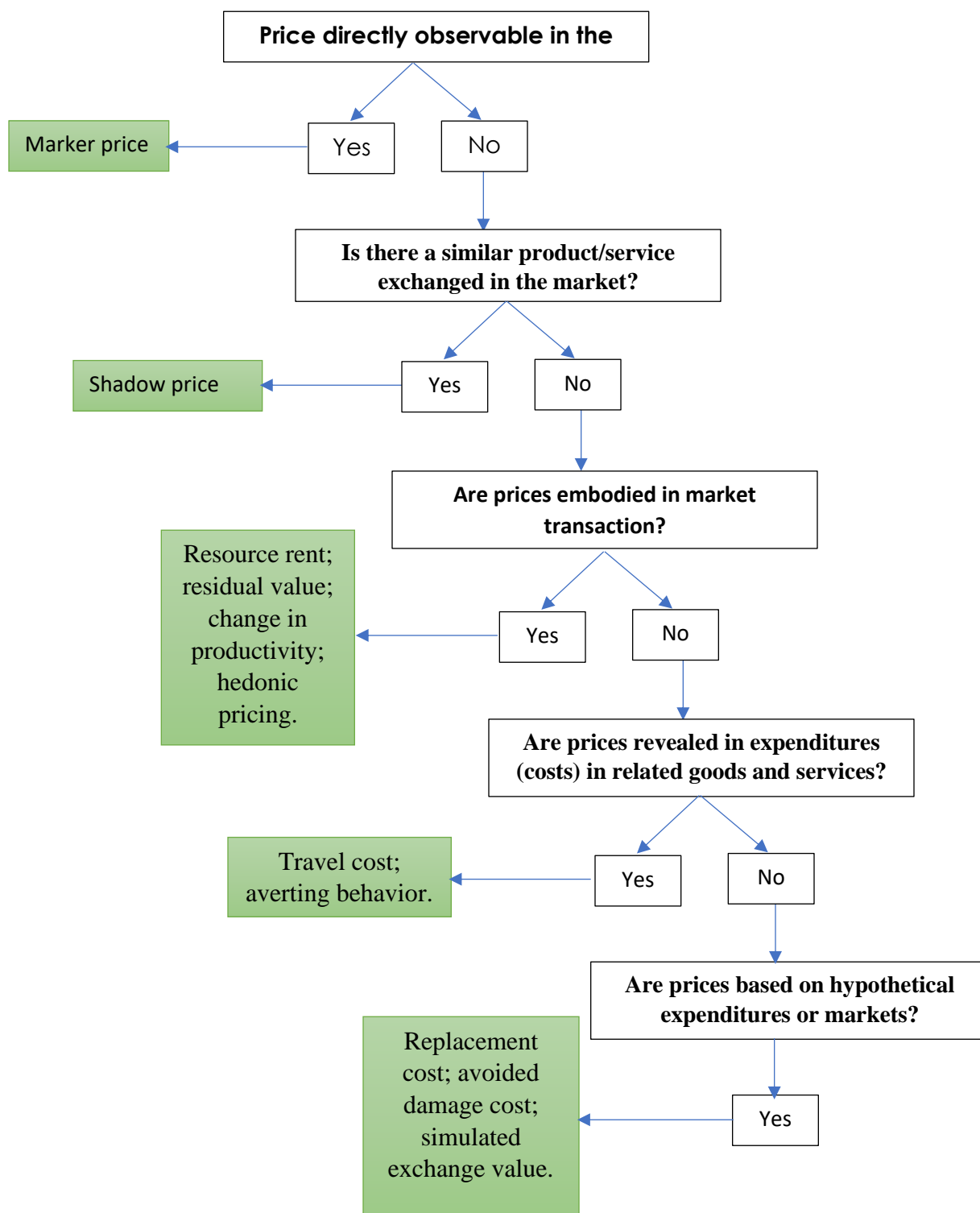


Figure 6: Decision tree for choosing monetary valuation methods following SEEA EA principles (CI, 2021)

MONETARY ASSET ACCOUNT

The key purpose of Monetary Asset Account is to record monetary values all ecosystem assets in an accounting area. The value of ecosystem assets is obtained by estimating the net present value (NPV) of ecosystem services supplied at the beginning and at the end of an accounting period. The change in values of assets at opening and closing stocks are disaggregated into: ecosystem enhancement, ecosystem degradation, ecosystem conversions, other changes in the volume, and revaluations (see definitions in Box 1).

The general formulation of the NPV approach is as follows:

$$V_{\tau}(EA) = \sum_{i=1}^{i=S} \sum_{j=\tau}^{j=N} \frac{ES_{\tau}^{ij}(EA_{\tau})}{(1+r_j)^{(j+1-\tau)}}$$

Where, where ES_{τ}^{ij} , the value of ecosystem service i in year j as expected in base year τ ; S , the total number of ecosystem services; r , the discount rate; and N , the asset life (UNSD, 2021).

Additional data collection is not required for monetary asset accounts since all inputs are provided by the Ecosystem Services Accounts (Monetary). However, implementation of the net present value approach requires several parameters to be determined (see the equation above). Below are some considerations for estimating the expected future returns of services which go into the monetary assets model:

- The **scope and definition of returns** that concerns the set of ecosystem services to be included in the valuation
- **Valuation of returns** that are based on exchange value concept and that only considers contribution of ecosystems

- The **future flow of ecosystems services in physical terms** to allow for the relationship between services considering *capacity* and *sustainability* issues
- Determination of **asset lives** based on patterns of ecosystem use and optimal management practices
- Determination of **expected institutional arrangements** in the future such as management regimes, taxes & subsidies, new market opportunities such as carbon markets.
- Determination of **discount rates** appropriate for a particular service – individual, market or social discount rates

Integrated and extended accounting for ecosystem services and assets

Past approaches of integration of ecosystem and environmental data with national accounting systems focused primarily on valuation of degradation and recording of degradation in terms of cost of capital. With emerging literature and data on ecosystem services enables expansion of this integration beyond just degradation with respect to *extended supply use tables* and *balance sheets*.

The extended supply use tables (ESUT) shows the relationship between economic units – households, businesses, governments – in terms of how each ecosystem services are produced or consumed. It serves several purposes including:

- Demonstrating the relative contribution of ecosystem sector to the economy as a whole
- Showing the share of the economy that is dependent on ecosystem assets
- Showing relative share of production and consumption of ecosystem services by different economic sectors

- Identifying sectors and industries that are most dependent on ecosystems for inputs to their production process
- Developing advanced models such as computable general equilibrium (CGE) models (Banerjee et al., 2021)

While the ecosystem accounts can be implemented at the subnational administrative areas (e.g., state, province), the integration of data into ESUT requires additional consideration. The supply use tables are labelled as “extensions” to the existing SNA accounts. As such, the integration of ecosystem data at the subnational scale requires that supply use tables disaggregated by administrative areas already exist or they can be downscaled from national SNA accounts.

THEMATIC ACCOUNTS

Considering that policy analysis often requires emphasis and focus on specific environmental themes, SEEA EA provides guidance on compiling accounts around four environmental themes: biodiversity, climate change, oceans and urban areas. The “core ecosystem accounts” are developed following standard accounting principles and for a specific EAA. However, some restrictions (e.g., geographical area, type of entity or classification) are not strictly applied in the development of thematic accounts, rather the focus is on helping decision-making processes that need analytical needs on an environmental theme.

For coastal ecosystem accounting in Liberia, we will focus on biodiversity thematic accounts.

Accounting for Biodiversity

While the ecosystem accounts provide information to describe the relationships between ecosystems, economic activity and human well-being, the thematic biodiversity account seeks to mainstream biodiversity into decision-making. Some of the data from the ecosystem extent, condition and services accounts can also provide input into the biodiversity accounts. The primary type of biodiversity account we will develop are species accounts, which provide opening and closing values for species or groups of species based on their conservation status, stocks (abundance or presence) or distribution. The steps to establish species accounts are:

- 1) Prioritize which species or species groups to measure, based on threat status, functional importance or indicator value
- 2) Compile existing data on target species and identify gaps

3) Collect new data in the field

4) Synthesize data and compile species accounting tables

The final list of priority species for accounts is still being determined, but potential candidates include the following.

Mangrove trees: We will choose one or more mangrove species, considering several criteria which include rarity/threat status and potential to model tree density based on remote sensing and LIDAR data (e.g., the tallest mangrove species may be distinguishable based on canopy height). The overall abundance of each mangrove species will be estimated based on its extent and density. If density cannot be calculated, we could use extent values only for the account.

Seagrasses: Similar to the approach for mangroves, we propose to develop species accounts for seagrasses based on their extent and density.

Fishes, molluscs and crustaceans: Due to their functional importance, especially as food for people, we will identify the highest priority species of fishes, molluscs and/or crustaceans based on their ecosystem service values. While field surveys can identify relative abundance in some areas, it will probably be more feasible to estimate opening and closing stocks based on market surveys and questionnaires with fishermen to quantify trends in catch per unit effort.

Sea turtles: Existing research in a few sites in Liberia is tracking activity for five turtle species, and these data could be used to develop species accounts for each of these sea turtle species, at least at a subnational scale.

Bird species: Birds are a priority for species accounts because they are one of the most cost-effective indicator taxa, which means patterns of bird diversity tend to reflect broader biodiversity patterns yet birds can be sampled quickly and

efficiently. Rather than focus on individual bird species (unless there is a particular species of conservation concern), we propose to consider changes in species richness and relative abundance for birds as a single species group.

Other potential species for accounts: Depending on initial research, other potential priorities include species accounts for select corals and sea cucumbers. Habitat-based approaches to understand changes in the extent and condition of habitat suitable for threatened species, such as the slender-snouted crocodile, will also be explored.

FIELD DATA COLLECTION

All of the accounts described in the earlier sections will to some degree depend on integration of existing data with new field survey data collection as well as modeling and desktop analysis. Field data will be strategic and targeted to fill the gaps needed for each of the accounts.

Objectives & considerations

Our steps and objectives for fieldwork are:

- Identify data gaps for each of the accounts
- Identify coastal ecosystem types to survey
- Prioritize which biophysical and socioeconomic data to measure
- Select field survey sites
- Assemble RAP science team and prepare field logistics
- Determine survey methodology
- Conduct field surveys
- Data analysis and synthesis, incorporate data into relevant accounts

To execute the workplan the following are some general considerations:

- Ideally, we will assemble a team of Liberian and international scientists, but COVID travel restrictions may impact timing especially for international participants.
- It is difficult to survey every ecosystem type, especially with replicates, so we will have to be strategic in filling key gaps. It is even more challenging due to the fact that mangroves and other coastal ecosystems tend to be highly heterogeneous.

- We will optimize selection of field sites to balance as broad coverage as possible at the national scale but also making it feasible in terms of time and resources, as well as accessibility to some of the hard-to-reach sites.
- Some data can be collected rapidly and only once, while other data require repeated field visits/long-term monitoring.

Types of data to be collected

- Ground-truthing and calibration of ecosystem types for the extent account
- Measure abiotic and biotic characteristics for condition and thematic biodiversity account (Table 8):
 - Sedimentation rate, salinity, heavy metals, soil organic carbon, plastics, canopy height/vegetation structure, biodiversity (key functional and/or indicator groups, e.g, birds, fishes, molluscs, crustaceans, plants; potentially use eDNA to identify broad suites of aquatic species)
- Household surveys to measure demographic information, fish and bushmeat consumption, firewood, timber, water, and NTFPs.
- Market surveys of bushmeat and fish species to understand priority species being used, quantities, unit price, etc (Table 7).

Table 7: A list of data to be collected through primary and secondary sources

Abiotic (Direct)	Biotic (Direct)	Indirect (Community and market surveys)
<ul style="list-style-type: none"> • Sedimentation rate • Heavy metals (sediment cores) • Soil organic carbon (sediment cores) • Plastics • Salinity 	<ul style="list-style-type: none"> • Birds • Herps • Fishes • Molluscs • Crustaceans • Plants (including mangroves, sargassum, seagrasses) • Corals 	<ul style="list-style-type: none"> • Demographic info • Fish, mollusc, crustacean and bushmeat consumption (as well as spp, unit price) • Other NTFPs • Firewood • Timber

	<ul style="list-style-type: none"> • eDNA • Other potential taxa: Terrestrial mammals, cetaceans, bees, beetles 	<ul style="list-style-type: none"> • Water use
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Table 8: Data types and data collection methods for different ecosystem variables

Ecosystem Characteristics	Ecosystem Variables	Data type	Data collection methods
Sedimentation rate	mm of sediment accumulated per year	Field survey	Field measurement
Plastics	oz plastics per ha	Field Survey	Survey
Salinity	Parts per thousands of dissolved salt	Field survey	Field measurement
Heavy metals	Parts per million of lead and mercury	Field survey	Field measurement
Soil organic carbon	Tons per hectare of carbon	Field survey	Sediment core
Biodiversity	Abundance of indicator species (mollusks, crabs, coastal birds...)	Field survey	Field measurement
Species composition	Species diversity (vegetation, marine)	Field survey	Survey, eDNA?
Canopy height	Canopy height (m)	Remote sensing	Lola's dataset, UMD datasets
NDVI	Maximum annual NDVI	Remote sensing	GEE
NDVI	Annual difference NDVI	Remote sensing	GEE
Age diversity	Vertical structure (unit unknown)	Remote sensing	GEDI, ask Lola
Age diversity	Age profiles	Field Survey	Field measurement
Migration potential	Meters of migration potential without obstruction	Remote sensing	DEM, Land-cover map
Patch Size	Patch size (ha)	Remote sensing	Landcover map
Fragmentation	Fragstats (clumpy, perimeter-edge ratio,	Remote sensing	Landcover, Fragstats R package

Survey Site Selection and Methods

In order to understand natural variability and heterogeneity, as well as to achieve robust sample sizes required for statistical analysis, it is important to include replicate survey sites across different ecosystem types and levels of degradation, but fieldwork is also expensive and time-consuming, so we propose the following balance.

Identify at least 3 general survey areas along the coast that span a wide range from northwest to southeast in order to understand natural heterogeneity along the coast. Each ecosystem type would be surveyed at least 1 site in each survey area. Where feasible, we will also survey 3 sites for each ecosystem type in each survey area (or at a minimum in one survey area) to include intact, moderately degraded and severely degraded ecosystems. This means that each ecosystem type would include somewhere between 5 survey sites (3 intact sites spread across the coast, 1 site experiencing moderate degradation and 1 severely degraded) and 9 survey sites (3 intact sites, 3 moderately degraded and 3 severely degraded).

We will focus on areas where studies have already been done, in order to build on existing information. Potential areas based on these criteria include: Grand Bassa, Robertsport (Lake Piso), Marshall, Greenville.

All taxonomic groups will be surveyed using standardized methods, following recommendations in Larsen (2016). Household surveys and questionnaires with fishermen will be developed and implemented in the field following FPIC and other standard protocols.

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