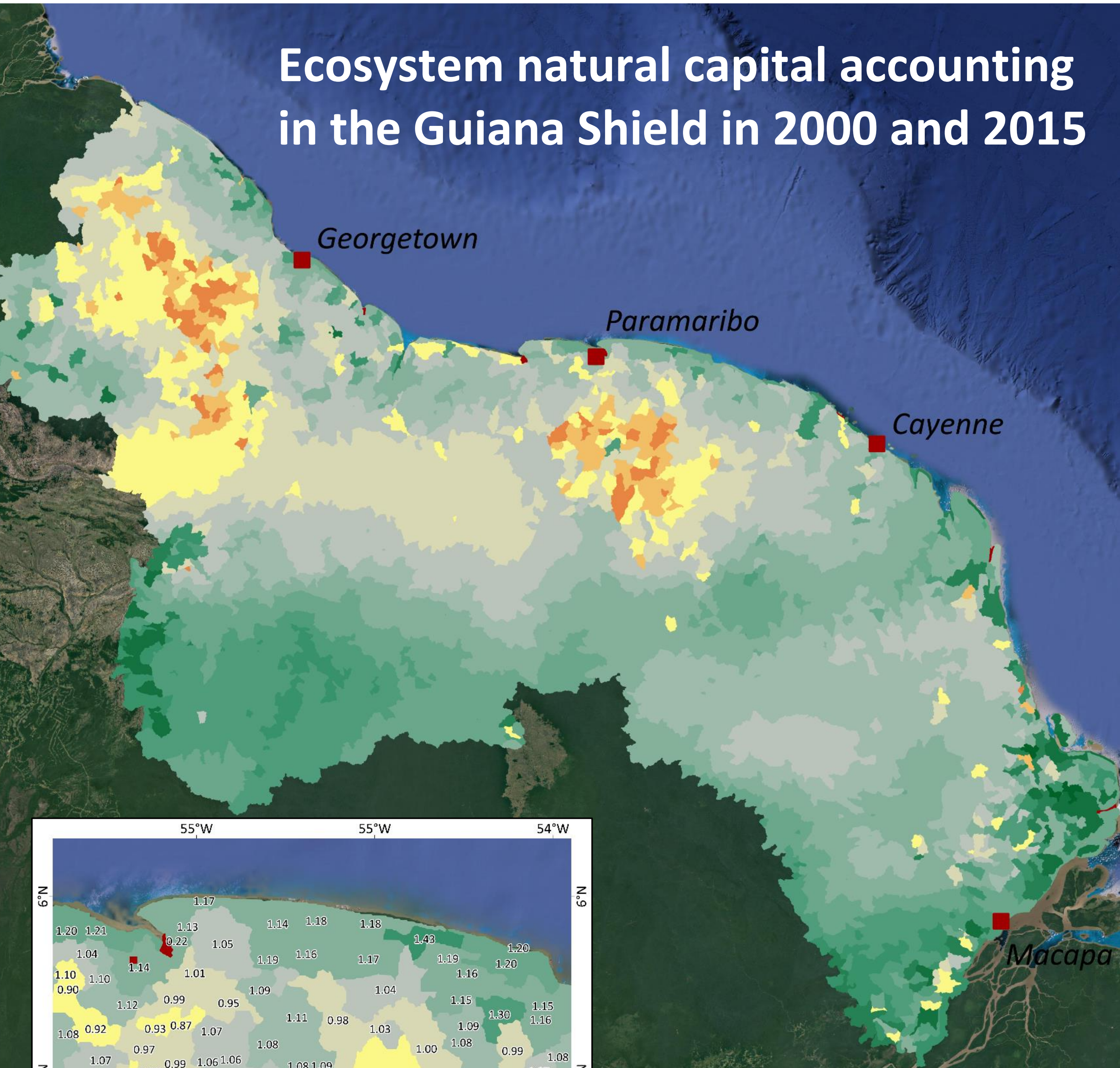
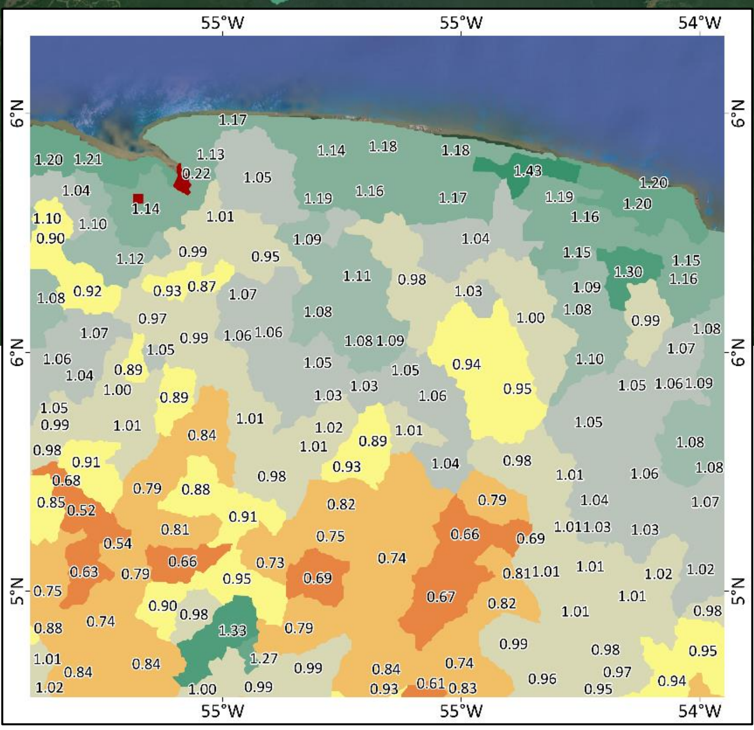
Ecosystem Services Observatory of the Guiana Shield

ECOSEO

Ecosystem natural capital accounting in the Guiana Shield in 2000 and 2015





APPLICATION OF THE QUICK START PACKAGE OF THE CONVENTION ON BIOLOGICAL DIVERSITY (CBD) FOR IMPLEMENTING AICHI BIODIVERSITY TARGET 2 ON INTEGRATION OF BIODIVERSITY VALUES IN NATIONAL ACCOUNTING SYSTEMS

ECOSEO – Ecosystem Services Observatory of the Guiana Shield

Preamble

This report has been carried out in the frame of the ECOSEO project - Ecosystem Services Observatory of the Guiana Shield.

ECOSEO is a transnational cooperation project between French Guiana, Suriname, Guyana and the state of Amapá in Brazil. Led by WWF France assisted by ONF International and WWF Guianas, the project is co-funded by the Interreg Amazon Cooperation Program of the European Union, the French Guiana Water office, and the project partners, namely: the National Forest Office (ONF) of French Guiana, the Foundation for Forest Management and Production Control (SBB) in Suriname, the Guyana Forestry Commission in Guyana, the Secretariat of the Environment (SEMA) in the State of Amapá and the University of Hannover (Germany).

The main objectives of ECOSEO are to highlight and promote the need for considering ecosystems values in decision-making and to build a transnational cooperation network to foster the sustainable development of the region.

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Executive summary

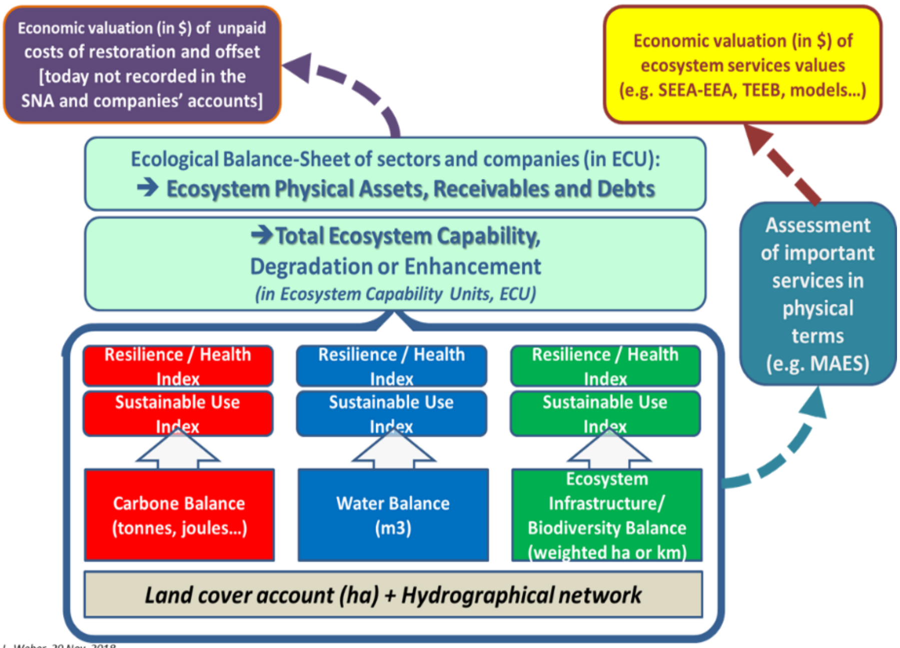
The Guiana Shield is in a privileged position in terms of natural resources as it is one of the few places left on Earth where development and conservation can proceed hand-in-hand – maintaining healthy ecosystems and advancing economically at the same time. Covering an area of 270 million hectares spread over six countries (Colombia, Venezuela, Brazil, Guyana, French Guiana (France) and Suriname), the Guiana Shield has an exceptionally rich natural capital. It includes a vast hydrographic network that, winding through forests and savannahs, represents as much as 10-15% of the world's fresh water reserves (FAO-AQUASTAT, 2010). The forest, almost omnipresent, is considered as one of the most intact in the world. Its biodiversity is spectacular, with a great wealth of species and high levels of endemism.

Nevertheless, this fragile ecosystem is increasingly threatened by the high population growth and the subsequent economic development needs. In addition to artificial and agriculture development, one of the main drivers of deforestation is mining activities that strongly affect the capacity of ecosystems to provide their goods and services essential to the well-being of human life. Considered as public goods, ecosystems benefits and services have long been, and still are, mostly undervalued. The natural capital of the Guiana Shield being still very rich compared to other parts of the world, there is an urgent need to recognize its true value at the local but also international level.

Countries involved in the ECOSEO project, namely Guyana, Suriname, French Guiana (France) and the state of Amapá (Brazil) are engaged to meet the Aïchi targets of the UN Convention on Biological Diversity (CBD). One of these targets is to include the natural capital in national accounting. However, reaching this target is still a long way off. The aim of ECOSEO is to address this topic through one of the first applications of the Ecosystem natural capital accounting (ENCA) experimental method in order to support countries in their commitments.

ENCA is an application of the UN System of Economic-Environmental Accounts – Ecosystem Accounting (SEEA-EA), recently adopted as an international statistical standard by the UN Statistical Commission. The Guidelines of the ENCA method have been published in 2014 by the CBD to support the implementation of natural capital accounting (Weber, 2014).

The method focuses on the measurement of an ecological value as opposed to monetary value, which is considered by the method as a second step that is not addressed here. The general approach combines the basic accounts of land use land cover (LULC) that constitute the common foundation on which the core accounts of Carbon, Water and Ecosystem Infrastructure functional services (including biodiversity) are then produced. Based on available data for each core account, the quantitative stocks balances is calculated, as well as an index of sustainable use of the resource and a health index. The quantitative and qualitative information given by sustainable use and health indexes are used to estimate a composite index called "internal unit value". The internal unit value of each core account are then averaged to estimate the ecological value, called ECU or Ecosystem capability unit. The values in ECU intend to estimate the "behaviour" and the resilience of systems. Once converted in ECU, the ecosystem capability of the three components (Carbon, Water and Ecosystem Infrastructure) can be added to estimate the Total Ecosystem Capability (TEC), which means the total capacity of ecosystem to deliver its services.



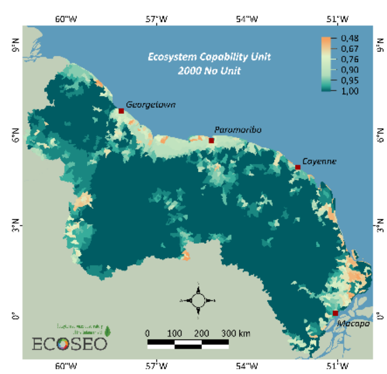
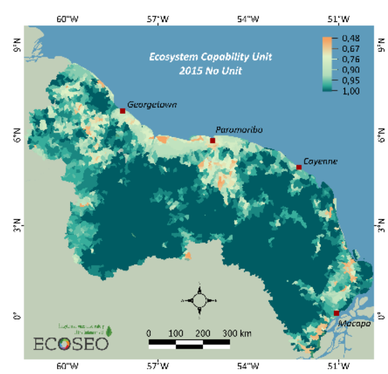
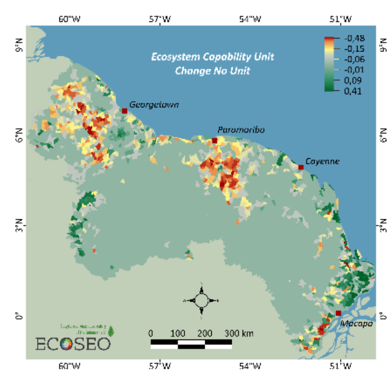
J.-L. Weber, 29 Nov. 2018

Overview of the Ecosystem Natural Capital Accounting (ENCA) framework

ENCA aiming to estimate the increase or loss of ecosystem capability, a monitoring of changes is necessary. Although ENCA recommends annual monitoring, this pilot study is limited to a monitoring on two dates. The years 2000 and 2015 were selected to reflect changes over a sufficiently long period, but also to take advantage of the maximum available data. As homogeneous information is required for all territories, input data come from global databases, except for LULC data that has been produced by the project partners with high confidence (Rahm et al., 2020a - see input data list here).

As the input data is of different sources and types (spatial resolution, geographic data, statistical data…), an ecosystem accounting unit or socioecological landscape unit (SELU) has been defined in order to compile this various information. The accounting results are thus provided at the scale of Hydroshed level 10 (HYBAS10) covering approximately 100 to 150 km2 (HydroBASINS database - Lehner, B. and Grill G., 2013), following the ENCA accounting data model (available here).

The cartographic results below illustrate the ecological value in ECU calculated for each Hydroshed or SELU for the years 2000, 2015 and changes. For each year, values below 1 show a quantitative or qualitative stress of resource.

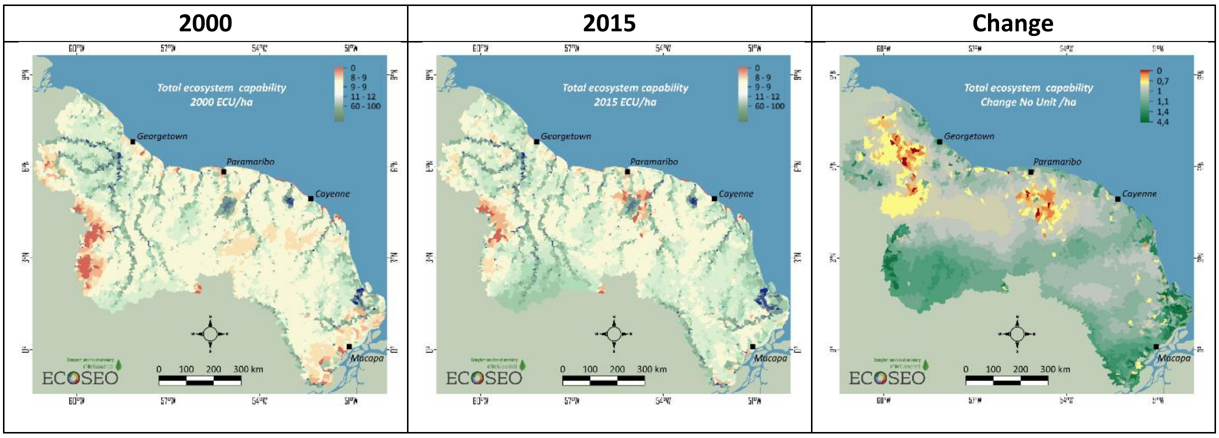
2000	2015	Change
		

Ecological value, in ECU (Ecosystem capability unit)

Most of the ECU losses represented by yellow, orange and red colours on the change map are mainly located in hotspot of gold mining activity, such as on the border between Suriname and French Guiana, as well as in northern Guyana. As the quantities of water are particularly abundant in the region, no stress regarding the use of this resource has been detected. Quantitatively, the losses are reflected more in the carbon and ecosystem infrastructure components linked to the loss of forest cover. In addition, the results reflect qualitative stress as well (i.e. linked to the health of ecosystems) that is also found for the water component, for which water pollution linked to mining activity has been estimated by remote sensing.

Losses in ECU value also occurred in the southeast of Amapá, linked to carbon losses from the combined effect of fires and erosion of soil organic carbon. In contrast, increases in the value of the ECU appeared between 2000 and 2015. These represented in dark green, located mainly in the southwest of Guyana and in the east of Amapá, come mostly from carbon gains following fires that occurred in 2000.

The resulting ECU values are then used to translate the net accessible potential of carbon, water and ecosystem infrastructure resources to the ecosystem capability. Once expressed in ECU, the ecosystem capability of the three components can be added to assess the Total ecosystem capability (TEC), i.e. the total capacity of the ecosystem to deliver its services.



Total Ecosystem Capability (TEC), in ECUs

As compared to the ECU map, the TEC change map shows a similar pattern but the changes seem less important in some areas. This is mainly due to the differences in precipitation regime between 2000 and 2015. In most places of the study area, precipitation in 2015 was 15% higher compared to the average of the last thirty years, whereas precipitation in 2000 was comparable to this average. Due to a monitoring based only on two dates, this difference has an impact on the results, especially on the accessible water potential but also on the accessible biomass potential (the Net primary productivity - NPP being influenced by precipitation).

The results of this study suggest that the region has so far succeeded in largely conserving the integrity of its ecosystems, which demonstrates its status of one of the most intact regions in the world. Almost the entire southern part of the region has ecosystem capability levels in 2015 that are comparable to 2000 (or even higher but this needs to be mitigated by exceptional climate events as mentioned above).

However, despite these positive results, it also shows that the capacity of the region's ecosystems to provide their provisioning, regulation and supporting services has decreased more or less intensively in some areas:

- Dark red indicates SELUs with 35 to 50% degradation of the Total ecosystem capability (TEC) between 2000 and 2015;
- Dark orange 25-35% degradation;
- Light orange 15-25%;
- Yellow 5-15%;
- Lightest green/yellowish less than 5%, which can be considered as stable areas given data uncertainties.

Degradation of the TEC or ECU is mostly related to gold mining and agriculture development that are the two first drivers of deforestation in the study area. This highlights the direct and indirect key role of forest ecosystems to human well-being, which was confirmed by Sieber et al. (2021) in the framework of the ECOSEO project. Following expert-based ecosystem services (ES) supply matrices at the border of French Guiana and Suriname, the study revealed that forest ecosystems have the highest ES capacities, followed by aquatic and marine ecosystems; whereas agricultural and urban land cover have weak to moderate capacities.

According to Bovolo et al. (2018), the loss of forest cover in the Guiana Shield could have disastrous consequences at both local and continental levels. Located at the start of two major ‘atmospheric rivers’ carrying moisture across South America (i.e. the Caribbean low-level Jet and the South American low-level jet (SALLJ) rivers), the forests of the Guiana shield should be considered as the guardians of South American climate. Regarding potential deforestation fronts, the study points to the main mining blocks in the region but also to the expansion of the Rupununi-Rio Branco savannah running through northern Brazil to southern Guyana. In comparison to the rest of the territory, the low total capability measured in 2000 and 2015 in this savannah found in southwest Guyana seems to confirm its vulnerable character and the need for frequent monitoring. The boundary with forest is abrupt and marks a general change in rainfall regime from a two wet season maritime climate over the coastal forests, to a continental climate with one wet season over the savannahs. In such mesic environments, savannah or ‘treeless states’ might represent stable alternatives to tropical forests (Hirota et al 2011, Staver et al 2011).

This study is the first application of the experimental method of Ecosystem natural capital accounting (ENCA) at such a large spatial scale, with such level of details. Beyond contributing to its demonstration and improvement, it provides a first assessment of the evolution of ecosystem capability in an integrated manner taking into account the different components of the ecosystem. Nevertheless, these first results have many limitations and should be read in the context of a pilot study for future improvement. Despite the use of detailed LULC data produced under the project, all other inputs come from global datasets, the accuracy of which may be limited at the local or even national level. An application on a finer scale from national or local data would permit to test and confirm the operational nature of the method to respond to a given problem, if the necessary input data are available and if validation / verification can be carried out.

In conclusion, it appears that today the territories in the region suffer from a lack of data to meet their international commitments to the Convention on Biological Diversity (CBD) on the subject of natural capital accounting (Aïchi Target 2). Indeed, a minimum of local data and information on the changes in time are necessary to account for the evolution of the state and capability of ecosystems with an enhanced level of confidence. The lack of data represented the main obstacle to the implementation of the method at the transnational level. Many data had to be extrapolated or cross-referenced to obtain the necessary information to account for this or that phenomenon.

As the method is flexible, it is possible to ignore those phenomena considering that it does not occur or to replace quantitative information with qualitative ones based on expert opinion. Anyway, in both cases, this has an impact on the level of detail and confidence of the results. The lack of data was revealed on the three accounting components of the analysis, i.e. on carbon and in particular on water and biodiversity. In connection with data acquisition, the results demonstrate also the need for more frequent monitoring as recommended by ENCA. The simple two-date comparison of the situation between 2000 and 2015 carried out in this study is not sufficient to establish a real trend over the fifteen years nor to mitigate exceptional climatic effects that could influence the results (e.g. precipitation of 15% above average in 2015). Therefore, to ensure the achievement of the objectives set by the international community with regard to natural capital accounting, it is above all essential to support countries in the production of relevant data for monitoring, as well as to build capacities on the implementation of the method. National ownership requires in-depth capacity building needs and the establishment of a pool of experts from different fields (biodiversity experts, hydrologists, foresters, statisticians, etc.).

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Acronyms

BII	Biodiversity Intactness Index
CBD	Convention on Biological Diversity
C_EC	Carbon Ecosystem Capability
CICES	Common International Classification of Ecosystem Services
CIUV	Ecosystem Carbon Internal Unit Value
DLT	Dominant Landscape Types
EAA	European Environment Agency
EAU	Ecosystem Accounting Unit
ECU	Ecosystem Capability Unit
EI_EC	Ecosystem Infrastructure Capability
EIIUV	Ecosystem Infrastructure Internal Ecological Unit Value
EIH	Ecosystem Infrastructure Health
EIUS	Ecosystem Infrastructure Use Sustainability
ENCA-QSP	Ecosystem Natural Capital Accounts - Quick Start Package
ENCA-QSP_FTI	ENCA-QSP Fast Track Implementation
ESA CCI	European Space Agency Climate Change Initiative
FAO	Food and Agriculture Organization
FCMU	Forest Cover Monitoring Unit
GBIF	Global Biodiversity Information Facility
GBLI	Green Background Landscape Index
GEO-BON	Group on Earth Observations Biodiversity Observation Network
GFC	Guyana Forestry Commission
HNVI	High nature value index
IBGE	Brazilian Institute of Geography and Statistics
IGNFI	Private Subsidiary of the French national geographic institute
INPE	Brazilian National Institute for Space Research
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre | European Commission
LBII	Local Biodiversity Intactness Index
LCEFU	Land Cover Ecosystem Functional Units
LCEU	Land Cover Ecosystem Unit (LCEU)
LCCS	Land Cover Classification System
LEAC	Land and Ecosystem Accounting
LULC	Land Use Land Cover
MMU	Minimum mapping unit

MRVS	Measurement, Reporting and Verification system
NEACS	Net ecosystem accessible carbon surplus
NEAWS	Net ecosystem accessible water surplus
NECB	Net ecosystem carbon balance
NEP	Net ecosystem production
NEWB	Net ecosystem water balance
NFMS	National Forest Monitoring System
NLEP	Net landscape ecosystem potential
NPP	Net primary production
NREP	Net river ecosystem potential
OAM	Observatory of mining activity (French Guiana)
ONF-French Guiana	National Forest Office of French Guiana
ONFI	ONF International
PRODES	Program for Monitoring Deforestation of the Amazon by Satellite
QA/QC	Quality assessment/ Quality control
RAWI	River Accessibility Weighted Index
REDD+	Reducing Emissions from Deforestation and forest Degradation, plus the sustainable management of forests, and the conservation and enhancement of forest carbon stocks
SBB	Forest Management and Production Control (Suriname)
SCU	Sustainable intensity of Carbon Use
SEEA-EEA	System of Environmental Economic Accounting - Experimental Ecosystem Accounts
SEEA-CF	System of Environmental Economic Accounting - Central Framework
SEEA-	W SEEA-Water
SELU	Socio-ecological landscape unit
SEMA	Secretariat of the Environment (State of Amapá)
SIWU	Sustainable Intensity of Water Use
SDG	Sustainable Development Goal
TEC	Total Ecosystem Capability
TEEB	The Economics of Ecosystems and Biodiversity
TEIP	Total ecosystem infrastructure Potential
UNFCCC	United Nations Framework Convention on Climate Change
W_EC	Water Ecosystem Capability
WIUV	Water ecological internal unit value
WWF	World Wide Fund for Nature

I | Introduction

The Guiana Shield, a region with exceptional natural capital that remains to be discovered

Covering an area of 270 million hectares spread over six countries (Colombia, Venezuela, Brazil, Guyana, French Guiana (France) and Suriname), the Guiana Shield has an exceptionally rich natural capital. It includes a vast hydrographic network that, winding through forests and savannahs, represents as much as 10-15% of the world's fresh water reserves (FAO-AQUASTAT, 2010). The forest, almost omnipresent, is considered as one of the most intact in the world. The biodiversity is spectacular, with a great wealth of species and high levels of endemism. Therefore, the Guiana Shield is in a truly privileged position in terms of natural resources, and it is one of the few places left on Earth where all options are still available, and where development and conservation can proceed hand-in-hand – maintaining healthy ecosystems and advancing economically at the same time.

The richness of these ecosystems and biological diversity provides the people of the region and all of humanity with very diverse benefits known as "ecosystem services" (Millennium Ecosystem Assessment, 2005). These include: **provisioning services** (e.g. food, fibre, fuel, water); **regulating services** (benefits obtained from ecosystem processes that regulate e.g. climate, floods, disease, waste and water quality); **cultural services** (e.g. recreation, aesthetic enjoyment, tourism, spiritual and ethical values); and **supporting services** necessary for the production of all other ecosystem services (e.g. soil formation, photosynthesis, nutrient cycling). These goods and services are essential to the sustainability of our well-being, as well as to future economic and social development. The Guiana Shield forest, for example, with an exceptional carbon stock estimated at 25 billion tons1, plays a crucial role in mitigating global climate change, in air purification and in the water regulation of watersheds of the region stretching from the Amazon to the Orinoco River. However, due to the size and richness of this territory as well as the lack of regional data, knowledge about ecosystems and their associated services remains limited.

A fragile ecosystem increasingly threatened

Difficult to access and sparsely populated, the region has been relatively spared so far by the hand of man and mass tourism. However, the population is growing rapidly and so are economic development needs. Biodiversity is not the only treasure of the Guiana Shield. Its subsoil is also home to reserves of gold, tungsten, coltan, aluminium and hydrocarbons. The legal (or sometimes illegal) extraction of these minerals has a significant environmental impact.

In addition to urban growth and the development of agriculture, mining activities reduce or destroy the capacity of ecosystems to provide their goods and services essential to the well-being of human life. They also affect the many populations living in the interior of the territory by damaging the natural resources and the habitats on which they depend.

An underestimation of the value of ecosystems in the decision-making process

Economic performance is one of the most important priorities of today's decision-makers. It is the main indicator of wealth and prosperity of countries. Unfortunately, the tools and frameworks used today to measure economic performance do not take into account critical components of wealth. This is particularly true for the huge economic value of ecosystems and the biological diversity that underpins them. The failure to account for the full economic values of ecosystems and biodiversity has been a significant factor in their continuing loss and degradation (GBO3, 2010; MA, 2005). The loss of natural ecosystem services already requires and will require more costly alternatives in the future. By investing and considering our natural capital in the decision-making process, we will achieve significant long-term savings (Union européenne, 2010).

Considered as public goods, ecosystems benefits and services have long been, and still are, mostly undervalued. The benefits and costs associated with their preservation and degradation have been largely excluded from the economic policies, markets and prices on which production, consumption, investment, land use and resources management practices are based. Many decisions have been made based on incomplete information, which undermines the achievement of sustainable and equitable development goals.

The natural capital of the Guiana Shield is still very rich compared to other parts of the world but there is an urgent need to recognize its true value at the local but also international level. This could help to avoid repeating the errors of the past and guide policies towards more sustainable development and prosperity for the generations of today and tomorrow.

Guiana Shield countries committed to integrating the value of ecosystems and biodiversity into the economic development process by 2020

Since the 2000s, the concept of ecosystem services has strengthened the importance of preserving natural resources and landscape units in political decision-making. In 2010, Parties to the Convention on Biological Diversity (CBD - composed among other of the countries of the Guiana Shield) adopted a revised and updated Strategic Plan for Biodiversity for the period 2011-2020. The plan includes a shared vision, mission, strategic goals and 20 ambitious but achievable objectives, called "Aichi Targets". The vision for the new plan is "Living in Harmony with Nature", where "By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people." In the shorter term and of particular interest is Goal A of the Strategic Plan for Biodiversity 2011-2020: " Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society" and (Aichi Target 2):" By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems." (CBD, 2020) This objective should be interpreted in the light of the CBD's adoption of an ecosystem approach, " a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way", recognizing that "humans, with their cultural diversity, are an integral component of many ecosystems." (CBD, 2010)

The other two Rio conventions, namely the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Convention to Combat Desertification (UNCCD), as well as the Sustainable Development Goals (SDGs) also recommend the adoption of an ecosystem approach. Indeed, through the introduction of the notion of "safeguards", the UNFCCC is committed to ensuring social co-benefits and biodiversity in the framework of the carbon reduction mechanism linked to deforestation and forest degradation (REDD+). The strategic objective of "land degradation neutrality – LDN" of the UNCCD is very close to the need to integrate the value of ecosystems and biodiversity into national decision-making and national accounts. The SDGs 15.9 has also recently confirmed this explicit requirement: “by 2020, integrate ecosystems and biodiversity values into national and local planning, development processes and poverty reduction strategies, and accounts", and it proposes the following indicator 55: “Country implements and reports on System of Environmental-Economic Accounting (SEEA) accounts”.

Knowledge, means and capacities still insufficient to meet international Conventions’ objectives

In view of the objectives set by the international Conventions, making progress now towards the concept of ecosystem services and the implementation of national accounts of ecosystems and biodiversity in their relationship to the economy and human well-being is therefore an urgent priority. Nevertheless, achieving these objectives represents a challenge for the region, which does not always have the necessary knowledge, means and capacities. Currently, the low level of knowledge of the value of ecosystems and their associated services is hampering their conservation interest. This gap and the lack of appropriate financial mechanisms have a direct impact on economic development decision-making, which is too heavily focused on resource extraction (mining and oil), which is often done at the expense of the physical or social environment.

In this context, the governments of the region, eager and committed to the international community to meet the objectives of the three Rio conventions and SDGs, can jointly benefit from support for more structured and systematic information to recognize, demonstrate and capture at best ecosystem values. The notions of recognizing, demonstrating and capturing ecosystem values refer here to the guidance documents of The Economics of Ecosystems and Biodiversity (TEEB) framed by the United Nations Environment Program (UNEP) (TEEB, 2010).

The ECOSEO transnational initiative does not aim at replacing each government's assessment of its natural capital. It offers a broader, more regionally integrated perspective for the critical valuation of the core of the Guiana shield, at its best biogeographical scale

II | Objectives & scope of the study

The main objective of this study is to deploy the concept of ecosystem accounting in the Guiana Shield with regard to the countries commitments to the CBD and other UN conventions. More specifically, the objective is to progress on the topic through the demonstration of the application of the experimental Ecosystem natural capital accounting Quick Start Package (ENCA-QSP) published by the CBD to support the implementation of the UN System of Economic-Environmental Accounts – Ecosystem Accounting (SEEA-EA). In March 2021, the SEEA-EA chapters on accounting in biophysical terms have been adopted as an "international statistical standard" by the UN Statistical Commission. ENCA-QSP proposes a package of operational methodologies and accounting tables for implementing the SEEA-EA. Figure 1 shows the extent of the study area that covers from east to west: the state of Amapá in Brazil, the French Overseas Department of French Guiana and the countries of Suriname and Guyana.

Given the low availability of homogeneous data at the regional level, the application of ENCA in the framework of this study is mainly based on the use of existing global data. Therefore, it is important to consider the bias that these data can induce when reading and analysing the results. The goal here is not to provide precise results on a fine scale (small watersheds, municipality, etc.) but to show the significant contribution to natural capital this region provides locally and globally, through a first gross estimate of the evolution of the state of ecosystems on a regional scale. Therefore, the aim is to highlight the major trends in the "total ecosystem capability" (TEC), i.e. the total and sustainable capacity of ecosystems to provide their services. The assessment is carried out by natural capital main components (carbon, water and ecosystem infrastructure) and includes natural processes and human impacts. Measuring and mapping change in TEC provides information of ecosystem degradation, stability or enhancement and allows comparisons with aggregates of economic growth such as GDP. Accounts of uses, which include harvests and abstraction of resource, allow identifying drivers of change and their magnitude and can support sector policies. Being produced from spatial data and statistics, ecosystem accounts map regions and areas where processes take place and issues happen, which is important for efficient land use planning.

The objective of this technical report is to recall the main stages of the ENCA methodology and to present the results of the regional analysis in the form of accounting tables but also and above all in a cartographic manner, in order to facilitate their visualization and analysis, and confirm the importance of the region in terms of natural capital.

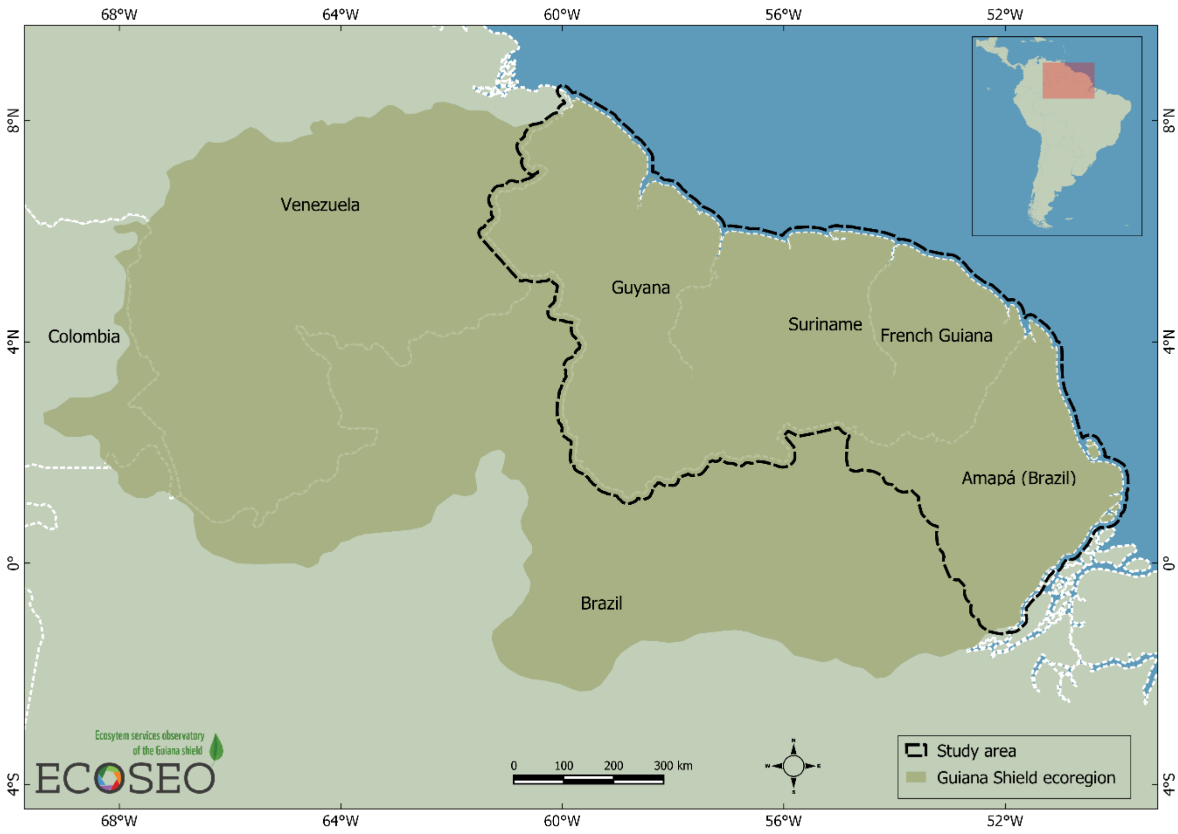


Figure 1 : Study area for the production of ecosystem natural capital accounts (ENCA)

III | ENCA general methodology

Not all data, economic or else are recorded in accounting books or expressed as accounting results but important decisions are based on accounts. Presenting ecosystem information in a format compatible to corporate and national accounting frameworks is a way to make it more operational, more imperative, prone at supporting existing and novel policies and mechanisms. To meet the data format and the agenda of decision-making, accounts should give importance to assess original capital and change description.

The method that has been tested to meet the aforementioned objectives in the frame of the ECOSEO project is the Ecosystem Natural Capital Accounting (ENCA) framework. ENCA is an application of the UN System of Environmental Economic Accounting on Experimental Ecosystem Accounts (SEEA/EEA). Methodology guidelines have been published in 2014 by the Secretariat of the Convention on Biological Diversity (CBD) (Weber, 2014), with the purpose of supporting the implementation of ecosystem accounts in relation to the CBD Aichi Targets by 2020.

The purpose of ENCA is to supplement the conventional accounts used by private and public organisations with information on the impacts on the ecosystems of their decisions and activities. The goal is to make them integrate into their information systems their accountability to ecosystem use when it results in losses of capabilities. Capability should be understood as the sustainable capacity of ecosystems to deliver services. Capability refers to the productivity and resilience of the systems themselves, hence to their aptitude at delivering in future services, presently identified utilities or other opportunities. Therefore, the value recorded in ENCA is an ecological value, which is different from the monetary value resulting from market transactions. ENCA's assessment of ecological value and ecosystem capability is done for all types of ecosystems considered as socio-ecological systems. It includes pristine forests, wetlands and other natural as well as modified and artificial systems (agriculture and urban systems). Both market and ecological values are social constructs but while the former measure utilities, the latter aim at assessing intrinsic ecosystem dimension.

The ENCA Quick start package (ENCA-QSP) published by the CBD aims at measuring the biophysical value of ecosystems in order to assess their degradation, stability or enhancement. To carry out this analysis, the general approach combines the basic accounts of land use land cover (LULC), which constitute the common foundation on which the core accounts of Carbon, Water and Ecosystem Infrastructure functional services (of land and rivers) including biodiversity are then produced. Each core account is composed of quantitative stocks balances and indexes of sustainability and health. Sustainability and health indexes integrate quantitative stress from resource use and qualitative diagnoses based on pollution and health assessment. Then, the indexes of the three components core accounts (Carbon, Water and Ecosystem Infrastructure) are combined into a composite index of ecological value called ECU (Ecosystem Capability Unit). Measurements of stocks and changes in ECU can be added up to calculate the Total Ecosystem Capability (TEC) (Figure 2).

The method applies to any kind of socio-ecological system and TEC can be added up by regions, countries, river basins… allowing comparisons in space and trends assessment, first of all of ecosystem degradation. Aggregated at the territorial level, TEC can be compared to the GDP, at least in terms of trends. Detailed at the company level, it is a way of incorporating externalities in their books and ultimately adding ecosystem natural capital to present recording of capital depreciation. Even if monetary valuation is not part of the current study, ENCA does not exclude it but consider it for a second step, after the completion of the QSP in biophysical terms. ENCA foresees monetary accounts in two areas: 1) the calculation of the costs needed for avoiding or repairing ecosystem degradation and 2) the valuation of specific ecosystem services in the context of trade-offs and cost benefit analysis.

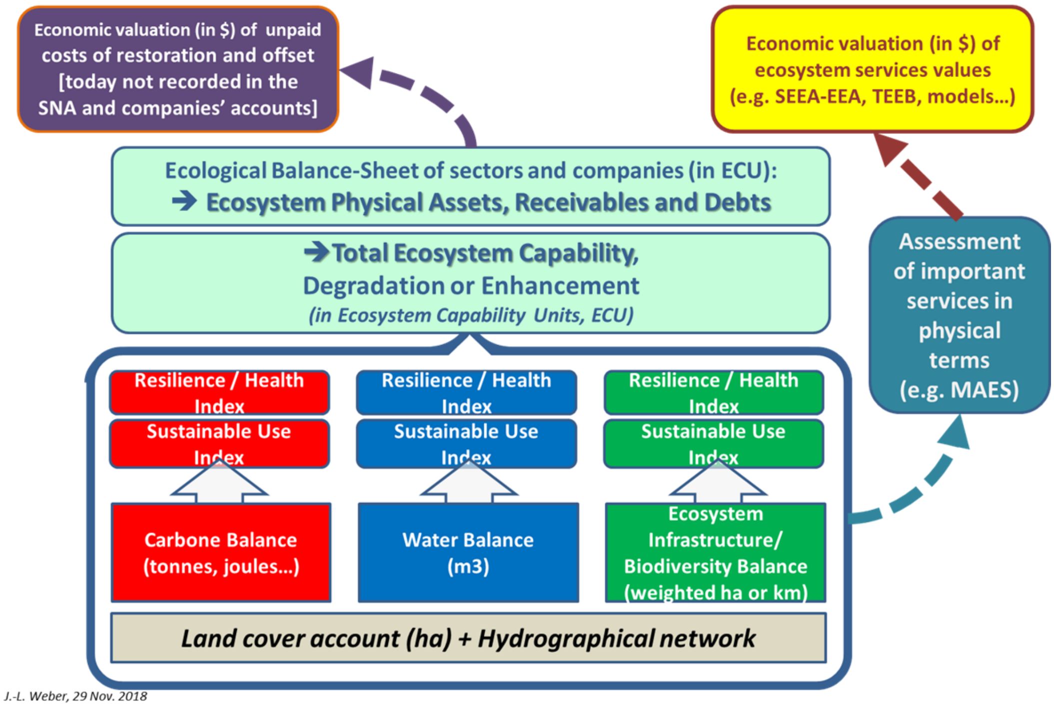


Figure 2 : Overview of the Ecosystem Natural Capital Accounting (ENCA) framework

IV | ENCA application in ECOSEO

IV.1 General approach & technical considerations

The guiding principle of ENCA-QSP is to use the best available data. The ENCA data model provides a precise guidance to integrating various types of data and the integrated framework leads to crosschecks for coming to a consistent result. ENCA being relevant at any scale, possible usable datasets are numerous, from satellite images and derived data (e.g. land cover, net primary production (NPP)…) to socio-economic statistics, administrative data (e.g. on water withdrawals), modelled data sets (e.g. on soils), various surveys and monitoring data. Because not all desirable data are easily available or even exist at a detailed scale, the process of implementing ENCA must be phased out and adapted to the needs and possibilities.

Like the Intergovernmental Panel on Climate Change (IPCC) guidelines to UNFCCC reporting, ENCA proposes a tiered approach to define the level of details or accuracy of the data used to build the results. Three levels of detail exist, from Tier 1... to Tier 3 (the most detailed approach). The Tier 1 or ENCA-QSP Fast Track Implementation (ENCA-QSP_FTI) approach relies mostly on global datasets, which are accessible from international databases; Tier 2 uses country specific data; Tier 3 is more complex using local data and possibly models.

In ECOSEO, the study being a pilot at the transnational level, the Tier 1 or ENCA-QSP_FTI approach is applied. However, as the ENCA data model can assimilate data with various properties, ENCA-QSP_FTI can itself be subdivided into a basic version (Fast Track Implementation - FTI 1) and an enhanced one (Fast Track Implementation - FTI 2) such as in ECOSEO where national data starts being used in addition to global data. Therefore, **results should be read with care given the variety of data integrated in the accounting process, their respective accuracy and relevance, as well as the adjustments done for their assimilation into the 1-hectare grid used for data processing.** Although as many datasets as possible were resampled into the 1 ha grid, not all results are pixel-scale relevant. The purpose of ENCA is to measure Total Ecosystem Capability and its components (Carbon Ecosystem Capability, Water Ecosystem Capability and Ecosystem Infrastructure Capability) by accounting units defined as socio-ecological landscape units (SELU). SELUs used for FTI accounts at the regional scale are based on river basins of hydrological level 10, with an average area of circa 150 square kilometres. Quantitative and qualitative indexes are designed to be relevant at this level.

The objective of ENCA being to show the evolution in time of ecosystem capability, i.e. the capacity of ecosystems to provide their services, an assessment at two dates is the strict minimum required in order to carry out a change analysis. **In ECOSEO, the analysis was carried out at two dates over a fifteen years period: in 2000 and 2015.**The selection of these two dates is based on the availability of data within international databases, as well as to coincide with the first regional LULC change map produced in parallel as part of this project.

However, **trends analysis from the comparison of data at two dates should be handled very carefully. Three points in time is better and annual series an objective to reach.** Indeed, observed change at two dates only may result of actual trends or can be the combined result of trends and seasonal or annual fluctuations, the whole combined with the uncertainties due to data accuracy. Some important data can be affected by annual fluctuations related to the meteorology such as the Net Primary Production of biomass or evapotranspiration for example. **In our case, significant rainfall fluctuations happened between 2000 and 2015** (2000 rainfall is the 30 years average while 2015 is 15% higher for most of the region). This fluctuation is the more serious in the particular case of the Guiana Shield where water is a very important part of the ecosystem potential.

Therefore, this two-date analysis of ecosystem change between 2000 and 2015 has to be considered in the context of a pilot project or demonstrator.

The following sections illustrate the application of the ENCA-QSP_FTI method in ECOSEO, through the input data used and output results. It focus on the production of the LULC basic accounts and the core accounts (Carbon, Water and Ecosystem infrastructure) to estimate in fine the Total Ecosystem Capability (TEC) (see Figure 2)**.** The method includes the following main steps:

1. Create the database and data structure needed for accounting (data assimilation scale and accounting units)
2. Collect the basic datasets (monitoring data and statistics)
3. Produce the basic LULC accounts
4. Produce the core accounts (Carbon, Water and Ecosystem infrastructure)
5. Measure the Total Ecosystem Capability (TEC)

IV.2 Data structure & collection

This section gathers the two first steps of the method: the definition of the data structure and the collection of datasets that will feed the Accounting database.

IV.2.1 Data structure

The aim of this first step is to collect reference geographical datasets to create the database of statistical units. Statistical units for ecosystem accounting is defined as spatial units.

ENCA distinguishes two spatial units for data analysis and integration:

1. The Basic Spatial Unit (BSU), which is the common spatial unit or resolution used to resample all geographical data in order to be compared or crossed (data assimilation)

2. The Ecosystem Accounting Unit (EAU), which is the spatial unit used to produce the accounts and to extract information from statistical data.

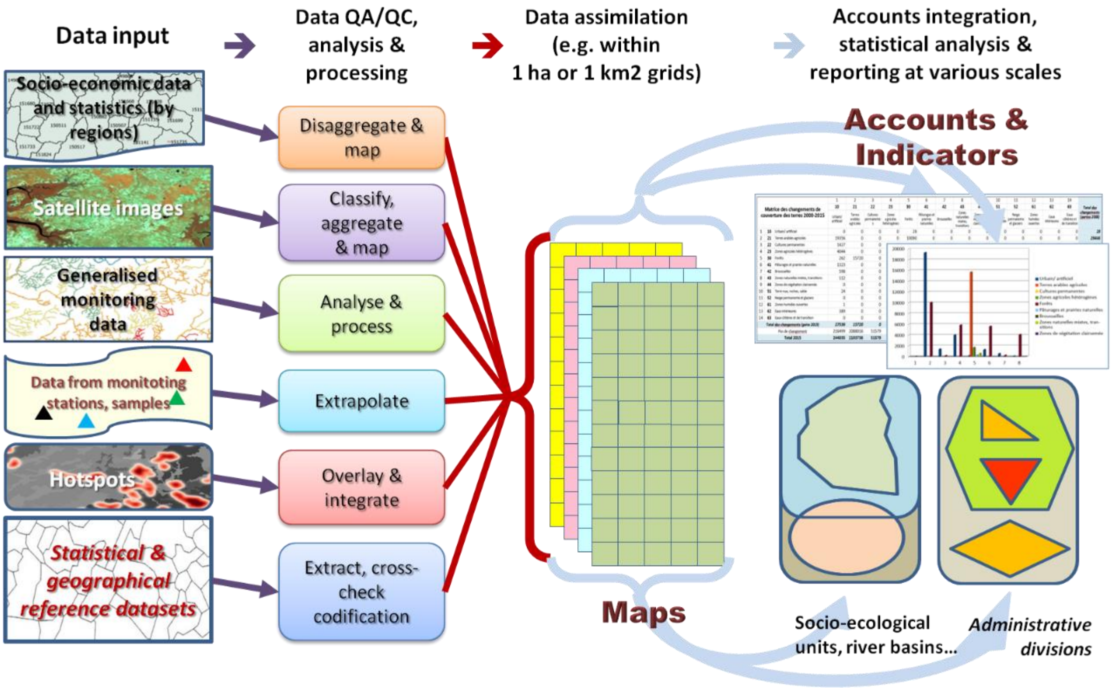


Figure 3 : The ENCA-QSP data structure : Assimilation & data integration of statistics and geodata

IV.2.1.1 Basic spatial unit (BSU)

Datasets collected to produce the accounts have different spatial resolutions, ranging from high/medium resolution (10-30m) to low resolution (250m-1km). The basic spatial unit is used to translate all different datasets in a common spatial unit or resolution. This spatial resolution is specific to each project depending on the scale of analysis but also on the resolution of input data.

In ECOSEO, given the large area of the study site and the wide variety of data resolutions, 1ha (100m x 100m) has been selected as basic spatial unit or resolution. This is a compromise between the resolution of the input data in order to preserve the information contained in the most resolved data and the size of the study area. As a result, this means that all geographical input data are systematically resampled to pixels of 100m x 100m.

IV.2.1.2 Ecosystem accounting unit (EAU)

Given the wide variety of level of detail provided by input data, a pixel-scale analysis would not be relevant for reporting the accounts, especially since it is sometimes necessary to cross-reference the input data with statistical data to extract additional information. Therefore, the production of the accounts is done at the object level, which gathers pixels information and is defined by the Ecosystem accounting unit (EAU).

As for the Basic spatial unit (BSU), the definition of the Ecosystem accounting unit is depending on the objectives of the study and its spatial extent. EAU can be based for example on: administrative layers (e.g. municipalities, regions…), landscape management units (e.g. natural parks), rather homogeneous ecosystem provisioning service units (e.g. biocarbon and land-cover ecosystem units), socio-ecological systems (e.g. socio-ecological landscape units (SELU)) or basic topographic areas (e.g. river sub-basins).

Different levels of EAU can also be defined in order to compare the results at different aggregated levels (e.g., level 1 can be the watersheds, level 2: municipality level, level 3: regional or national level…).

In ECOSEO, given the objective of the study, Ecosystem accounting unit (EAU) has been defined on Socio-ecological landscape unit (SELU), such as recommended by ENCA_QSP_FTI. Socio-ecological landscape units are the intersection of a Dominant Landscape Types (DLT) and watershed limits. In Europe, where the landscapes are very fragmented, priority is given to DLT. For the Guiana Shield, the large masses of apparently homogeneous forest lead to giving priority to the limits of watersheds, which are then characterized according to their DLT.

Therefore, Figure 4 shows the Ecosystem accounting units (EAUs) or SELUs selected in ECOSEO, which are based on the Hydroshed level 10 (HYBAS10) extracted from the HydroBASINS database (Lehner, B. and Grill G., 2013). HydroBASINS is a series of polygon layers that depict watershed boundaries and sub-basin delineations at a global scale. The goal of this product is to provide a seamless global coverage of consistently sized and hierarchically nested sub-basins at different scales (from tens to millions of square kilometres), supported by a coding scheme that allows for analysis of watershed topology such as up- and downstream connectivity. It follows the Pfafstetter concept[1] and provides levels 1 to 12 globally (12 being the most detailed information).

HYBAS10 is a compromise that has been adopted after tests with HYBAS12 (some additional smaller units but no clear value added) and HYBAS8 (a bit large and too many border effects). HYBAS10 have an average area of 100 to 150 km^2, fit for the ENCA-QSP_FTI diagnosis.

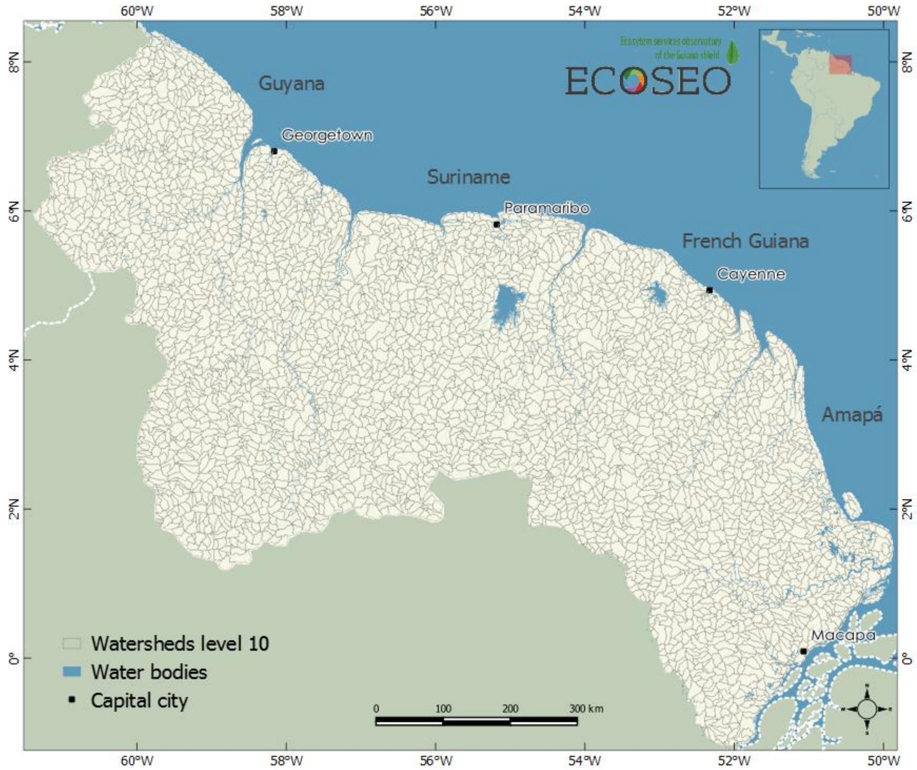


Figure 4 : ECOSEO's Ecosystem accounting units (EAUs) or SELUs, corresponding to HydroBASINS watersheds of level 10
(HYBAS10 - Source: HydroBASINS - here used as Ecosystem accounting units https://www.hydrosheds.org/page/hydrobasins)

[1] A detailed description of the Pfafstetter coding is provided in literature (e.g., Verdin and Verdin 1999)

IV.2.2 Datasets collection

The inventory of existing data in the region is the preliminary step to the production of experimental ecosystem accounts. Ecosystem accounts can be produced from existing global data but their accuracy depends on the quantity, quality and accuracy of available input data. However, attention is not only on the data as such, but on the capacity of the data to match the requirements of the accounts. Accurate, quality-assessed and controlled data will make better accounts, without losing sight of their relevance to the accounting framework.

The start of the ECOSEO project therefore focused on data identification and collection. The process took place in three stages:

1. Regional and national data identification through a stakeholder's survey. The project partners conducted surveys in each territory. The purpose of the survey was to identify the main relevant initiatives related to the valuation of ecosystem services and ecosystem accounting that have taken place in the region in recent years. In this survey, stakeholders were asked about the type of data produced and their level of access.

2. Regional and national data collection through a specific workshop organized with project partners during the second regional meeting of ECOSEO in Paramaribo, July 2019. In order to guide and structure the data collection process, a list of priority data for the production of ecosystem accounts was drawn up, accompanied by an Excel spreadsheet designed to provide as much information as possible on these data. The top 10-priority list gathered Background data (administrative layers, settlements, roads, protected areas, mining concessions…), Land use/land cover and change data, Water data (hydrological network, river catchments), Green infrastructure (agriculture statistics, population census data) and Bio-carbon data (forestry statistics, logging production and volumes, biomass data). The top 20-priority list completed the top 10 list with data such as national meteorological data, water flows & water pollution, vulnerability of natural habitats, biodiversity, waste disposal, fisheries statistics and environmental data on population.

3. Global data collection through a literature review and the consultation of online databases. The process started from the default datasets indicated in the ENCA-QSP manual for each individual accounting item. Because of fast development of data since 2014 when the manual was published, an update had to be done to identify the best available data at the time of making the accounts in the Guiana Shield.

At the end of this collection process, it emerged that many data were lacking even if most of the top 10-priority data list were in principle available in the different territories. However, these data were also very heterogeneous regarding the acquisition date, coverage, consistency and content, which limited their operational use for a regional analysis. The access or availability of homogeneous regional data fit for the production of accounts was restricted to regional products on land cover and gold mining (Rahm et al., 2020a; Rahm et al., 2017).

As a result, in ECOSEO, except for the LULC change map including data on gold mining that is a true creation of the project, input data are coming from various global databases. The full list of input data selected and used to produce the ecosystem accounts are available in Excel table format (see table here)**. It is important to stress that all of these datasets are common to the four territories but have limitations because most of it are computed at the global scale and often independently from each other.**

The ENCA-QSP_FTI data model in spreadsheet format (available here), which provides a detailed and synthetic view of the successive stages to compute the accounts, shows the large amount of information that can be integrated in ENCA. However, not all data is required to produce ecosystem accounts. Depending on the objectives of the study, the accounts can be produced in a simplified way from a reduced selection of data or in more detail, integrating a larger amount of input data in an attempt to provide a more complete picture of the impacts on ecosystems. To best illustrate the potential of the ENCA method and try to capture as many phenomena as possible, the objective here was to integrate as much input data as possible. Therefore, in several cases, additional information were produced from the spatial analysis or modelling of input data. Although the results of these analyses contain uncertainties locally, they should provide valuable information on a regional basis, allowing further analysis.

IV.3Basic land use land cover (LULC) accounts

The basic accounts of land use land cover (LULC) constitute the common foundation on which the core accounts of Carbon, Water and Ecosystem Infrastructure functional services (of land and rivers) including biodiversity are then produced.

In accounting terms, the stocks of LULC for 2000 and 2015 correspond to the area covered by each LULC classes in 2000 and 2015. The flows of LULC are consumption and formation, corresponding to the area covered by LULC changes between 2000 and 2015. Flows can generally be related to anthropogenic activities, but in some cases uncertainties result from the fact that change results from a combination of many causes, natural and human; a special category is necessary for these. Figure 5 shows an example of the LULC flows on the forest tree cover.

The LULC map having 13 different classes, the combinations of change are numerous and are thus translated into a limited number of classes reflecting the processes such as artificial development, agriculture extension, internal conversions, managements and alteration of forested land, restoration of natural habitats... (see Figure 5).

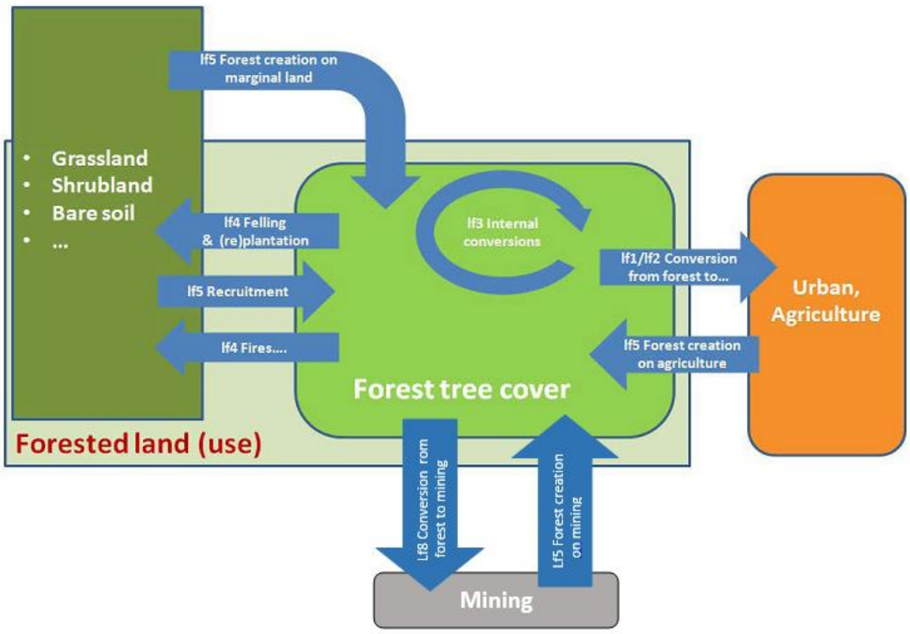


Figure 5 : LULC flows on forest tree cover

As mentioned above, LULC maps were produced as part of ECOSEO to build the most accurate basic accounts possible, since they form the building block of ecosystem accounts. The aim was to replace the global LULC products that lack most of the LULC changes in the region, which are mainly occurring at fine scale. This is particularly the case with gold mining activities for example, which are barely detected by global products despite being one of the main drivers of LULC change in the region. The ECOSEO LULC products are briefly presented below, as they are fully described in Rahm et al. (2020a).

The first step of the production was to define a common classification of LULC types following the guidelines of ENCA-QSP, which recommend a subdivision based on the Land-cover ecosystem functional units (LCEFU) classification (Weber, 2014 – see Annex VIII.1). Based on the LCEFU classification and the information contained in national data, the classification shown in Figure 6 has been commonly adopted to map LULC. The classification is subdivided in two levels of details and level 2 is the one selected to map the study area.

Class level 1	*Class level 2*	*Label*
1	**Artificial surfaces (including urban and associated area)**	
	11	*Infrastructure*
	12	*Settlements*
	13	*Mineral extraction sites*
2	**Cropland**	
	21	*Herbaceous crops*
	22	*Woody crops*
	23	*Shifting cultivation*
3	**Grassland**	
	30	*Grassland*
4	**Forest Tree cover**	
	41	*Forest tree cover*
	42	*Mangroves*
5	**Shrubland, bushland, heathland**	
	50	*Shrubland, bushland, heathland*
6	**Barren land**	
	60	*Barren land*
7	**Wetland**	
	71	*Open wetlands*
	72	*Inland water bodies*
	73	*Coastal water bodies, lagoons, estuaries*
	74	*Intertidal zones*

Figure 6 : ECOSEO LULC classification

Based on this LULC classification and ENCA-QSP recommendations, the following computation matrix of LULC flows has been adopted in ECOSEO (Figure 7). More details about these flows are reported in Annex VIII.2.

Year T0 \ Year T1		Infrastructure	Settlements	Mineral extraction sites	Herbaceous crops	Woody crops	Shifting cultivation	Grassland	Forest tree cover	Mangroves	Shrubland, bushland, heathland	Barren land	Open wetlands	Inland water bodies	Coastal water bodies, lagoons, estuaries	Intertidal zones
		11	12	13	21	22	23	30	41	42	50	60	71	72	73	74
Infrastructure	11	lf0	lf3	lf3	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf6	lf6
Settlements	12	lf3	lf0	lf3	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf6	lf6
Mineral extraction sites	13	lf3	lf3	lf0	lf7	lf7	lf7	lf5	lf5	lf7	lf5	lf6	lf6	lf7	lf6	lf6
Herbaceous crops	21	lf1	lf1	lf8	lf0	lf3	lf3	lf5	lf5	lf5	lf5	lf6	lf6	lf6	lf6	lf6
Woody crops	22	lf1	lf1	lf8	lf3	lf0	lf3	lf5	lf5	lf5	lf5	lf6	lf6	lf6	lf6	lf6
Shifting cultivation	23	lf1	lf1	lf8	lf3	lf3	lf0	lf5	lf5	lf5	lf5	lf6	lf6	lf6	lf6	lf6
Grassland	30	lf1	lf1	lf8	lf2	lf2	lf2	lf0	lf5	lf5	lf6	lf6	lf6	lf6	lf6	lf6
Forest tree cover	41	lf1	lf1	lf8	lf2	lf2	lf2	lf6	lf0	lf3	lf4	lf4	lf7	lf6	lf6	lf6
Mangroves	42	lf1	lf1	lf8	lf2	lf2	lf2	lf6	lf3	lf0	lf7	lf6	lf6	lf7	lf6	lf6
Shrubland, bushland, heathland	50	lf1	lf1	lf8	lf2	lf2	lf2	lf6	lf5	lf5	lf0	lf6	lf6	lf6	lf6	lf6
Barren land	60	lf1	lf1	lf8	lf2	lf2	lf2	lf6	lf5	lf5	lf6	lf0	lf6	lf6	lf6	lf6
Open wetlands	71	lf1	lf1	lf8	lf2	lf2	lf2	lf6	lf7	lf7	lf6	lf6	lf0	lf3	lf3	lf3
Inland water bodies	72	lf1	lf1	lf8	lf2	lf2	lf2	lf6	lf7	lf7	lf6	lf6	lf3	lf0	lf7	lf7
Coastal water bodies, lagoons, es	73	lf1	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf0	lf7
Intertidal zones	74	lf1	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf7	lf0

lf1	Artificial development
lf2	Agriculture development
lf3	Internal conversions, rotations
lf4	Management and alteration of forested land
lf5	Restoration and development of habitats
lf6	Changes of land-cover due to natural and multiple causes
Lf7	Other land cover changes n.e.c. and reclassification
Lf8	Mining development
lf0	No observed land-cover change

Figure 7: ECOSEO LULC flows

In the Guianas (Guyana, Suriname and French Guiana), LULC information was produced by the project partners at 30m resolution based on the use of high to medium satellite imagery (Rahm et al., 2020a). In Amapá, LULC information was extracted from the SEEA version of the LULC map produced by the Brazilian Institute of Geography and Statistics (IBGE) based on MODIS data (250m), complemented by gold mining data from Rahm et al. (2020b) and mangroves data from Global Mangroves Watch (GMW – Bunting et al., 2018). In the end, all products were resampled at 100m resolution (1ha grid) to fit with the accounting used for ECOSEO (see section IV.2.1.1). The following figures illustrate the mapping results of LULC 2000, LULC 2015 and LULC flows between 2000 and 2015.

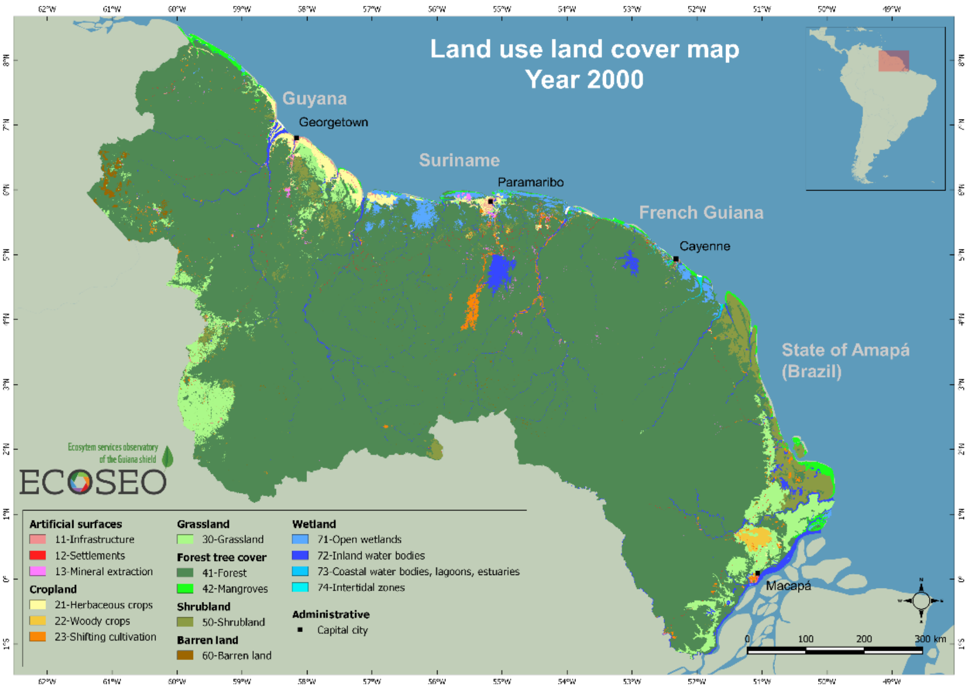


Figure 8 : LULC map of ECOSEO's study area in 2000 at 100m resolution

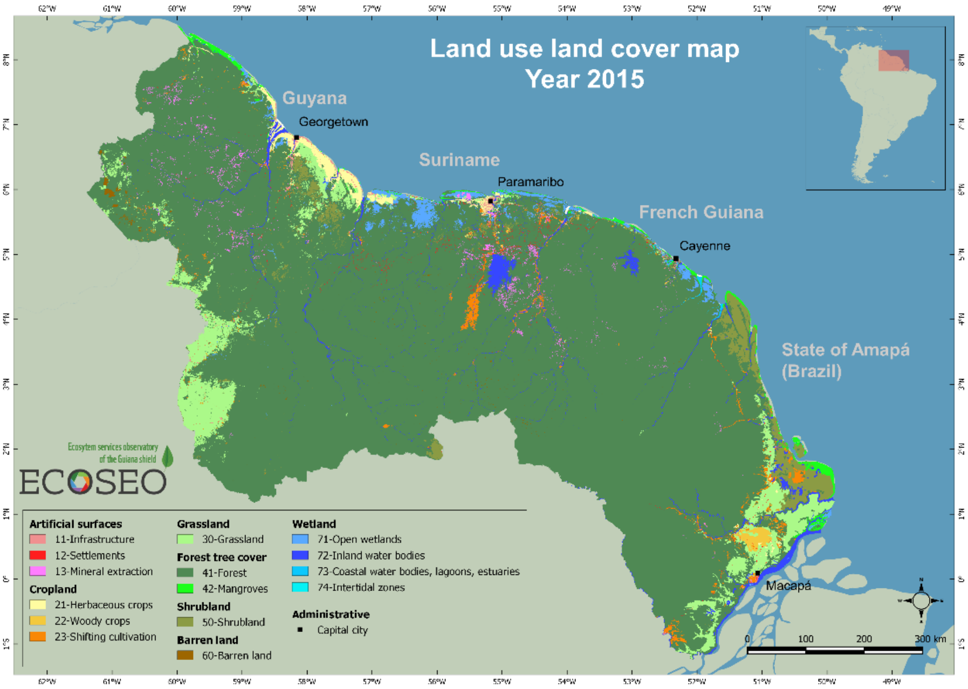


Figure 9 : LULC map of ECOSEO's study area in 2015 at 100m resolution

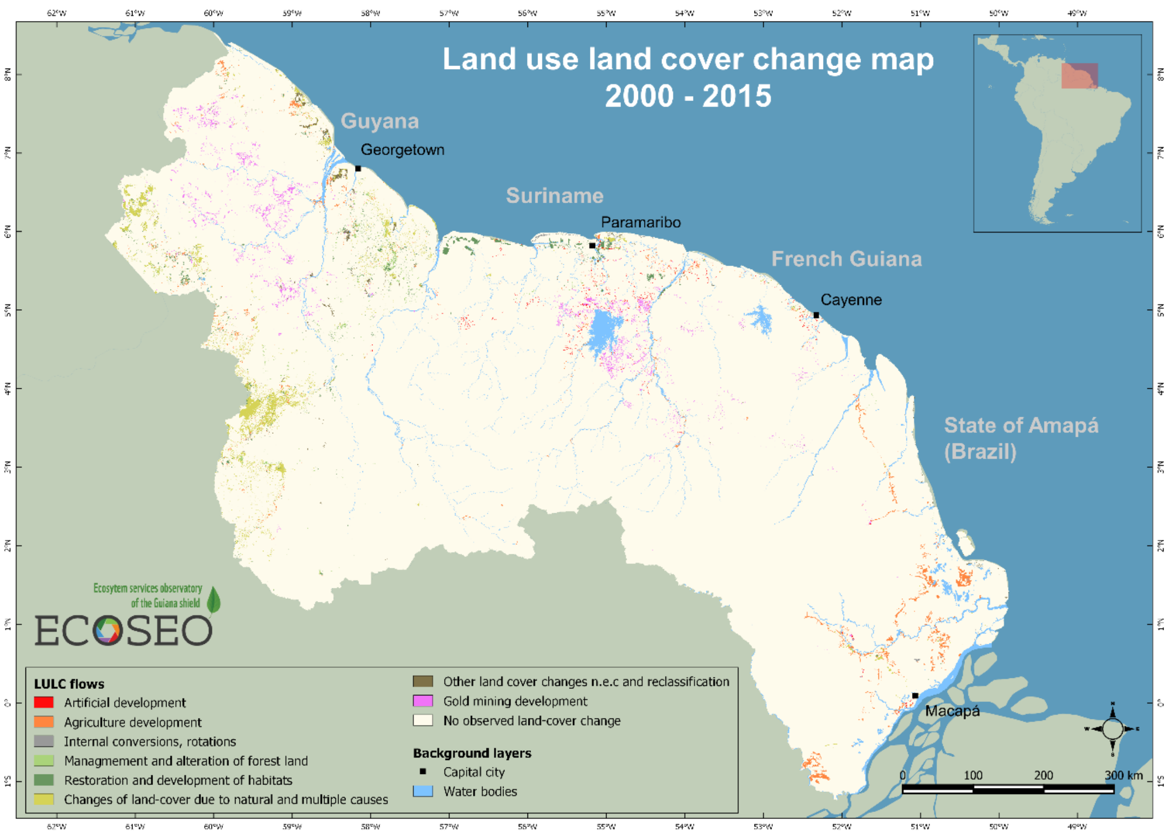


Figure 10 : Map of LULC change flows in ECOSEO's study area between 2000 and 2015 at 100m resolution

Figure 11 shows that the two most important drivers of change in the region are agricultural development followed by mining, which often consumes the forest. Agricultural development is the primary cause of deforestation in French Guiana and Amapá, while in Suriname and Guyana mining is the primary driver. The third cause of LULC change, ahead of artificial development (infrastructure and settlements) in terms of land cover, is habitat restoration. Essentially concentrated in Suriname (~70%) where it is the primary cause of land conversion in the country, it results mainly from the conversion of old agricultural land into fallow areas (Rahm et al., 2020a).

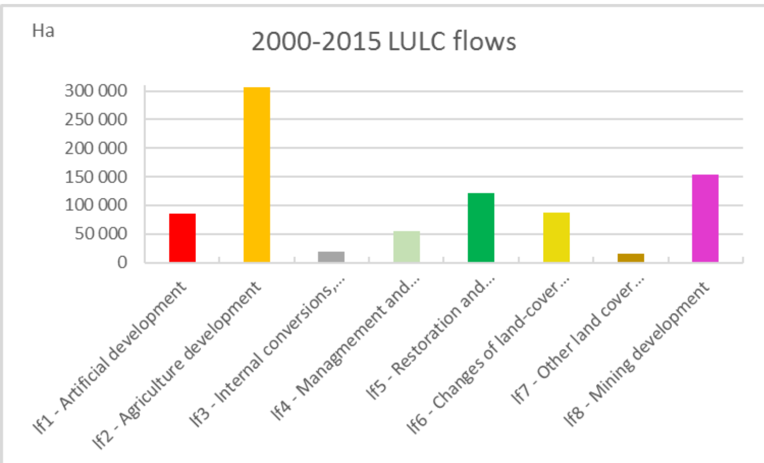


Figure 11 : Area covered by the different LULC flows between 2000 and 2015 in ECOSEO's study area

IV.4 Core accounts

ENCA-QSP subdivides the core accounts into three categories: Carbon, Water and Ecosystem Infrastructure functional services (of land and rivers) including biodiversity. Each core account is built following similar steps and general accounting structure, which is made up of four different accounting tables (Figure 12).

The first three tables present the quantitative balance of resources (Step 1). Table I reports the Basic balance of stocks and flows of the resource; Table II estimates the surplus / potential of accessible resource; Table III reports the total use or consumption of the resource. From this quantitative assessment, Table IV then compiles a quantitative index of sustainable intensity of use of the resource, supplemented by a qualitative index of ecosystem health (Step 2). These two indexes are eventually averaged to obtain the Ecological internal unit value of the resource, which provides an indication of the state of the resource based on its use and the ecosystem resilience capacity (Step 3). This internal unit will be used in a next step to calculate the ENCA unit price, i.e. the Ecosystem Capability unit (ECU) price.

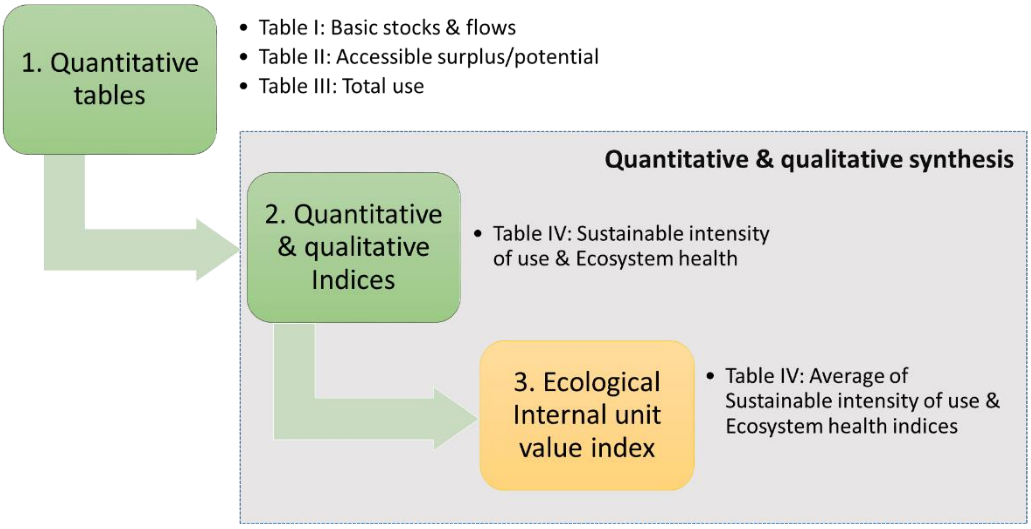


Figure 12 : Main production steps for each Core account

According to this diagram, this section provides for each account, one after another:

1. A description of the content and the results of quantitative tables
2. A synthesis and analysis of the main results from quantitative and qualitative indicators

The ENCA-QSP_FTI data model presented before (available here) provides a detailed and synthetic view of the successive stages to compute the indicators. It indicates all the input data that can be integrated into the accounts as well as the mathematical relationships between the different accounting lines, allowing understanding better the stages of production. Therefore, **for a full understanding of the steps described below, it is strongly recommended to consult this model in parallel**.

IV.4.1 Ecosystem carbon account

Considering ecosystem services, carbon accounts have an important role as they make most of the so-called “provisioning services”: food, fibre and fuel.

Figure 13 shows how the carbon account is integrated in ENCA, following the same accounting table structure as described above. **Ecosystem carbon account is calculated in <u>tonnes of carbon</u>**.

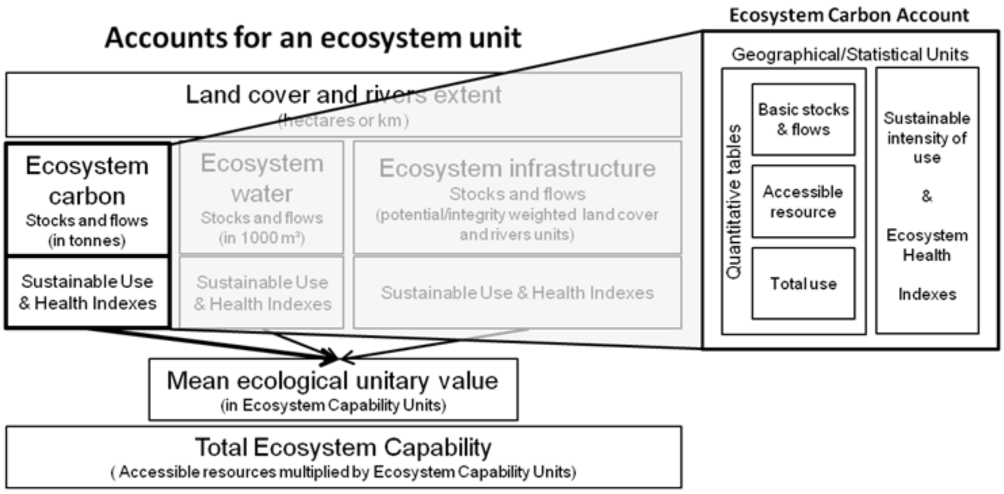


Figure 13: Integration of the carbon account in ENCA (Source: Jazmín Arguëllo, 2019).

The ecosystem carbon account aims at assessing the ecosystem's sustainable capacity to produce biomass (measured as biocarbon) and the way this biomass is used by crops, harvest and tree removal, sterilized by artificial developments, and destroyed by soil erosion or forest fires. It also integrates the carbon that is assimilated by the atmosphere and oceans (Figure 14).

ENCA-QSP focuses mainly on inland terrestrial and water ecosystems and excludes the ocean. Marine ecosystems are included as far as they are an extension of inland systems and can be described in the same way.

In ECOSEO, only few data was available regarding coastal ecosystems, in particular for fisheries that are not addressed. Regarding the atmosphere, the focus is given to the exchanges of the ecosystem with the atmosphere: net primary production of biomass, respiration of soil and combustion of biomass[2].

[2] Additional tables (not produced in ENCA-QSP_FTI) can record on the one hand the use of fossil carbon and on the other hand the emissions of bio-carbon to the atmosphere (CO2 and CH4)

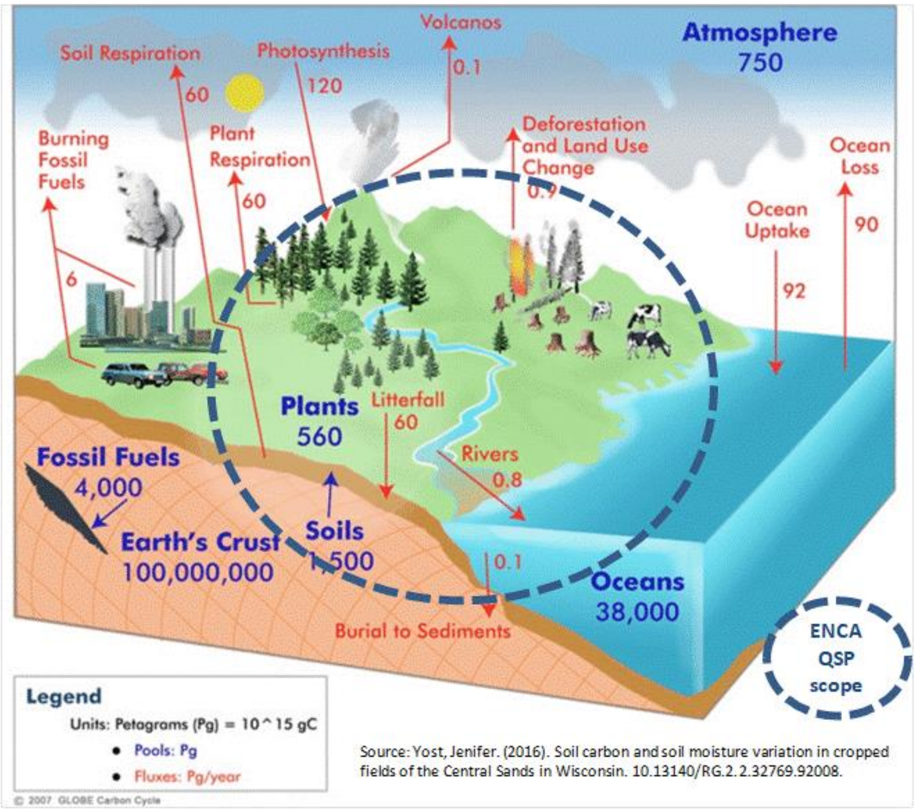


Figure 14 : Simplified Carbon cycle (Source: Yost, 2016)

The following Figure 15 shows the general content of the four accounting Tables for Carbon in ENCA-QSP with the main outputs described here after.

Quantitative tables	I. Ecosystem Carbon Basic Balance	Stocks Primary and secondary production of biocarbon Withdrawals Natural perturbations	*Total inflow of biocarbon* *Net Ecosystem Carbon Balance*
	II. Accessible Resource Surplus	Total inflow of biocarbon Accessible stock carried over Restrictions of use Other accessibility corrections	*Net Accessible Resource Surplus*
	III. Total Uses of Ecosystem Bio and Geo-Carbon	Total use of biocarbon Imports/biocarbon commodites contents Imports/ embedded biocarbon Direct use of fossil carbon Fossil carbon embedded into commodites	*Direct use of biocarbon* *Biocarbon requirement* *Total carbon requirement*
Quantitative & qualitative synthesis	IV. Table of Indexes of Intensity of Use and Ecosystem Health	Sustainable intensity of ecosystem carbon use Composite ecosystem biocarbon health index	*Biocarbon ecological internal unit value*

Figure 15 : Structure and content of the ENCA-QSP ecosystem carbon account

IV.4.1.1 Carbon quantitative tables

IV.4.1.1.1 Main drivers of change in carbon stocks and flows

The main driver of change in carbon stocks are changes in stocks of living aboveground biomass and changes in stocks of soil organic carbon

Living aboveground biomass stocks between 2000 and 2015 show that 2/3 of the region remains stable while the remaining is affected in various ways under the influence of multiple factors (Figure 16). Stable areas are mostly that of pristine forest while areas of more open vegetation and/or with human activities are the more affected.

Changes in soil organic carbon stocks mainly reflect the impact of conversion of forested land to mining activity (Figure 17). In some ecosystem accounting units (SELUs) where mining activity is particularly dense, the organic carbon in the soil has decreased by around 20%.

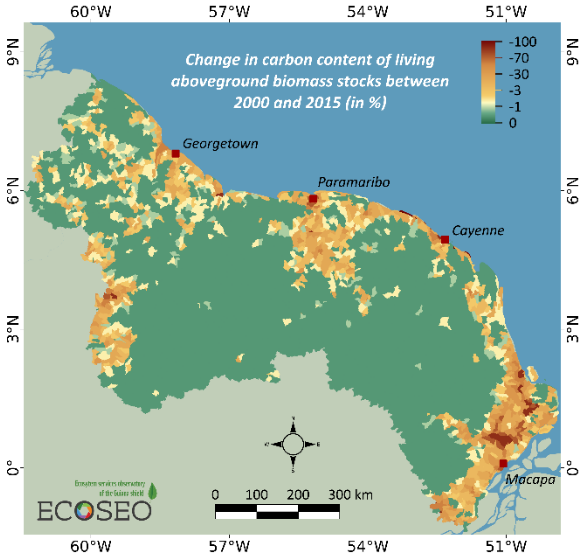


Figure 16 : Change in carbon content of living aboveground biomass stocks between 2000 and 2015 (in %), per Ecosystem accounting units (SELUs)

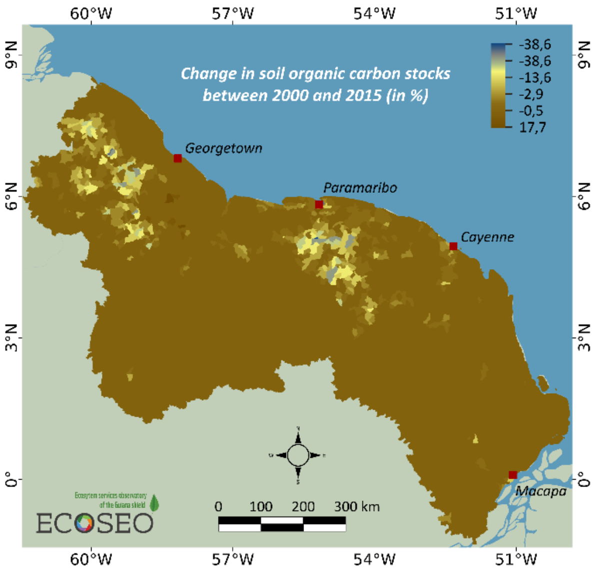


Figure 17 : Change in soil organic carbon stocks between 2000 and 2015 (in %), per Ecosystem accounting units (SELUs)

The main driver of carbon gains (inflows) is the Net Primary Production (Figure 18), which is strongly influenced by precipitations (see Figure 38 in water accounts). The NPP reflects on the Net Ecosystem

Carbon Balance (NECB), the Net Ecosystem Accessible Carbon Surplus (NEACS) and even more on the Net Ecosystem Accessible Carbon Potential that shows very similar trends.

As a result, NECB (Net Ecosystem Carbon Balance) drop is often more visible in areas where less rain occurred, especially when it is associated with a loss of carbon from human activities. Analysing maps of the other drivers of NECB change gives elements for understanding what happened and where, colours and accounting tables by SELUs providing the corresponding numbers.

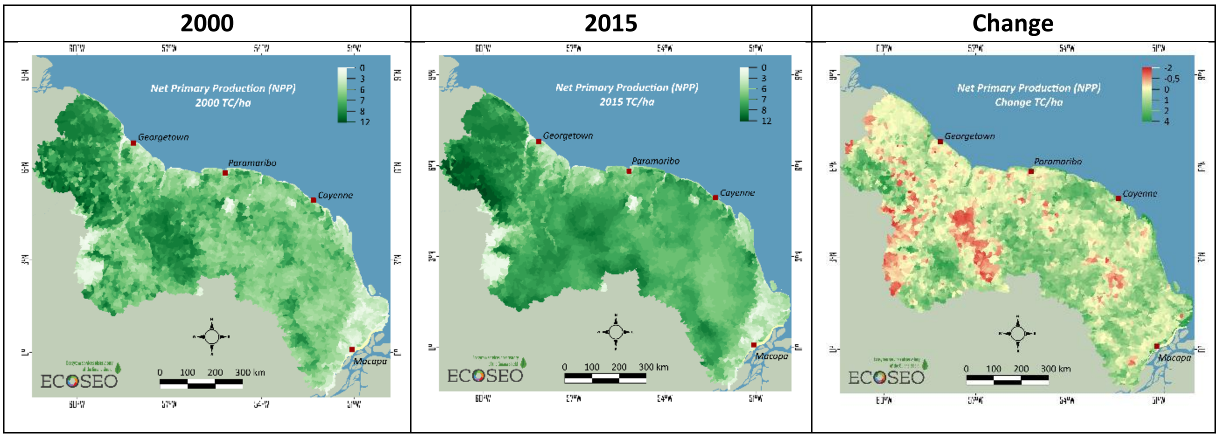


Figure 18 : Net primary production (NPP), in tonnes of carbon per ha, per Ecosystem accounting units (SELUs)

The main drivers of carbon loss (outflow) that can be highlighted among the many datasets integrated into ENCA tables are wood removals, indirect loss of biomass due to mining extraction, fires and soil erosion.

Roundwood net removals have been extrapolated from satellite images on biomass and on trees losses. “Net” means that it includes only roundwood products, not roots, branches, bark which are recorded in a separate item of forestry production residuals, altogether with other trees losses due to clearing of tracts and fall of large trees. Total removals have been compared to FAO statistics duly corrected from the usual “expansion factor”. Assessment by satellite imagery is two times higher than in statistics, which can be explained by data uncertainties; but also, according to FAO, by in situ damages and by informal roundwood logging.

Figure 19 suggests that forestry intensity has on the average moderately increased in the region with apparent raise of activity in accessible areas along the coast in Suriname and French Guiana and in the east of Amapá. This gross assessment from satellite data should however be improved for future assessment using more accurate information if available.

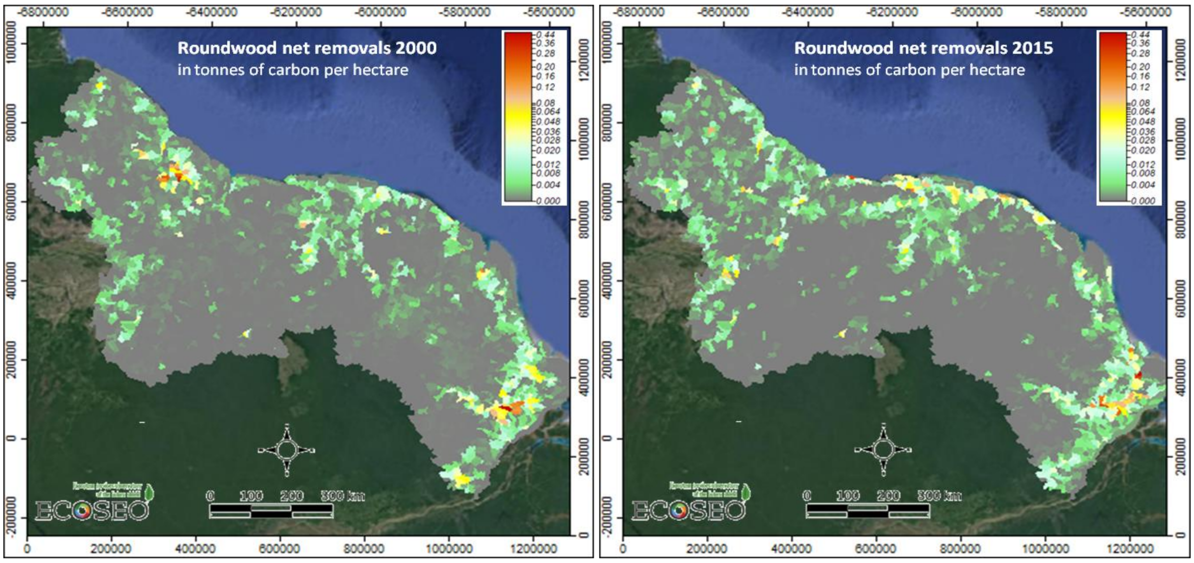


Figure 19 : Round wood net removals, in tonnes of carbon per ha, per Ecosystem accounting units (SELUs)

Loss of trees biocarbon due to mining extraction is a sub-indicator of all indirect losses due to land use change. It measures separately the impacts of mining extraction that have been monitored by the ECOSEO project and which is the main driver of deforestation and ecosystem degradation in the Guianas (Rahm et al., 2020a&b). Calculation of annual flow has combined 2000 and 2015 land cover, the corresponding biomass and annual tree losses. Figure 20 highlights the spread of losses of biomass due to mining extraction and the places where it happens, many of them being hotspots of ecosystem degradation. Impacts of mining extraction on water quality and on the functioning of the ecosystem infrastructure are assessed in separate accounts (see water & ecosystem infrastructure accounts).

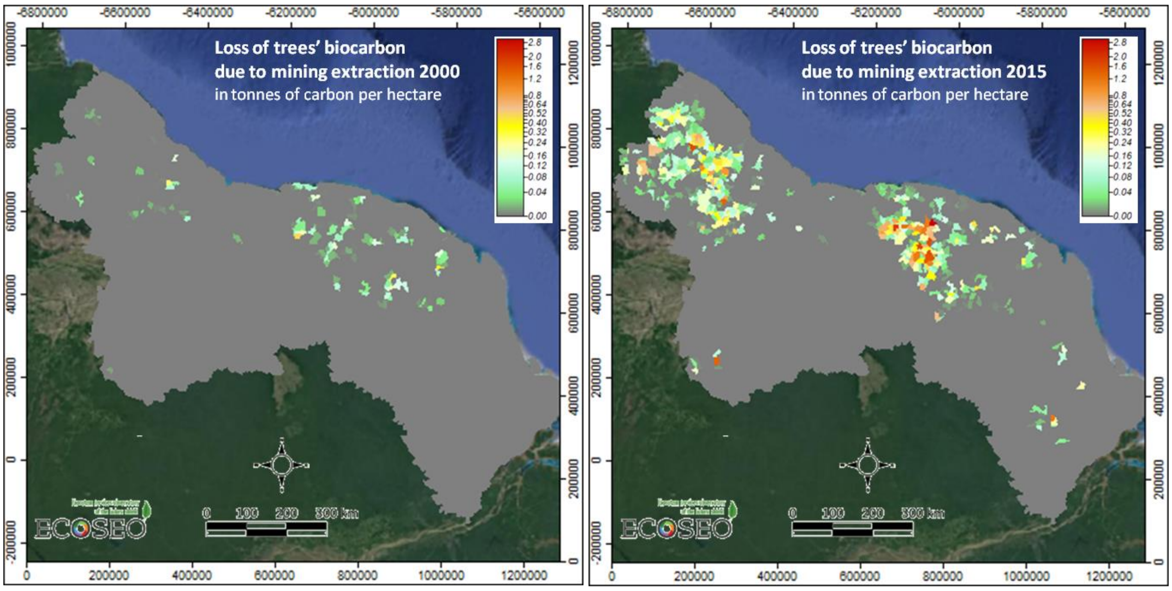


Figure 20 : losses of trees' biocarbon due to mining extraction, in tonnes of carbon per ha, per Ecosystem accounting units (SELUs)

Loss of biocarbon due to fires of natural or multiple origin is assessed from observation of fires by satellites. As these observations by the MODIS satellite are of lights and not of the impact of fires, the assumption has been taken that 20% of the biomass is burnt. The maps show that fires occur essentially in areas with open vegetation, not in dense forests, except where human activities take place. This measurement has limited precision but the maps below show a clear extension of the burnt areas from 2000 to 2015, while we could have expected an opposite evolution due to a wetter 2015 year.

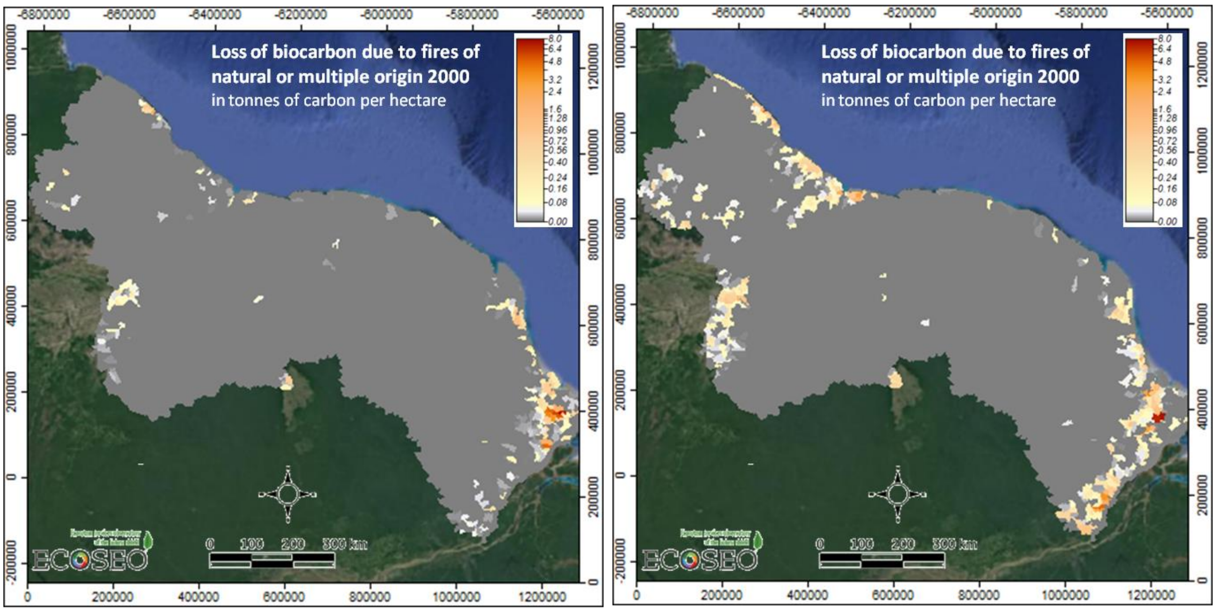


Figure 21 : losses of trees' biocarbon due to fires of natural or multiple origin, in tonnes of carbon per ha, per Ecosystem accounting units (SELUs)

Loss of soil organic carbon due to soil erosion has been assessed in ENCA based on the Global Soil Erosion Modelling platform (GloSEM) from the Joint Research Centre of the European Commission and the Global forest watch dataset (Hansen et al., 2013), which provides information on forest change and tree canopy cover encoded as a percentage per output grid cell in the range 0–100. The results are based on the assumption that 100% of canopy cover or shrubs protect soil from erosion. Therefore, most of the carbon losses occur in artificial or open areas. As for previous outflows above, these results remain coarse given the low level of detail provided by the input data and the need to cross them to extract the information. Given the importance of soils in the carbon cycle, access to high quality data is necessary in order to be able to estimate this variable more accurately and reliably.

Soil erosion is a major problem in the Amazonian basin. In this part of the Guiana Shield, the high cover of dense forest strongly limits carbon loss caused by soil erosion. However, soil erosion can be an important factor of carbon loss since the Guiana shield has poorer soils in comparison to the rest of the Amazon (ter Steege et al 2012) and disturbed 'open' areas are known to be prone to soil erosion (Labriere et al 2015). This is visible for example in the grassland area in the southwest of Guyana that shows higher level of carbon loss due to soil erosion, but also in the North-East of the country dominated by savannah, agriculture and grassland. It is interesting to note the contrast in soil thickness and carbon content between the coastal areas of the region and the forested zones where values of soil organic carbon are much lower, hence potentially vulnerable.

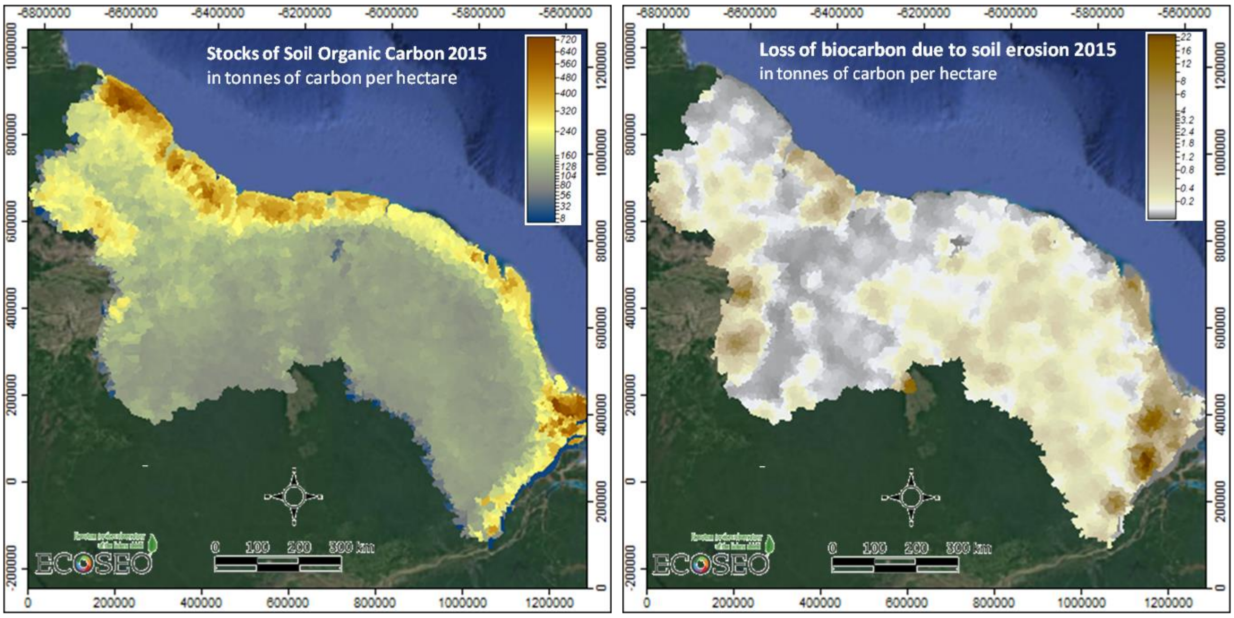


Figure 22 : Stocks of soil organic carbon for 1 meter depth (left) and loss of soil organic carbon due to soil erosion (right) in 2015, in tonnes of carbon per ha, per Ecosystem accounting units (SELUs)

IV.4.1.1.2 Table I: Ecosystem carbon basic balance

The Ecosystem carbon basic account describes the balance of stocks and flows and their relationships, in tonnes of carbon. Ecosystem carbon flows describe how much biomass is produced from managed and unmanaged vegetation, how much is available for use, and how much is lost as direct or indirect consequences of anthropogenic activities and natural disturbances.

In ECOSEO, Ecosystem carbon stocks & flows accounts are calculated from available input data (see input data table here):

- **Carbon stocks** include aboveground living biomass carbon, soil organic carbon and livestock carbon data.
- **Carbon flows** are composed of Inflows of biocarbon (called gains in IPCC guidelines) and Outflows (called loss):
  - Inflows are based on the Net Primary Production (NPP)[3] data and Production residuals and transfers (incl. leftovers)
  - Outflows include harvesting of agricultural crops and wood, (net) indirect anthropogenic losses of biocarbon resulting from LULC change, soil erosion and forest fires.

From the information contained in these input data, additional stock and flows information can be extracted based on the ENCA-QSP_FTI data model. Some of these data, for example, are obtained by extrapolation using emission factors (e.g. the carbon contained in litter and dead wood or roots, which is calculated from aboveground biomass carbon data and a default reference emission factor); others by cross-referencing with LULC change data (e.g. biocarbon loss resulting from LULC change).

[3] Net Primary Production (NPP) measures the biomass generated by photosynthesis by the vegetation. It is primary because it is the energy source for all other life forms. It is net because one part of primary production is used by vegetation to fuel photosynthesis. Conventional measurement from satellite images are expressed in kg of dry biomass (called dry matter in the Copernicus datasets used here). Thy are converted to carbon

The total of these stocks and flows calculated within the ENCA model allow eventually measuring the <u>Net Ecosystem Carbon Balance (NECB)</u> of each ecosystem (Figure 23). NECB can be calculated in two ways:

- From flows: $\boxed{\text{NECB1[Flows] = Total Inflows of biocarbon - Total Outflows of biocarbon}}$

Eq. 1: Net Ecosystem Carbon Balance (NECB1) [Flows], in tonnes of carbon

- From stocks: $\boxed{\text{NECB2[Stocks] = Total Closing stocks - Total Opening stocks}}$

Eq. 2: Net Ecosystem Carbon Balance (NECB2) [Stocks], in tonnes of carbon

In theory, Net Ecosystem Carbon Balance calculated from stocks should be equal to Net Ecosystem Carbon Balance calculated from flows. In practice, it is not the case because of many data issues when measuring NPP on the one hand and change in stocks (in particular trees growth) on the other hand. Comparing the two assessments of NECB is in this context important to assess the quality and consistency of the various datasets used for accounting, to detect anomalies and to make accounting reconciliations when possible. Ultimately, the stated difference between NECB Stocks and NECB Flows is recorded as a separate item called adjustment. This issue is important as Net Ecosystem Carbon Balance is an indicator similar to the "carbon sequestration" (CO_2 removal) of the IPCC carbon balances. The current progress in measuring this latter variable will provide new and improved datasets on biomass stocks, biomass production and crops, which will be useful for ENCA. In the short term, only Net Ecosystem Carbon Balance from flows (NECB1) is compiled.

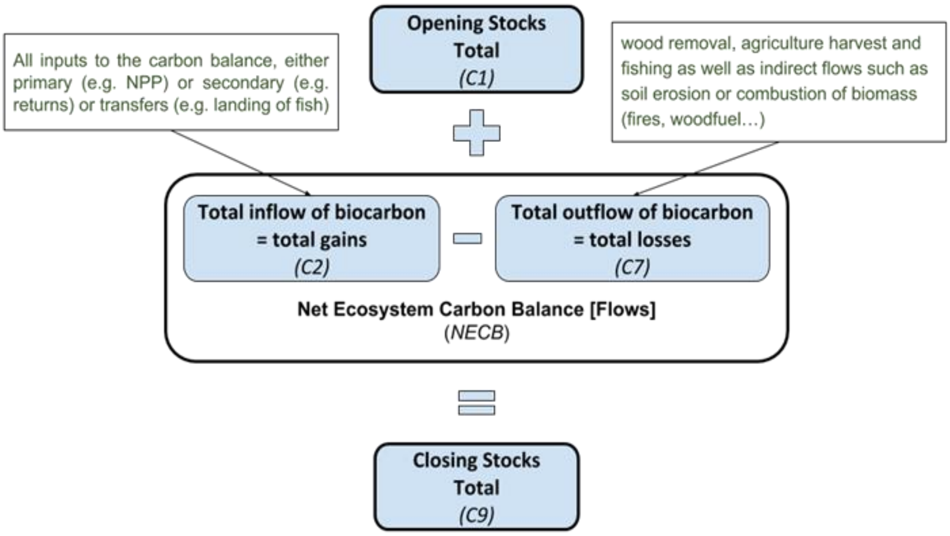


Figure 23 : Ecosystem carbon basic balance & calculation of Net ecosystem carbon balance (NECB)

Figure 24 below shows the resulting Net ecosystem carbon balance from flows (NECB1), in tonnes of carbon.

2000	2015	Change

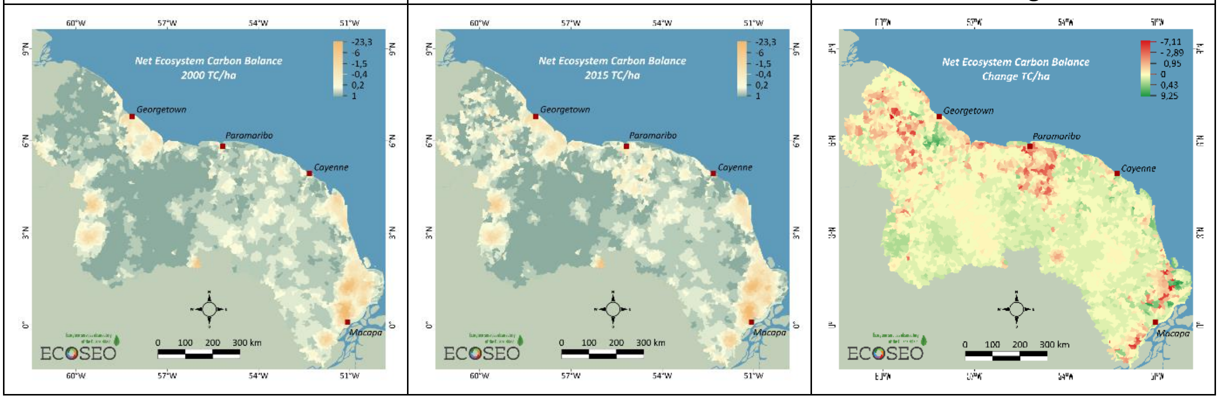


Figure 24 : NECB1[Flows] - Net Ecosystem Carbon Balance of flows, in tonnes of carbon per ha, per Ecosystem accounting units (SELUs)

IV.4.1.1.3 Table II: Accessible Carbon surplus

To be sustainable, not all ecosystem biomass can be exploited as a biocarbon resource, only a surplus corresponding to its renewal. More exploitation than the surplus means a withdrawal on stocks. Stocks of biomass are not mere stores of biocarbon that can be mined in a way similar to fossil assets; they are essential parts of the system that reproduces the resource. The depletion of these stocks is not just a loss of an economic asset; it is a degradation of the ecosystem's capability to renew itself.

The goal of this accounting is to estimate:

- The **Net Ecosystem Accessible Carbon Surplus (NEACS)**, which is the amount of carbon resourcesthat can be used by humans in a sustainable way. It reflects the net gains/surplus of biocarbon that can be used without causing a depletion of the exploitable resource. It is an intermediate aggregate for calculating in Table IV, the synthetic index of Sustainable intensity of Carbon Use (SCU), i.e. the ratio of NEACS to Total Uses (withdrawals and induced losses).

- The **Net Ecosystem Carbon Potential (NECP),** which is the total carbon/biomass potential of the ecosystem, available for human use as well as for the ecosystem reproduction. It will be use as the quantitative element of the synthetic index of Carbon Ecosystem Capability (CEC): NECP x Ecosystem capability unit (ECU) value.

Net Ecosystem Accessible Carbon Surplus (NEACS) is calculated as the Net inflow of biomass carbon (gains) weighted by the Index of limitation of use. The purpose of this adjustment is to reflect the fact that protected areas are generally assigned with restrictions of use, in particular of trees felling. This reduces the accessible resource and will be reflected in the Sustainable intensity of Carbon Use if wood removals take place in these areas.

$$\boxed{\text{NEACS = Net inflow of biomass carbon x Index of limitation of use}}$$

Eq. 3: Net Ecosystem Accessible Carbon Surplus (NEACS), in tonnes of carbon

In case of important natural losses, Net inflow of biomass carbon can be negative. In this case, NEACS, which takes only the positive values of net inflow, is set to 1 the lowest value (by convention to avoid NO VALUES in calculating ratios) (Figure 25).

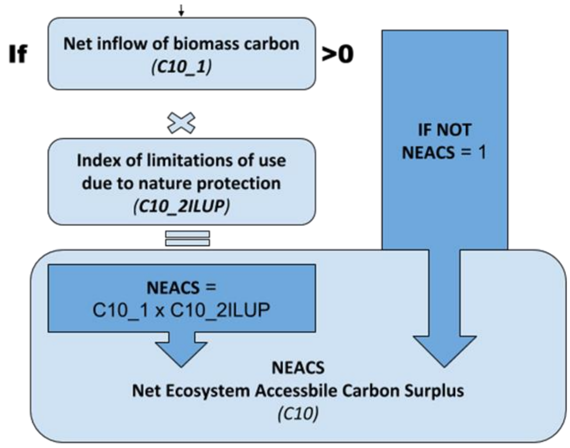


Figure 25 : Calculation of the Net Ecosystem Accessible Carbon Surplus (NEACS)

The Net inflow of biomass carbon is extracted from Table I of the ENCA-QSP_FTI data model as the difference of Total Inflows minus Total Outflows of exploitable carbon (net of soil erosion):

Net inflow of biomass carbon = Total Inflows of biocarbon – Total Outflows of exploitable carbon (biocarbon loss from forest fires of natural and multiple origin + Total decomposition of biomass).

Eq. 4 : Net inflow of biomass carbon, in tonnes of carbon

The Index of limitation of use (ILUP) reflects for carbon surplus assessment the different restriction levels of exploitation of specific ecosystems. In ECOSEO, ILUP has been estimated in the same way as the NATURILIS index established for the Ecosystem infrastructure account based on protected areas and IUCN categories (see Annex VIII.3.2 for more details) (Figure 26). As a result, the accessible carbon surplus in these ecosystems will be reduced by the weights defined for ILUP to express more severe ecosystem degradation in case of carbon overuse. The construction of this index could be refined with more direct information according to legal status, where exploitation can be either strictly forbidden or tolerated, as well as by considering some limitation related to the different type of ecosystem.

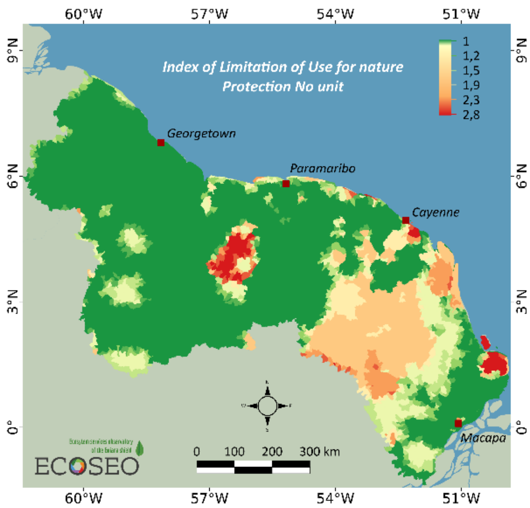


Figure 26 : Index of limitation of use to nature protection (ILUP)

Figure 27 below shows the resulting Net Ecosystem Accessible Carbon Surplus (NEACS), in tonnes of carbon per ha for each SELUs. The effect of ILUP is visible and shows limited accessibility to carbon surplus due to nature protection. Since NEACS is based on the total influx of biocarbon, which is mainly linked to the photosynthetic activity represented by the net primary production (NPP), the latter occupies a preponderant place in its calculation. The Net Ecosystem Accessible Carbon Surplus (NEACS) is therefore strongly linked to the quality of the NPP data. As NPP models include variables on precipitations, NEACS will be influenced by the annual meteorological conditions. Differences in precipitations between 2000 (equivalent to the 30-year average level) and 2015 (15% more precipitation compared to 2000 for most of the region) have to be considered for interpreting changes in NEACS between these two dates.

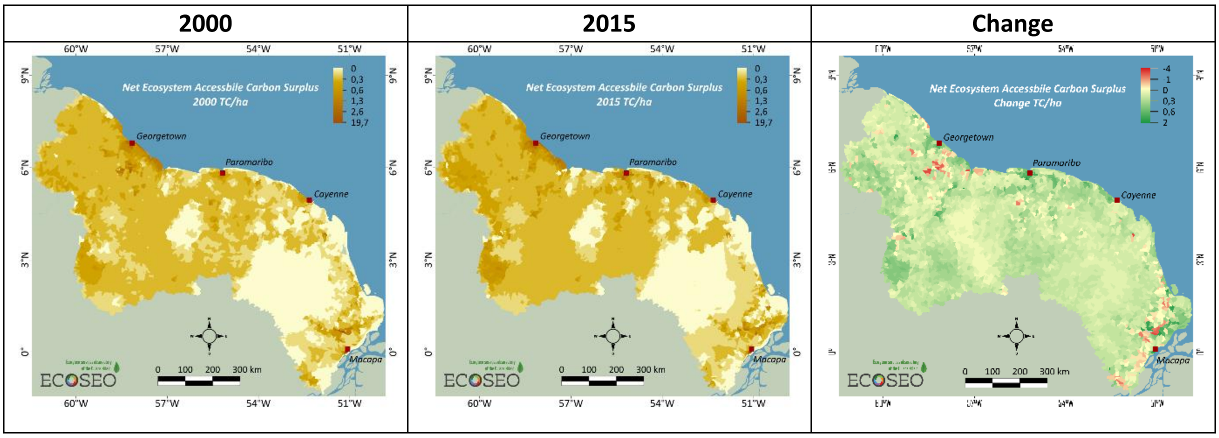


Figure 27 : Net Ecosystem Accessible Carbon Surplus (NEACS), in tonnes of carbon per ha, per Ecosystem accounting units (SELUs)

NECP, the Net Ecosystem Carbon Potential, is computed as**:**

NECP = NPP (Net Primary Production) + Net increase of secondary biocarbon (incl. livestock, fish stocks, soil...) + Forestry residuals – Fires from natural origin.

Eq. 5 : Net Ecosystem (Accessible) Carbon Potential (NE(A)CP)

In ECOSEO, net increase of livestock and fish stocks has not been estimated due to lack of data. Only decomposition of litter and dead wood to soil and Forestry residuals have been recorded as secondary resource.

NECP is used as the quantitative element for the calculation of the Carbon Ecosystem Capability (CEC) which equals NECP x ECU unit value. In absence of any indication, all fires have been recorded as from natural and multiple origins. This solution should be discussed in future updates of ENCA, as long as it underestimates the human factor. Such revision would increase NECP on the one hand and degrade the SCU index, hence CIUV and the ECU unit value, with possibly some effect on the Carbon Ecosystem Potential.

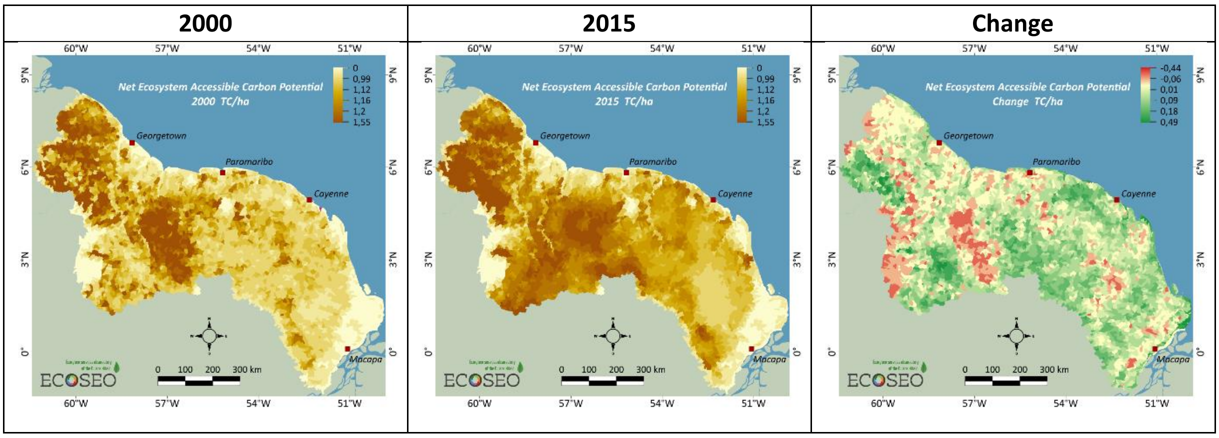


Figure 28 : Net Ecosystem Carbon Potential (NECP), in tonnes of carbon per ha, per Ecosystem accounting units (SELUs)

IV.4.1.1.4 Table III: Total use of ecosystem biocarbon

In ENCA-QSP_FTI, Table III is limited to the calculation of the **Total use of ecosystem biocarbon,** which is calculated from data extracted from Table I:

Total use of biocarbon = Total withdrawals of biocarbon + Net indirect anthropogenic losses of biocarbon and biomass combustion

Eq. 6 : Total use of ecosystem biocarbon, in tonnes of carbon

In ECOSEO, the Total withdrawals of biocarbon corresponds to the Total harvest of agriculture crops, wood & other vegetation; the Net indirect anthropogenic losses of biocarbon and biomass includes the Net loss of biocarbon due to land use change (lcf1 Artificial development) and the combustion of woodfuel.

The aim of this Table III is mainly to identify clearly the uses of biocarbon[4] that can be compared later in Table IV with the Net Ecosystem Accessible Carbon Surplus (NEACS) to assess the Sustainable Carbon Use (SCU) index.

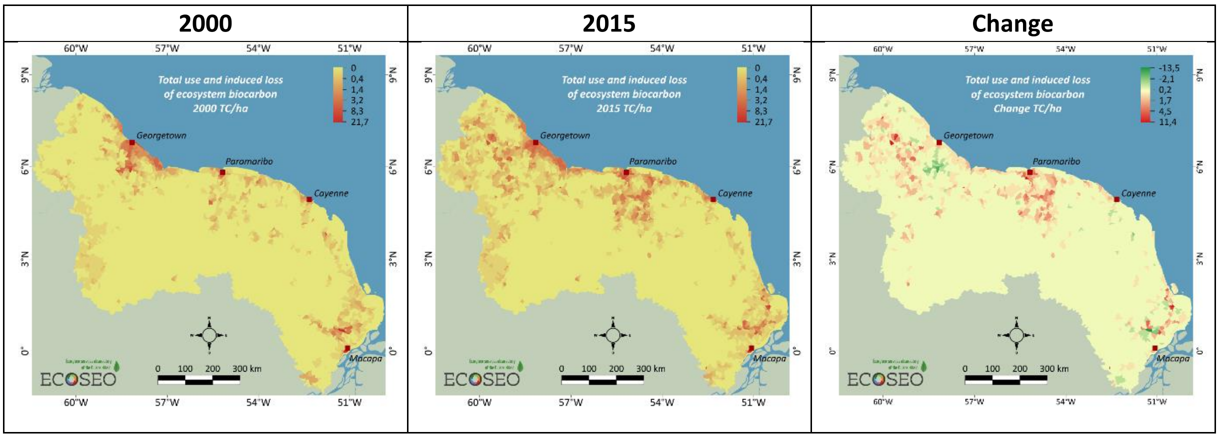


Figure 29 : Total use of ecosystem biocarbon, in tonnes of carbon per ha, per Ecosystem accounting units (SELUs)

[4] Additional objectives (not included in ECOSEO) are 1/ to present if appropriate more details of withdrawals (this is not the choice presently done as long as for example, detail of agriculture crops is presented in the basic balance) 2/ to add additional items for the use of fossil carbon in order to bridge to IPCC totals

IV.4.1.2 *Quantitative & qualitative synthesis of Carbon account*

Ecosystem capability to deliver services in a sustainable way relates to extent and quantities, as well as to more qualitative elements and ecosystem health. Regarding ecosystem carbon, renewal of the carbon resource, its quality and the conditions of renewal have to be considered. These conditions can mostly be seen as internal or external to the carbon cycle, linked to the general functioning of the ecosystem and in particular the effects on other components such as water, integrity and biodiversity.

This section aims to make a synthetic analysis of the carbon accounts based on quantitative and qualitative variables, through:

1. The sustainable intensity of Carbon use (SCU) index, a quantitative index calculated in Table IV from Table II & III data
2. The Carbon Ecosystem Health (CEH) index, a qualitative index produced in Table IV
3. The Ecosystem Carbon Internal Unit Value (CIUV), which is the most aggregated indicator of Table IV, combining SCU and CEH

IV.4.1.2.1 *Sustainable intensity of Carbon use (SCU) index*

The Sustainable intensity of carbon use (SCU) index is the ratio of Net accessible resource surplus (NEACS) to Total use of ecosystem biocarbon, calculated respectively from Table II and Table III:

SCU = Net ecosystem accessible carbon surplus (NEACS) / Total use of ecosystem biocarbon

Eq. 7 : Sustainable intensity of Carbon Use (SCU) index

Figure 30 shows the results of the SCU index, which ranges between 0 and 1 with no specific unit, as it is a ratio of carbon units. Values below 1 quantify the unsustainable use of carbon from a quantitative standpoint (depletion of stock), which implies a stress leading to ecosystem degradation. Oppositely, a ratio ≥ 1 means that from a quantitative point of view, the exploitation of the resource is sustainable (no depletion of stocks on the average, per Ecosystem accounting units - SELUs). Improvements in sustainability of use represented in green on the change map mostly coincide with open vegetation areas that suffered carbon losses from fires in 2000 (southwest of Guyana and East of Amapá); highest levels of depletion of stock, shown in red, are located in mining areas.

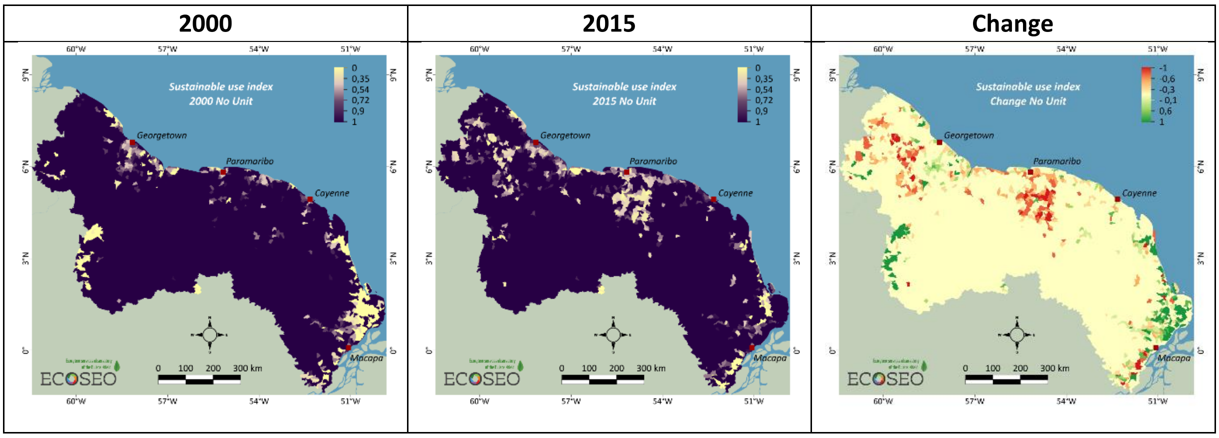


Figure 30 : Sustainable intensity of Carbon Use (SCU) index, ranging between 0 and 1

IV.4.1.2.2 Carbon Ecosystem Health (CEH) index

The Carbon Ecosystem Health Index summarizes other symptoms of ecosystem distress. The list of indicators, depending on available data and knowledge, can be as long as they contribute to the overall diagnosis of ecosystem health. There is no unique solution to deriving a diagnosis from the set of indicators retained. The rationale is similar to a medical diagnosis where the conclusion is not necessarily a function of the number of observations but more probably of the severity of a few or even of one.

CEH aims at capturing qualitative values of the carbon. Because of lack of data, the carbon in water has not been assessed in the present ENCA-QSP_FTI version. Would it had been done, it is clear that tonnes of carbon in fish, in sediments, in eutrophicating organisms or in urban waste water should not be simply added up. For vegetation, only trees are addressed in an approach similar to the Biodiversity intactness index (BII) where stability over time is the highest value. Regarding soil erosion, a vulnerability index is estimated.

Forest stability is an important element of **its natural resilience** and long-term sustainability. In absence of direct data on forest age that could be used as a proxy of forest stability, an indirect assessment has been done from data based on the sum of losses and gains of trees (from UMD's Global Forest Change database). For 2015, the two 2000-2015 sets have been added up as both indicate rejuvenation and/or instability. Not such data exist prior to 2000 and the assessment is done for this year only with gains of trees, assumed to indicate previous losses. This inconsistency limits comparability between 2000 and 2015, although not completely as data show that trees losses were still in average low in 2000 (Figure 31).

The forest carbon stability index (CEH1) show here a low range but surprisingly widespread loss of stability even in areas expected to be more pristine and untouched. This can also be explained by the accuracy of the input data, such as the UMD's Global Forest Change database that sometimes misestimates tree gains and losses.

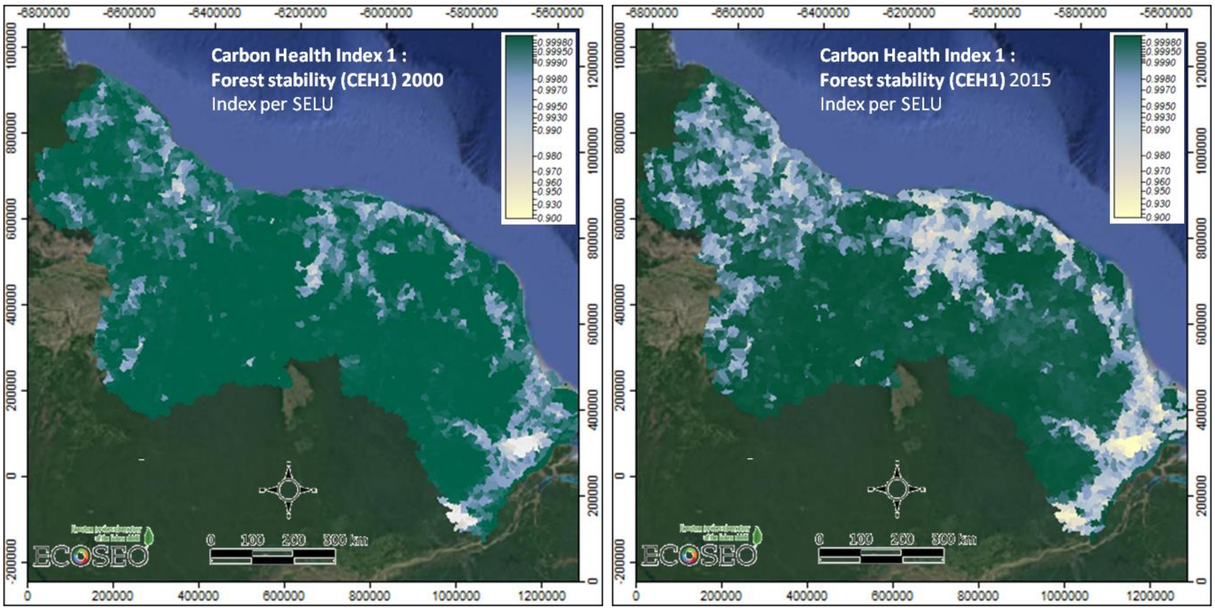


Figure 31 : CEH1 - Forest carbon stability index, ranging between 0 and 1

Soil resistance to erosion index (CEH6) is assessed regarding actual losses of organic carbon due to erosion (which include protection of soil by forest) and the Rainfall erosivity factor (R-factor) of the RUSLE standard model that measures rainfall's kinetic energy and intensity to describe the effect of rainfall on sheet and rill erosion. (data from JRC's Global Soil Erosion)[5]. Change between 2000 and 2015 is mostly driven by forest cover and rainfall.

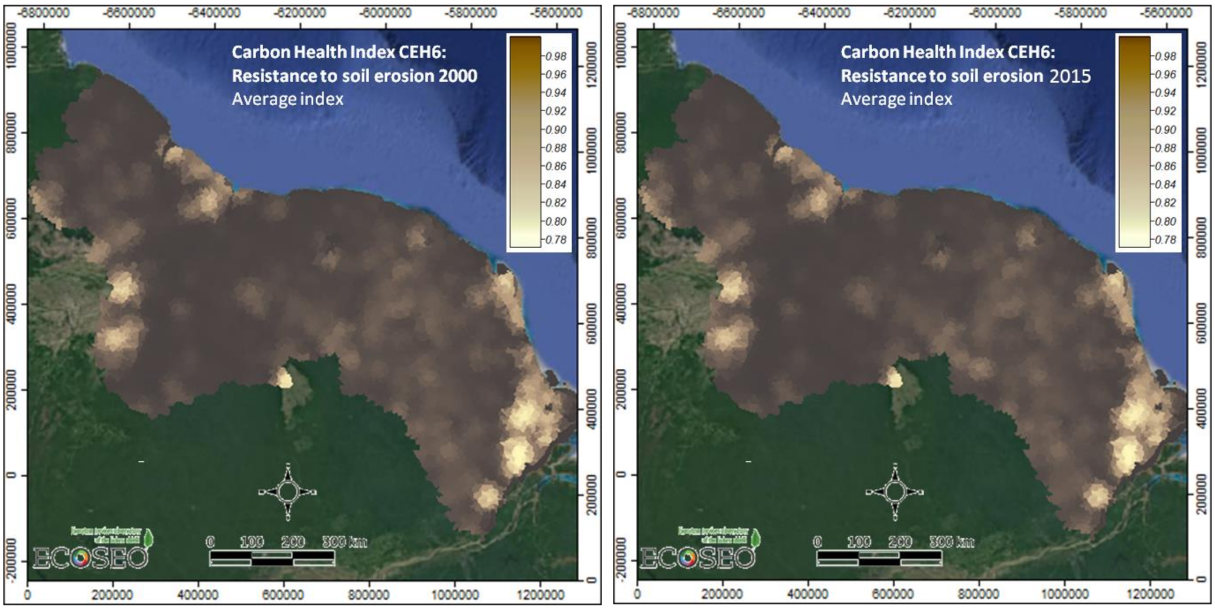


Figure 32 : CEH6 - Soil resistance to erosion index, ranging between 0 and 1

The Carbon Ecosystem Health index is in theory the outcome of a diagnosis, which combines data and expertise in the same way as medical diagnoses are done. When elementary indexes are numerous, the diagnosis should be based on a decision tree, for example using Bayesian Belief Networks as it is done in medicine. In ECOSEO, because only two symptoms have been assessed, a simple multiplication of the two factors is done (Figure 33):

$$\boxed{CEH = CEH1*CEH6}.$$

Eq. 8 : CEH - Carbon Health Index

Health degradation comes mostly from the forest stability index, hence in artificial development areas (infrastructure, settlements and mining areas).

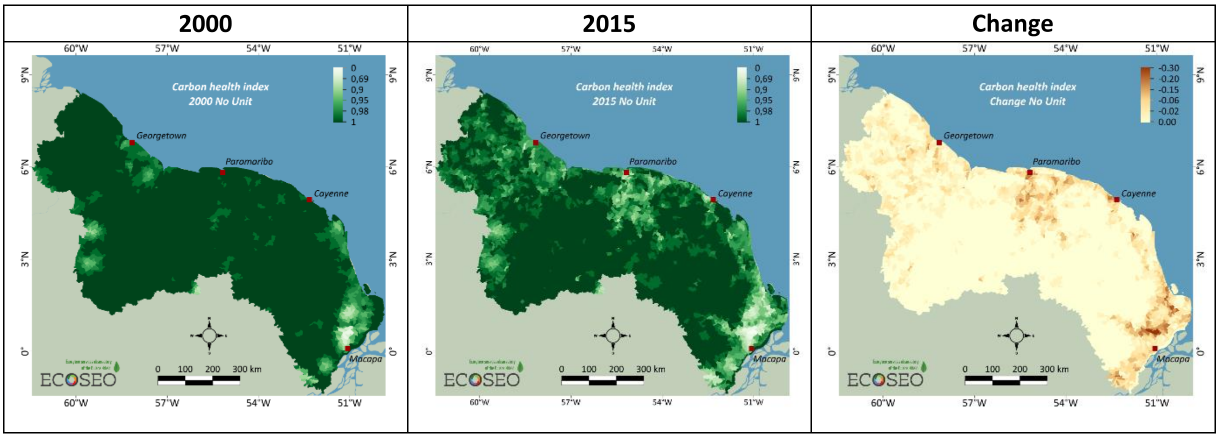


Figure 33 : CEH - Carbon Health Index, ranging between 0 and 1

[5] https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity

IV.4.1.2.3 Carbon Internal unit value (CIUV)

Finally, the **Ecosystem Carbon Internal Unit Value (CIUV)** is the arithmetic average of both indices, SCU (Sustainable intensity of carbon use) and CEH (Carbon health index):

$$\boxed{\text{CIUV} = (\text{SCU}+\text{CEH})/2}$$

Eq. 9 : Ecosystem Carbon Internal Unit Value (CIUV) index

From the standpoint of ecosystem carbon, it is a condition indicator between 0 and 1, which aggregates, combines and summarizes the state of the resource based on quantitative and qualitative information. This internal unit will be used in a next step to calculate the ENCA unit price, i.e. the Ecosystem Capability unit (ECU) price.

Going back to the set of ecosystem carbon accounts from which CIUV is calculated, it is possible to identify the main factors contributing to it (Figure 34). For example, the 2000 map show effect of the scar of large fires in the North and North-East Amapà and South-West Guyana, which are less intense in 2015, showing positive difference of the CIUV in these areas. The 2015 map show a slight decline or stability in a majority of SELUs as well as swift decrease of CIUV in areas of development of activities as the change map highlights.

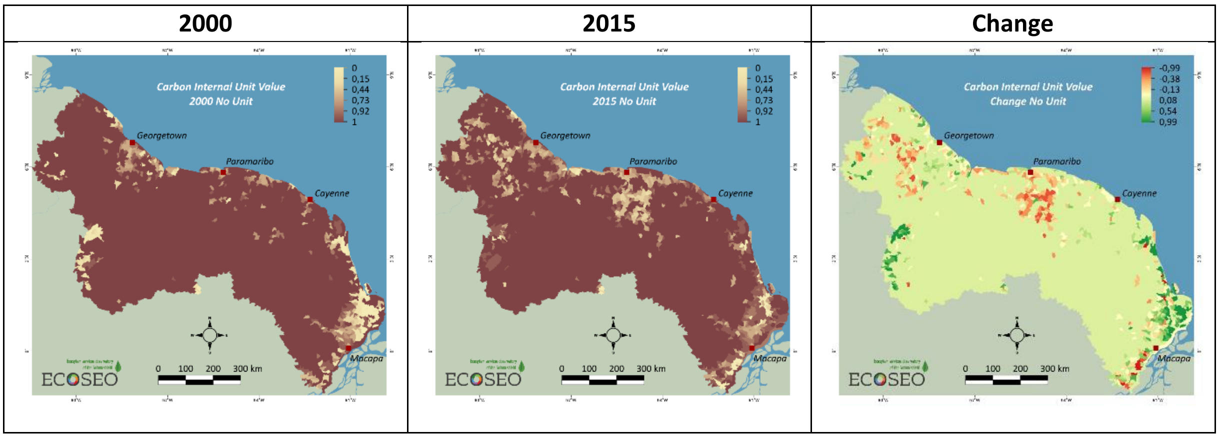


Figure 34 : Ecosystem Carbon Internal Unit Value (CIUV), ranging between 0 and 1

IV.4.2 Ecosystem water account

Figure 35 shows how the water account is integrated in ENCA, following the same accounting table structure as for the carbon account and described in introduction of the core accounts (see IV.4). **Ecosystem water account is calculated in thousands of cubic meters, 1000 m³.**

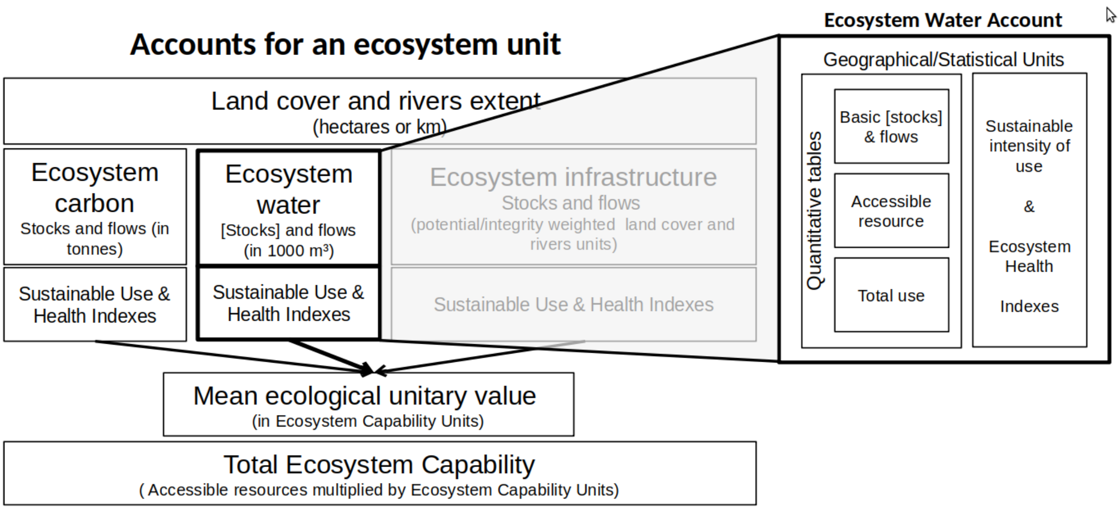


Figure 35 : Integration of the water account in ENCA (Source: Jazmín, 2019)

The water account addresses the water cycle and all the interactions, exchanges (natural or artificial) and transformations (recycling of wastewater, etc.) of water in the study area. Figure 36 below shows the various stocks and flows that should be recorded in ideal water accounts.

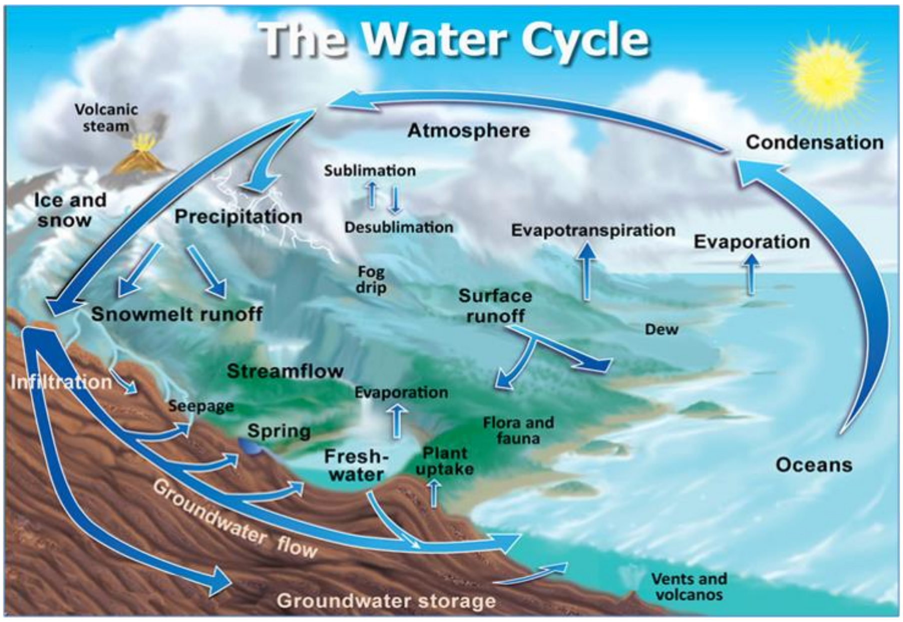


Figure 36: The Water Cycle (Source: Perlman and Evans, 2019)

In addition to natural flow, Water accounts record flows of use of water and of used water discharge by economic sectors.

ENCA water accounts are a branch of the SEEA Water accounts (SEEA-W) and are articulated to the Water chapter of the SEEA Central Framework (SEEA-CF). In practice, simplifications are possible and needed due to unavailable data.

In ENCA, the stocks of water are only presented as a set of descriptors for the various water components (assets) with their specific metric, with no attempt of calculating a Total Stock in cubic metres. Instead, ENCA focuses on the measurement of flows and the resulting Water Surplus (based on accessible resource and its use) and Water Potential (a constituent of ecosystem capability), by ecosystem accounting unit (which integrates hydrological basins boundaries). Water flows accounts are also simplified thanks to the absence of stock calculation, since total opening and closing stocks do not need to be balanced by the effect of the flows. Therefore, the complete description of natural internal water transfers between “water assets” is no more needed. In fact, only the flows of surface water to groundwater must be calculated (percolation and aquifers drainage), and when data is missing, ENCA-W can accommodate of the net value of these flows. This treatment is consistent with the ENCA definition of groundwater, which is considered only in its connection to the surface where ecosystems stand.

As for the carbon, the water account includes quantitative and qualitative assessments that are translated respectively by the Sustainable intensity of use of the resource and its health conditions. The accounts are structured in the same way with three quantitative tables (Table I to III) and one table that synthetizes quantitative and qualitative information (Table IV). Figure 37 below shows the general content of the four accounting Tables for Water in ENCA-QSP with the main outputs described here after.

Quantitative tables	I. Ecosystem Water Basic Balance	Stocks Primary and secondary production of water Transfers between water bodies and basins Actual Evapotranspiration Abstraction of water, supply and use Returns to waste water and losses	*Total inflow of water* *Net Ecosystem Water Balance*
	II. Accessible Resource Surplus	Total renewable water resources Accessible stock carried over Restrictions of use Other accessibility corrections	*Net Accessible Water Resource Surplus*
	III. Total Uses of Water	Total use of ecosystem water: blues, grey & green water Imports/water commodities contents Imports/ embedded water	*Total use of ecosystem water* *Direct use of water* *Total water requirement*
Quantitative & qualitative indices	IV. Table of Indexes of Intensity of Use and Ecosystem Health	Sustainable intensity of ecosystem water use Composite ecosystem water health index	*Water internal ecological unit value*

Figure 37: Structure and content of the ENCA-QSP ecosystem water account

IV.4.2.1 Water quantitative tables

IV.4.2.1.1 Main drivers of change in water flows

In ECOSEO, Water flows accounts are calculated from available Inflows and Outflows input data on precipitations, irrigation, evapo-transpiration, watersheds, LULC… (see input data table for Water accounts here)[6].

The Guiana Shield is one of the regions with the highest precipitations but it also holds one of the highest water surplus in the world (FAO-AQUASTAT, 2010). Therefore, issues related to water quantities are not expected to be found.

The main driver of water gains (inflow) is rainfall. On average, 2015 is an exceptional year with 15% more precipitations than the 30-year average while 2000 is equivalent to the 30-year average (Figure

[6] In ECOSEO, not all needed data were available to compute the full water accounts and more complete and accurate account would require inputs form national sources. This should provide a better picture in particular in relation to the managements of the water resource (storage and transport), water quality, wastewater treatment and discharge (which has been addressed only in the case of the French Guiana for which data were available). Water pollution is therefore probably underestimated. Integrating local knowledge to ENCA is feasible as demonstrated in Arguëllo (2019) but it requires more work and the active participation of experts from water and other agencies who have collected such data and know how to interpret them.

38). The distribution of precipitation is not homogeneous and varies from place to place. Although overall, there is a higher rainfall in 2015, the change map shows also a drop in precipitation in northern Guyana as well as in the central area of the region, from western Guyana to western French Guiana. These effects of exceptional or extreme climatic phenomena demonstrate the limits of a two-date monitoring and the need for more frequent ones to be able to smooth or adjust the results. ENCA includes an adjustment table for this purpose. In the context of this study, such adjustment was only tested at the aggregated administrative level.

Even if water quantities do not seem to be an issue in the region, when looking in more detail, it is more contrasted and some regions such as the savannahs of western Guyana are showing a more temperate rainfall pattern at around 1000 mm/year.

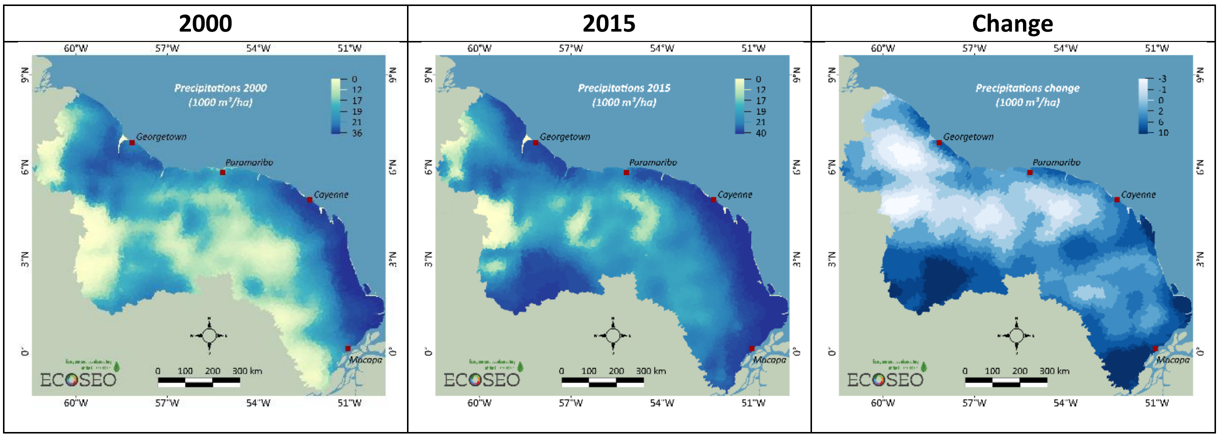


Figure 38 : Average precipitations, in 1000 m3 per ha, per Ecosystem accounting units (SELUs)

Furthermore, considering that surface water is the main water resource, not all ecosystem accounting unit (i.e. watershed of level 10) are supplied by rivers in a generous way (Figure 39), meaning that one large part of the ecosystem water resource is provided by the forest and depends on its conservation.

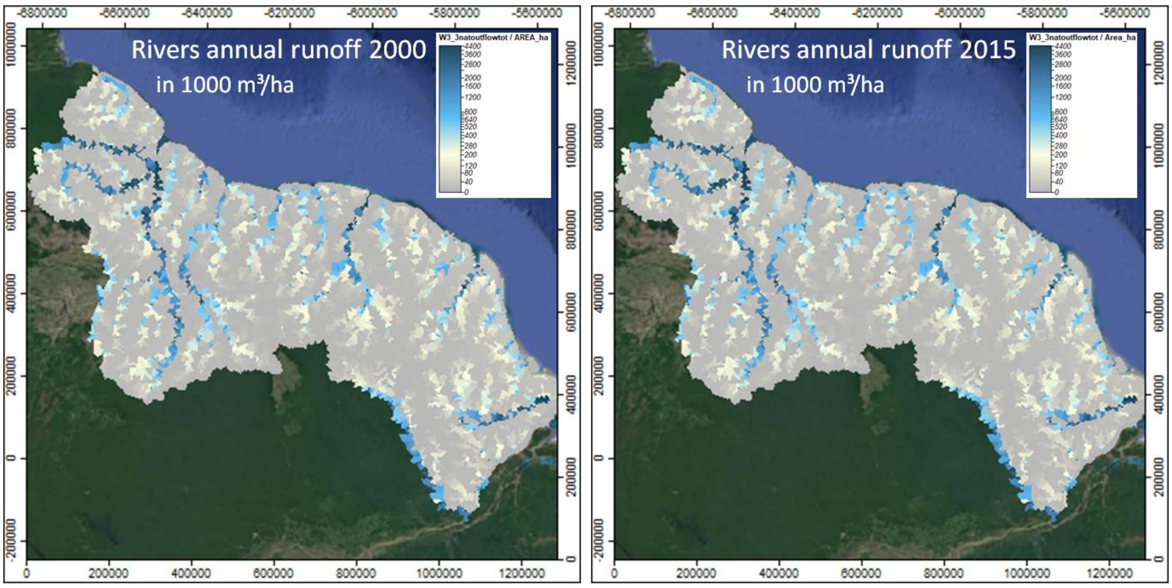


Figure 39 : Rivers annual runoff in 2000 (left) and 2015 (right) in 1000 m3 per ha, per Ecosystem accounting units (SELUs)

Although not very significant compared to other inflows, the level of crop irrigation was also estimated by crossing AQUASTAT, LULC and CGIAR / IFPRI gridded data (see input data list).

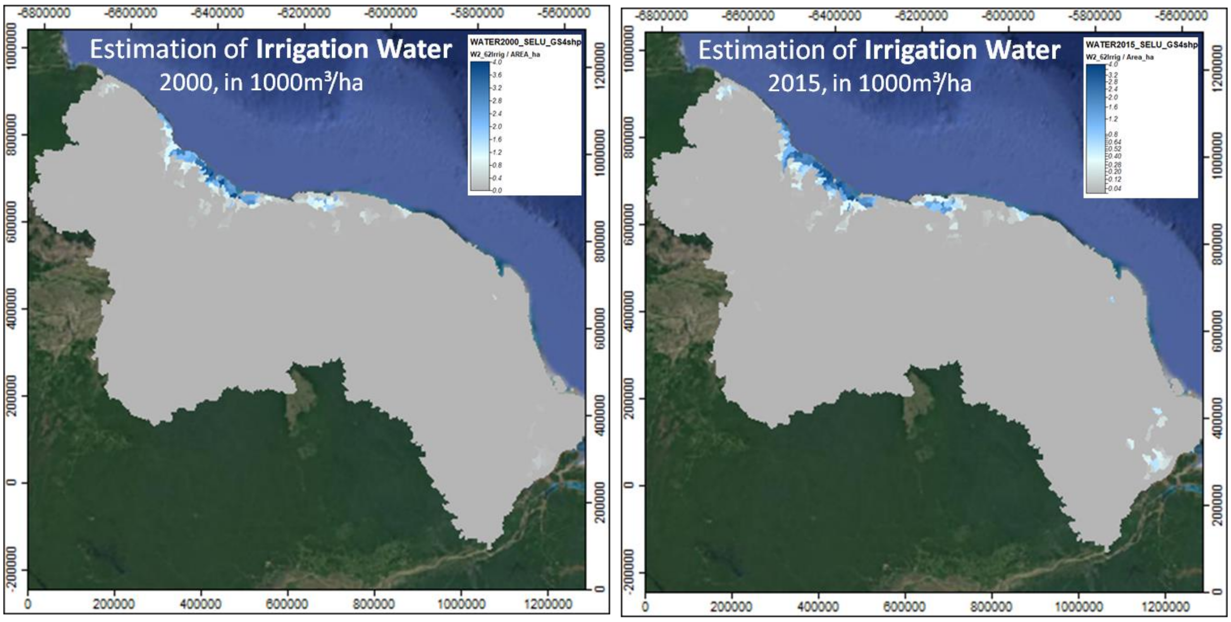


Figure 40 : Estimation of water irrigation in 2000 (left) and 2015 (right), in 1000m3 per hectare, per Ecosystem accounting units (SELUs)

The main driver of water loss (outflow) is actual evapotranspiration (AET), which is the amount of water that evaporates from the surface and is transpired by plants. AET is strongly influenced by the precipitation, which it balances with a very similar pattern. Other factors that affect evapotranspiration include the plant's growth stage or level of maturity, percentage of soil cover by vegetation, solar radiation, humidity, temperature, and wind.

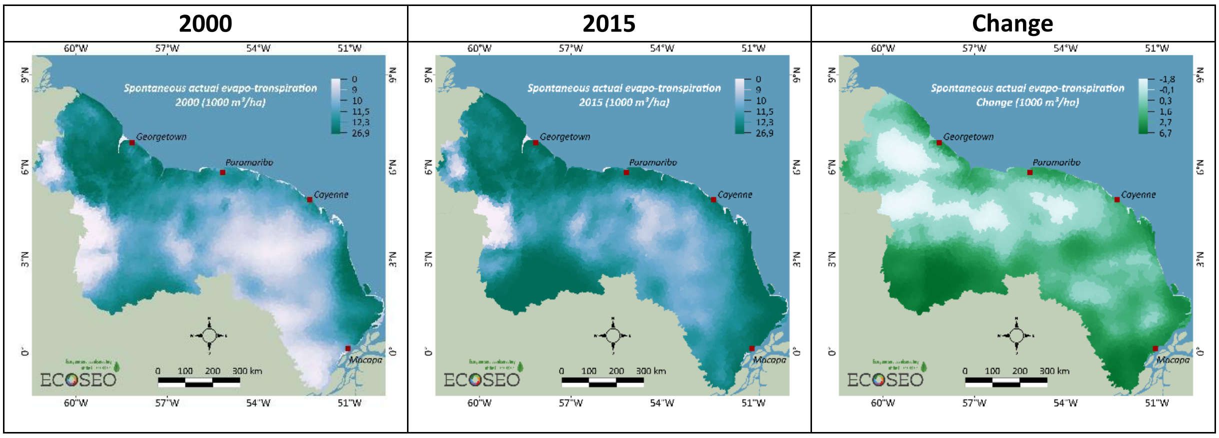


Figure 41 : Actual evapotranspiration (AET), in 1000m3 per hectare, per Ecosystem accounting units (SELUs)

The ENCA_QSP_FTI model (available here) provides the full list of inflows and outflows information integrated in the accounts.

IV.4.2.1.2 Table I: Ecosystem water basic balance

The Ecosystem water basic account describes the balance of the flows, in 1000 m^3.

In ENCA, the water accounts track the flows from precipitation, infiltration, runoff, down to final outflow. Figure 42 illustrates the main natural water flows for an ecosystem accounting unit or SELU, i.e. watershed of level 10. It shows that the net water transfers between water bodies (e.g. percolation W2_22 vs groundwater drainage W2_23) or river basins (e.g. surface inflow W2_31 vs surface outflow

W3_31) are recorded, as well as between the atmosphere and the river basin (e.g. Precipitations W2_1 - Actual evapo-transpiration (AET) W3_1 = Total available effective rainfall W4a).

W2_1-W3_1 = W4a

W4a + W2_23 - W2_22 = W3_31-W2_31

→ W2_23 - W2_22 = W2_2a = W3_31 - W2_31 - W4a

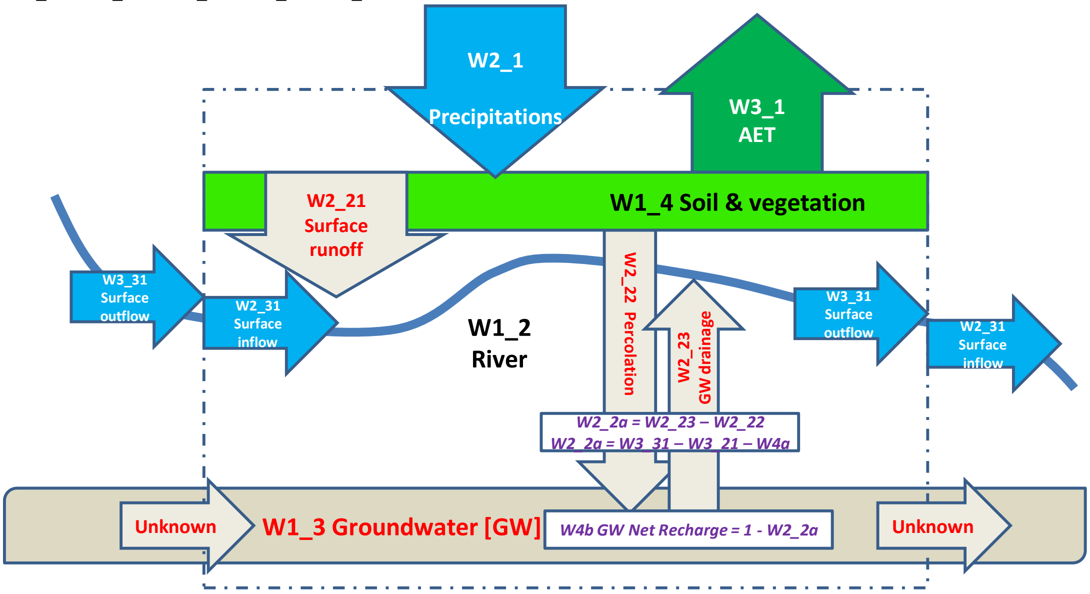


Figure 42: Simplified chart of main natural water flows for an Ecosystem Accounting Unit (without lakes/reservoirs and without water abstraction and returns)

- Inflows input data include precipitation and irrigation;
- Outflows input data are evapo-transpiration, freshwater use
- Rivers runoff, which is outflow for a basin and inflow for the next one.

In addition to these, ancillary data on watersheds such as population and agriculture statistics, LULC and dams locations have been collected and used to estimate additional variables.

The total of these flows calculated within the ENCA-QSP_FTI model allow eventually measuring the <u>Net Ecosystem Water Balance (NEWB)</u> for each Ecosystem accounting unit (Figure 43):

$$\boxed{\text{NEWB[Flows] = Total Inflows of water - Total Outflows of water}}$$

Eq. 10: Net Ecosystem Water Balance (NEWB) [Flows], in 1000 m^3

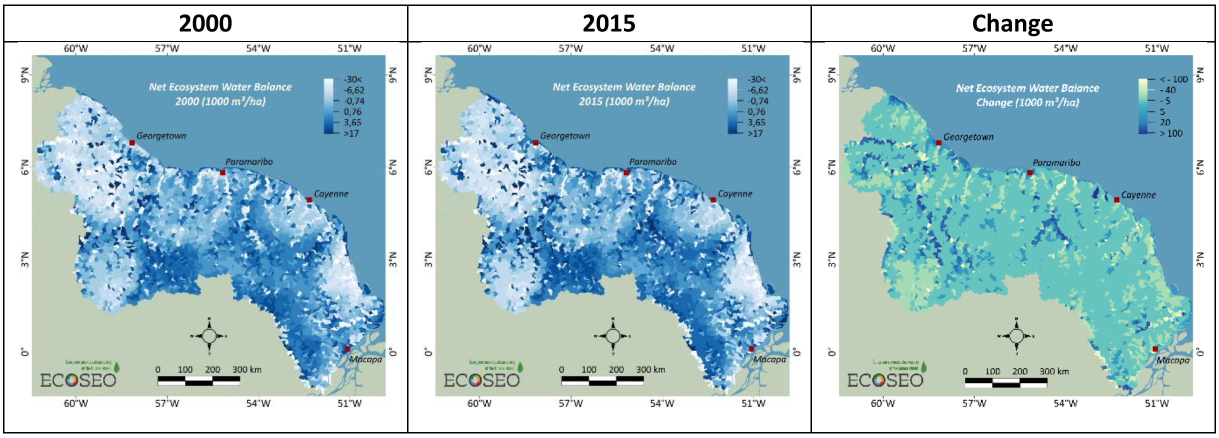


Figure 43 : Net Ecosystem Water Balance (NEWB) [Flows], in 1000 m3 per ha, per Ecosystem accounting units (SELUs)

IV.4.2.1.3 Table II: Accessible water surplus

One of the aims of Ecosystem water accounts is to assess the sustainability of use of the water resource. Therefore, as for carbon, it is necessary to define precisely how much water can realistically be exploited or accessed. The renewable water resource has first to be identified, then the many constraints that limit access to it: costs, location timeliness, quality, legal limitations, etc. Without a precise definition of the water that is actually exploitable, it is difficult to assess the sustainability and impacts of water use. The issue has long been discussed, in particular in the FAO AQUASTAT system and in Postel et al (1996).

Therefore, on top of the basic water balance, Table II derives two different aggregates:

- **The Net Ecosystem Water Surplus (NEWS)**, which is the amount of an inland water resource that can be used in a sustainable way. It includes primary resource[7] and secondary resource[8]. NEWS corresponds to the exploitable water resource of FAO AQUASTAT. In Table IV, NEWS is divided by Total Use in order to estimate the index of Sustainable Intensity of Water Use (SIWU). As long as elements are missing on the quantitative status of water bodies, namely groundwater and soil, the basic ratio NEWS/Total Use is adjusted with other indicators (see below). Important to note is that NEWS can be modified by storage in reservoirs and water transport.

- **The Net Ecosystem Accessible Water Potential (NEAWP)**, which is the total accessible water by humans and the ecosystem itself. It will be further multiplied by the average Ecological Capability Unit (ECU) value to calculate the Water Ecosystem Capability of each ecosystem accounting unit (SELU). Figure 44 illustrates the component of NEAWP. In ECOSEO, three of the five components were calculated:

    - Lakes & reservoirs runoff potential (W8_1) is estimated by the sum of the stock of water and the runoff divided by the SELU's total area in ha;
    - River runoff land potential (W8_2) is the runoff multiplied by the ratio of the areas of watercourses to SELU's total area in ha;
    - Snow and glaciers (W8_3) is not relevant for the region;

[7] Primary water resources are made up of precipitations, Internal spontaneous water transfers received, natural inflows from upstream territories

[8] Secondary water resources are made up of artificial inflows of water from other territories and the sea, wastewater returns/discharge to inland water assets, and other returns of abstracted water to inland water assets.

- Groundwater accessible recharge potential (W8_4) has not been estimated at this stage; As long as no data are accessible on groundwater recharge from surface water and discharge to rivers is available, this variable has, provisionally not been taken into account;
- Soil and vegetation water potential (W8_5) is estimated by the transpiration of the vegetation (proxy = Actual evapotranspiration (AET)/2).

To improve the results, Groundwater accessible recharge potential (W8_4) should be estimated and the calculation of Soil and vegetation water potential (W8_5) should be improved.

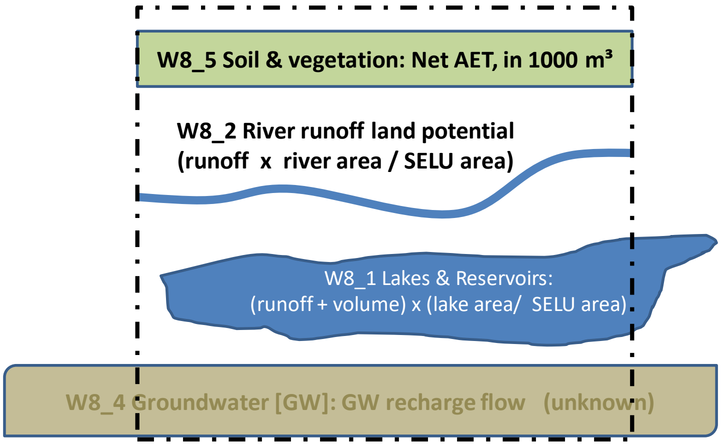


Figure 44: Estimation of the Net Ecosystem Accessible Water Potential (NEAWP, W8 in data model) , W8 = SUM(W8_1:W8_5)

Figure 45 and Figure 46 below show respectively the resulting Net Ecosystem Water Surplus (NEWS) and Net Ecosystem Accessible Water Potential (NEAWP), in 1000 m^3. Changes in the level of precipitation between 2000 and 2015 affect the water accounts and more particularly the Net Ecosystem Water Surplus (NEWS) and Net Ecosystem Accessible Water Potential (NEAWP). They both show negative changes in areas where the precipitation level was lower in 2015 and positive changes where the precipitation level was higher.

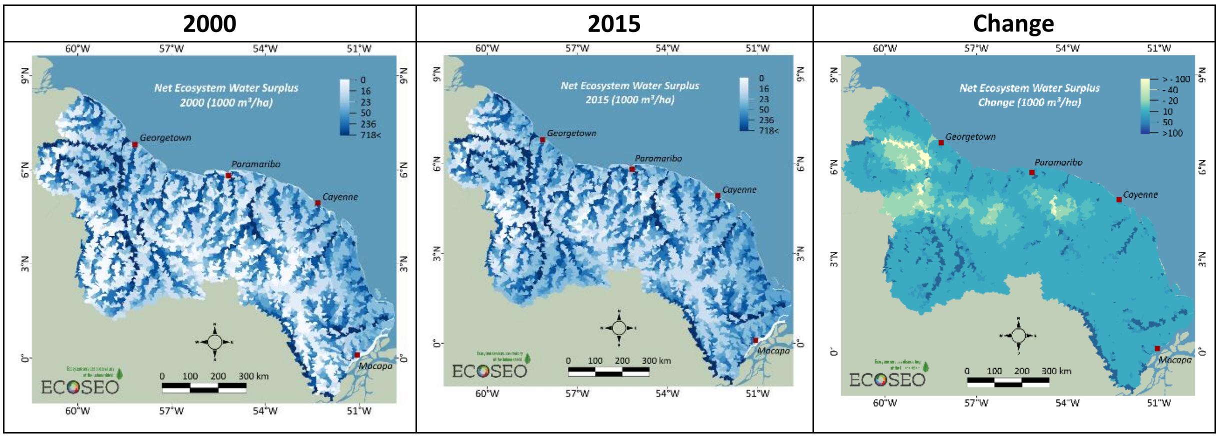


Figure 45 : Net Ecosystem Water Surplus (NEWS), in 1000 m3 per ha, per Ecosystem accounting units (SELUs)

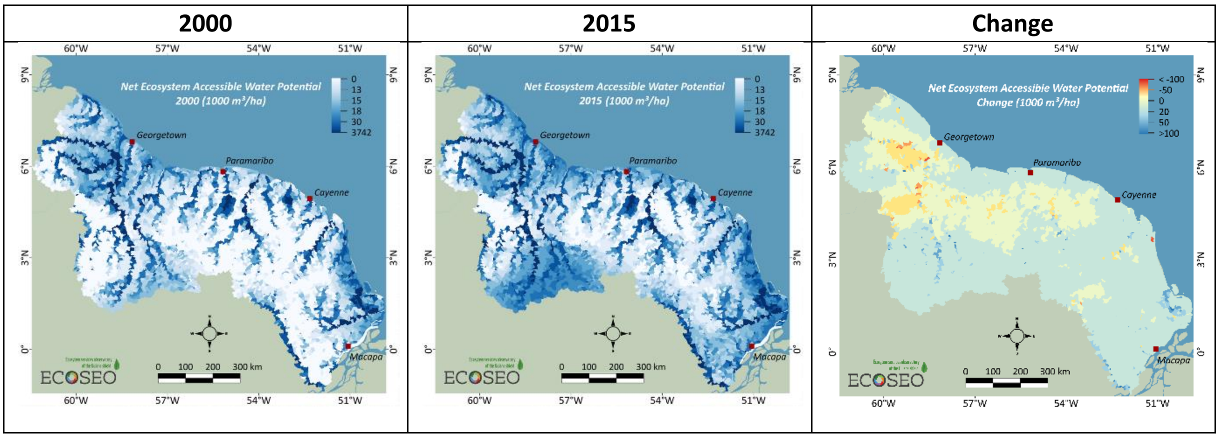


Figure 46 : Net Ecosystem Accessible Water Potential (NEAWP), in 1000 m3 per ha, per Ecosystem accounting units (SELUs)

IV.4.2.1.4 Table III: Total use of ecosystem water

Water uses are recorded in the Basic water balance (Table I), replicated, and possibly detailed in Table III.

Main water uses are municipal water, hydroelectricity production and uses by agriculture. On the average, water is very abundant in the Guiana Shield but consumption is mainly concentrated in the populated and agricultural coastal areas and at the large dams of Brokopondo in Suriname and Petit-Saut in French Guiana, which are firstly designed for electricity production.

In absence of detailed local statistics, water use was estimated in ECOSEO in relation to other variables, in particular LULC data. In the case of municipal water, it is possible to use population estimations by grids produced by the EU JRC's Global Human Settlements database to downscale FAO AQUASTAT national statistics. Use of water for hydroelectricity production has been estimated by the runoff at the exit of the reservoirs. For agriculture, water use is derived from FAO AQUASTAT, LULC, CGIAR and evapotranspiration data.

Green Water (W9-2 in the table model) is the share of the rain, which feeds agriculture (rainfed agriculture). In ENCA-QSP_FTI, it is estimated as 50% of the spontaneous evapotranspiration (W31AET) of cropland and grassland, i.e. LULC classes 21, 22, 23 and 30. Deficit in green water needs to be compensated by irrigation, which is blue water.

Figure 47 illustrates the Total use of ecosystem water.

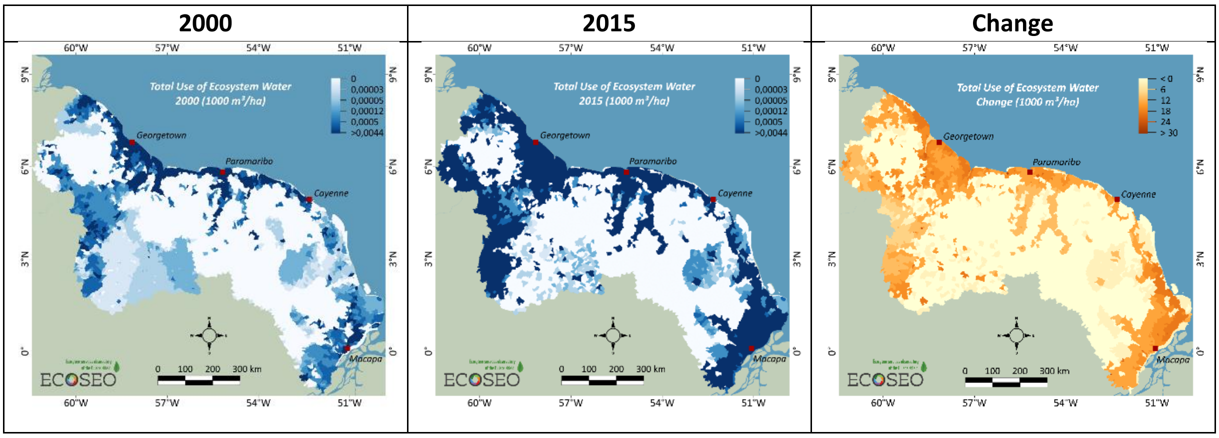


Figure 47 : Total use of ecosystem water, in 1000 m3 per ha, per Ecosystem accounting units (SELUs)

IV.4.2.2 Quantitative & qualitative synthesis of Water account

IV.4.2.2.1 Sustainable intensity of water use (SIWU)

<u>The index of Sustainable Intensity of Water Use (SIWU)</u> is, as for carbon account, the ratio of the net ecosystem accessible surplus to the total use of the resource, calculated respectively from Table II and Table III:

$$\boxed{\text{SIWU= Net Ecosystem Water Surplus (NEWS) / Total use of ecosystem water}}$$

Eq. 11 : Sustainable Intensity of Water Use (SIWU) index

When this ratio is > 1, it is taken as =1, when < 1, the ratio is taken, showing unsustainable use of water, i.e. ecosystem degradation resulting from water use. It is important to note that the stress in a given year is calculated at the end of the accounting period and that the impact of the intensity of water use will therefore be felt in the next period.

The resulting SIWU index demonstrates as expected that there is no problem of water quantities in the region (Figure 48). The water surplus fully compensates the total use of the ressource. Therefore, water issues will only be reflected in terms of water quality (see below).

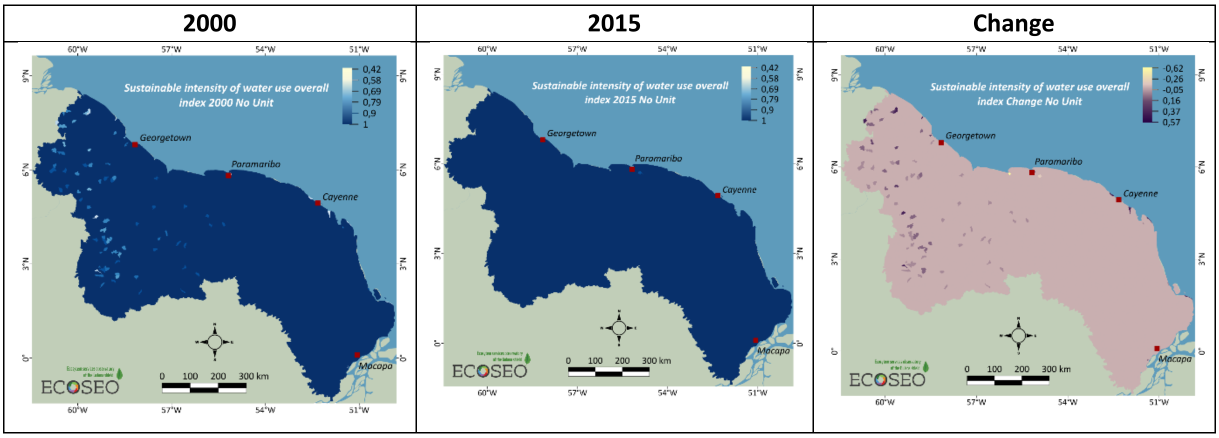


Figure 48 : Sustainable Intensity of Water Use (SIWU) index

IV.4.2.2.2 Ecosystem water health (EWH)

Would the quantitative aspects not matter, water quality issues can be suspected. Water quality issues of large reservoirs like Brokopondo and Petit Saut are mentioned in the literature but other issues relate, for example, to pollution by mining extraction, by agriculture or by untreated municipal wastewater. In the latter case, main cities being at the seaside, their pollution do not affect rivers but transitional and marine coastal ecosystems instead. As insufficient information on coastal zones was accessible for this demonstration of ENCA-FTI accounts, these ecosystems have not been assessed in the present study. Estimation of pollution from mining extraction has been attempted, taking into accounts areas of exploitation by ecosystem accounting unit (SELU) and water runoff, with the assumption that one contaminated SELU contaminates in turn three downstream basins. Moreover, groundwater salinity has been estimated as a coefficient based on the area mapped in the BGR/UNESCO WHYMAP database used for ENCA-FTI. It is a static index. In both cases, the purpose was to quickly highlight some pollution issues and invite experts for more precise inputs in the future based on their own data sources. The list of indicators, depending on available data and knowledge, can be as long as they contribute to the overall diagnosis of ecosystem health. There is no unique solution to deriving a diagnosis from the set of indicators retained. The rationale is similar to a medical diagnosis where the conclusion is not necessarily a function of the number of observations but more probably of the severity of a few or even of one.

The composite index of ecosystem water health (EWH) illustrated by Figure 49 summarizes symptoms of ecosystem distress from ground water salinity and gold mining. Ground water salinity being a static index, changes reflects above all potential impacts of gold mining on freshwater, such as mercury contamination and water turbidity (Rahm et al., 2020b).

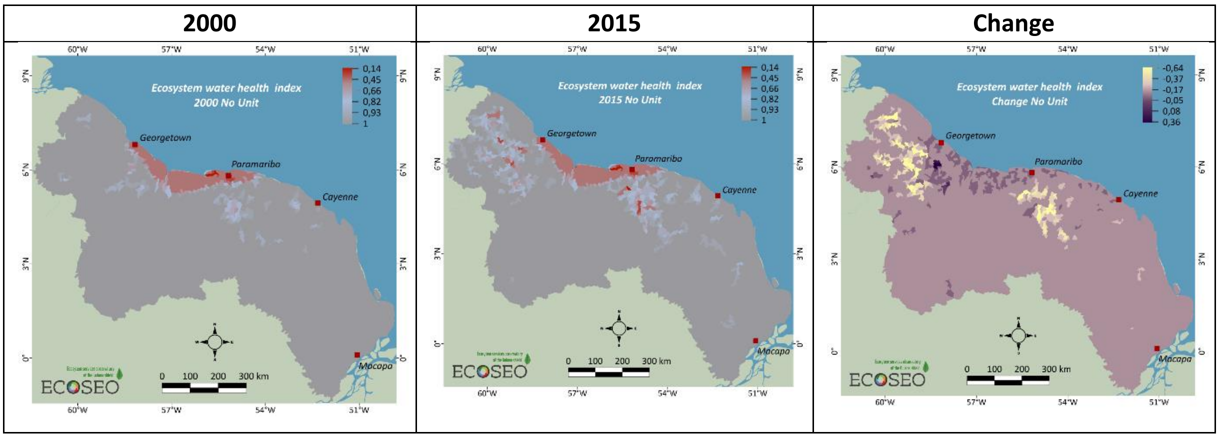


Figure 49 : Ecosystem water health (EWH) index

IV.4.2.2.3 Water internal unit value (WIUV)

Finally, as for the carbon accounts, the **Water ecological internal unit value (WIUV)** is the arithmetic average of the quantitative index of Sustainable intensity of water use (SIWU) and the qualitative index of Ecosystem water health (EWH):

$$\boxed{WIUV = (SIWU+EWH)/2}$$

Eq. 12 : Water ecological internal unit value (WIUV) index

The Water ecological internal unit value (WIUV) is a measure of the Water ecological internal “price”, based on physical variables, not money. At this stage, it does not consider the external effects of water condition on biomass and ecosystem integrity; the integration is done in a next step where Ecosystem ecological value will be calculated in ECU (Ecosystem capability units).

When this ratio is > 1, it is taken as =1, when < 1, the ratio is taken showing degradation. As there is no problem of quantity, the WIUV only highlights the problems related to the quality of water resources. As long as no data is available on the use of groundwater, the latter are assessed in this application only in relation to gold mining. Additional data on other pollutions, including for lakes and reservoirs would give a more complete picture. The large area of salinized groundwater suggests a potential strong limitation to the use of groundwater.

2000	2015	Change

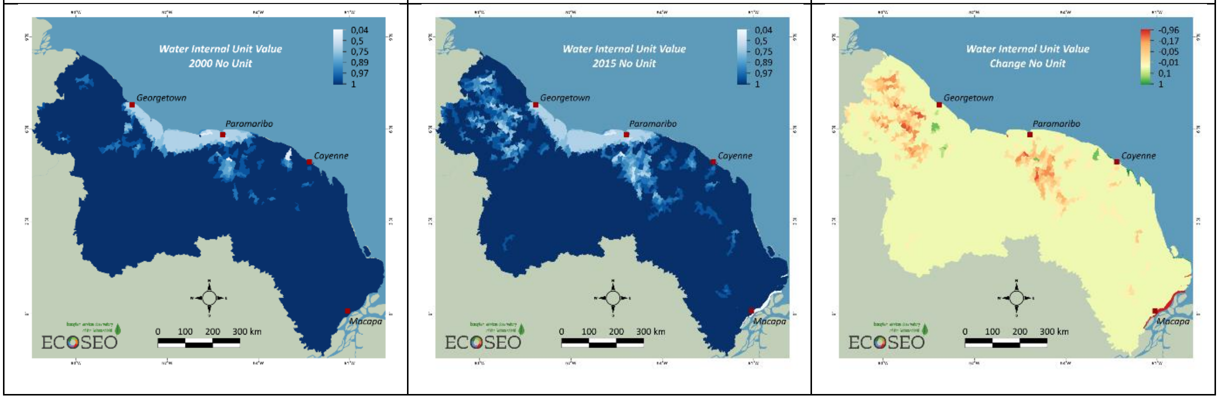


Figure 50 : Water ecological internal unit value (WIUV) index

IV.4.3 Ecosystem infrastructure functional services account

The 2005 Millennium Ecosystem Assessment report defined ecosystem services (ES) as benefits people obtain from ecosystems and distinguishes four categories of ecosystem services, where the so-called supporting services are regarded as the basis for the services of the other three categories: provisioning, regulating and cultural services (MA, 2005). To prevent double counting in ecosystem services audits, for instance, The Economics of Ecosystems and Biodiversity (TEEB) replaced "Supporting Services" in the MA with "Habitat Services" and "ecosystem functions", defined as "a subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services" (TEEB, 2010). Ecosystems are multifunctional and they potentially deliver a bundle of material and intangible services, which are used in various proportions according to the natural or socio-economic contexts.

In the case of provisioning services, quantities can be measured in simple terms as tonnes or m³ or even in joules. It allows producing material flow type accounts as well as supply and use tables to bridge them to economic statistics of products and to the national accounts. Provisioning services of food, energy and fibre provided by ecosystems are incorporated by the economy (formal and informal) into commodities and constitute by far the major part of all ES. They are duly recorded in ENCA.

Other ecosystem services, so-called regulating and socio-cultural in the provisional Common International Classification of Ecosystem Services (CICES)[9], are more complex to characterize and to measure as they are intangible and cannot be quantified directly.

ES-based approaches attempted to assess regulating and socio-cultural services with a variety of methodologies and measurement units. One consequence of this methodological issue is that aggregation of several services is problematic, even impossible beyond a small number of them. **The standpoint of ENCA is that because intangible ecosystem services are not additional, it is preferable to measure the potential of ecosystems to provide them.** This potential is assessed from a system perspective considering their robustness, integrity and resilience, on the one hand, and people's access on the other hand. In ENCA, only access to ecosystem potential in the neighbourhood is considered (Long distance access through transport of persons or goods is not recorded as an ecosystem service but as an economic service).

[9] The Common International Classification of Ecosystem Services (CICES) is a classification scheme developed to accounting systems (like National counts etc.), in order to avoid double counting of Supporting Services with others Provisioning and Regulating Services. https://cices.eu/

Three types of systems are considered for this assessment: the land systems, the river systems and the coastal marine systems. As mentioned earlier, the latter have not been assessed in the ENCA-QSP_FTI application. Figure 51 shows how the Ecosystem infrastructure functional services account is integrated in ENCA, following the same accounting table structure as for the carbon and water accounts. **Ecosystem infrastructure account is expressed in <u>ha weighted by various indices.</u>**

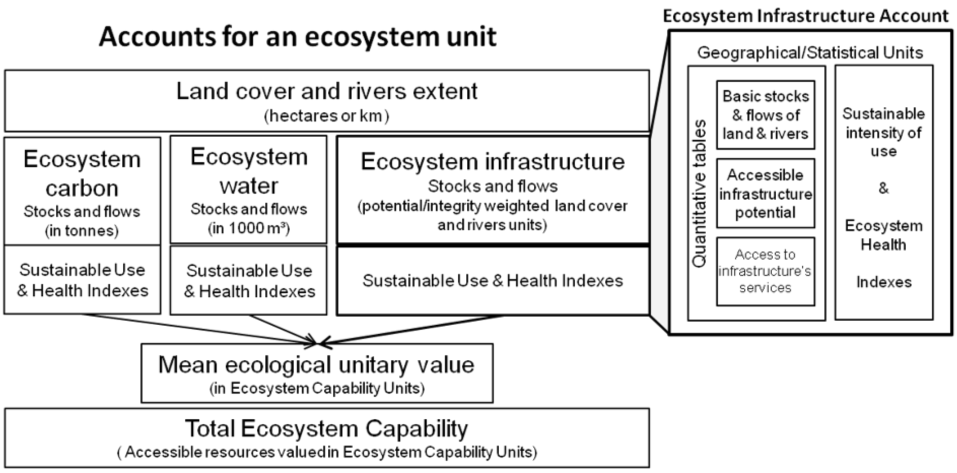


Figure 51: Integration of the ecosystem infrastructure account in ENCA. (Source: Jazmín Arguëllo, 2019).

Figure 52 **below shows the general content of the four accounting Tables for Ecosystem infrastructure in ENCA-QSP with the main outputs described in the next subsections. The ecosystem infrastructure account is composed into one part related to terrestrial ecosystems and another related to aquatic ecosystems;** both are then synthesized**.** As for carbon and water accounts, it includes quantitative and qualitative assessments that are translated respectively by the intensity of use and health conditions. The accounts are structured in the same way with three quantitative tables (Table I to III) and one table that synthetizes quantitative and qualitative information (Table IV).

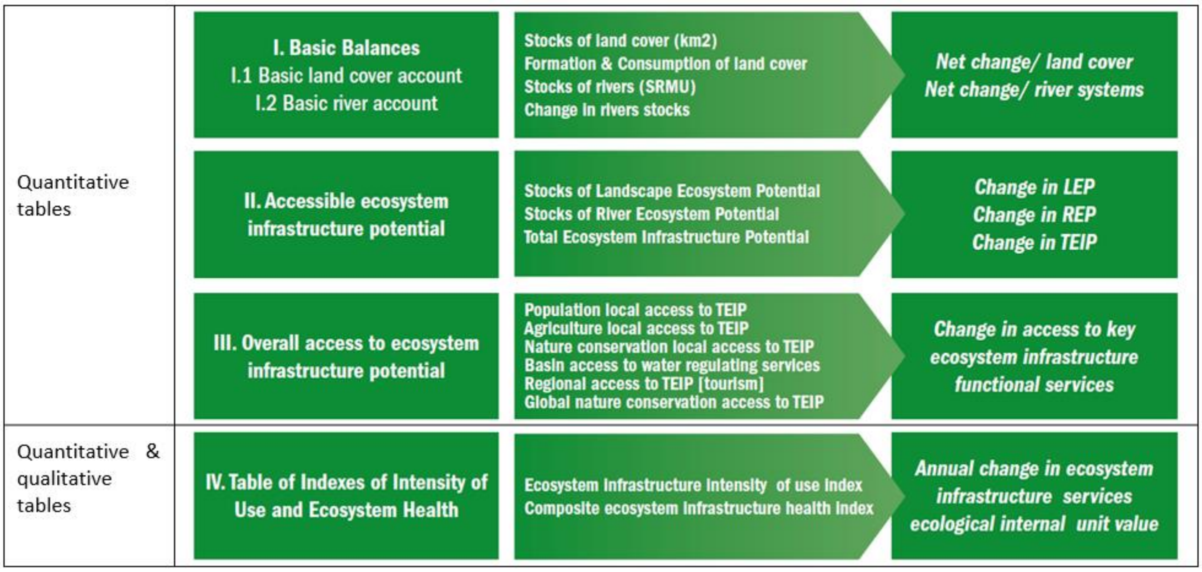


Figure 52: Structure and content of the ENCA-QSP Ecosystem infrastructure functional services account

Figure 53 illustrates the main processing steps of the Ecosystem infrastructure account and the main outputs (and their relationship) that are extracted from Tables 1 to IV. It shows in particular that **biodiversity holds an important place in the accounting Table IV of indices of ecosystem health**. **The purpose of this account is not to produce a comprehensive indicator of species biodiversity but to**

use biodiversity indicators to make a diagnosis of ecosystem health. Biodiversity is not recorded as stocks and flows. The number of species in one ecosystem compared with another is not necessarily of interest; instead, biodiversity change is an essential indicator of the present and future state of an ecosystem. Even with such change, losses or increases of species need to be interpreted in the context of the ecosystem health assessment and considering an appropriate baseline.

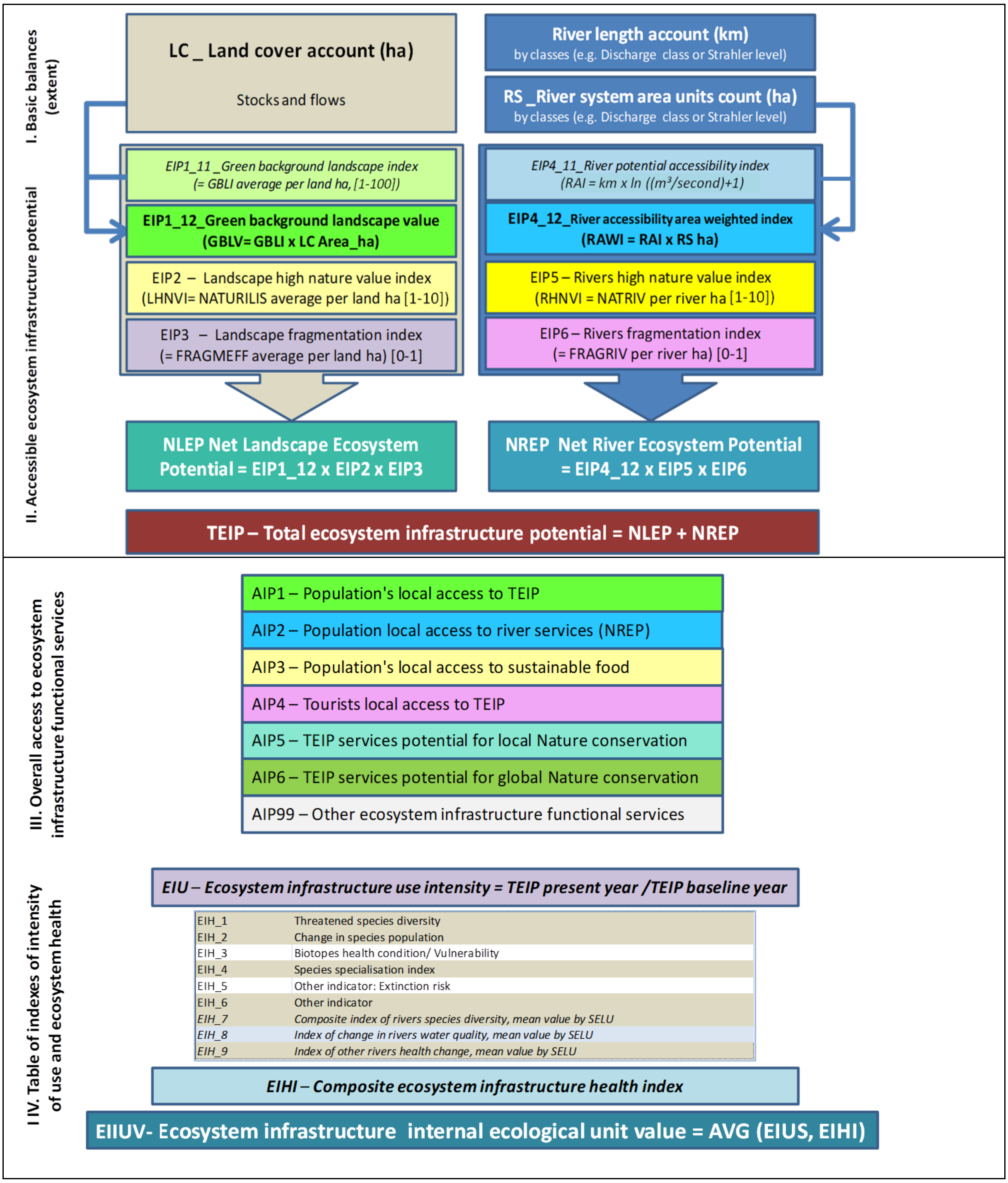


Figure 53: Main processing steps of the Ecosystem infrastructure account

IV.4.3.1 Ecosystem infrastructure quantitative tables

IV.4.3.1.1 Table I: The ecosystem infrastructure basic balances

The ecosystem infrastructure accounting framework is composed into one part related to terrestrial ecosystems and another related to aquatic ecosystems, resulting in two different accounting units and two accounting sub-tables:

1. **Land cover (inland and coastal marine) units, <u>in hectares.</u>**

2. **River systems extent (RSE) units, <u>in km.</u>**

Rivers are recorded separately in a first step as they are considered as objects of the hydrological networks that connect ecosystems.

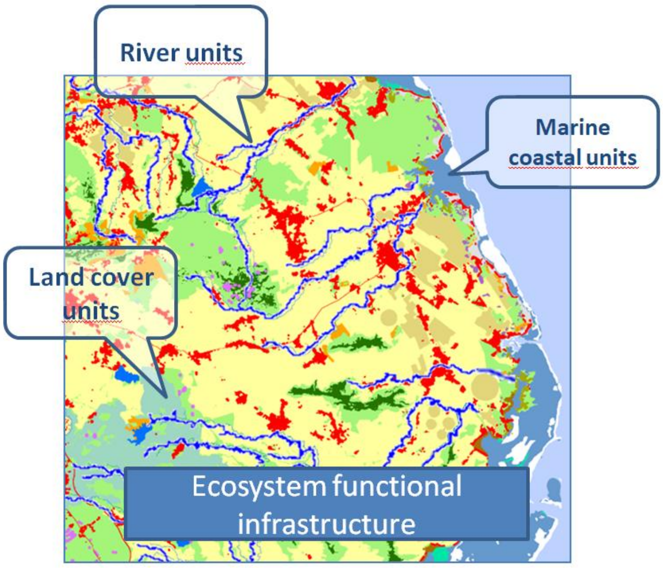


Figure 54 : Ecosystem functional infrastructure

<u>**The basic balance of land cover**</u> was produced earlier (see IV.3 Basic LULC accounts) for each ecosystem accounting unit (SELU), i.e. watershed of level 10. The accounting table records the area of each LULC class in 2000 and 2015 for land cover stocks and the area of LULC change for land cover flows (consumption and formation).

<u>**The basic balance of the River system extent (RSE)**</u> is based on river length. As for LULC data, rivers are grouped in classes based on their characteristics to differentiate their role in the ecosystem. In ECOSEO, river reaches are classified according to their discharge level in m^3/second (Figure 42):

1. Streams, Flows < 1 m^3/s
2. Small rivers - 1=<Flows<5 m^3/s
3. Medium river – 5 =< Flows < 10 m^3/s
4. Large river - 10 =< Flows < 100 m^3/s
5. Very large river – 100 m^3/s < Flows

Rivers are extracted by SELU, which is possible without creating outlier units during the intersection because the ecosystem accounting units (SELU) are based on the limits of river basins. Change in basic river stock is only indicative at this stage. It includes change of rivers due to water use and river management, and changes due to natural causes, including efficient rainfall.

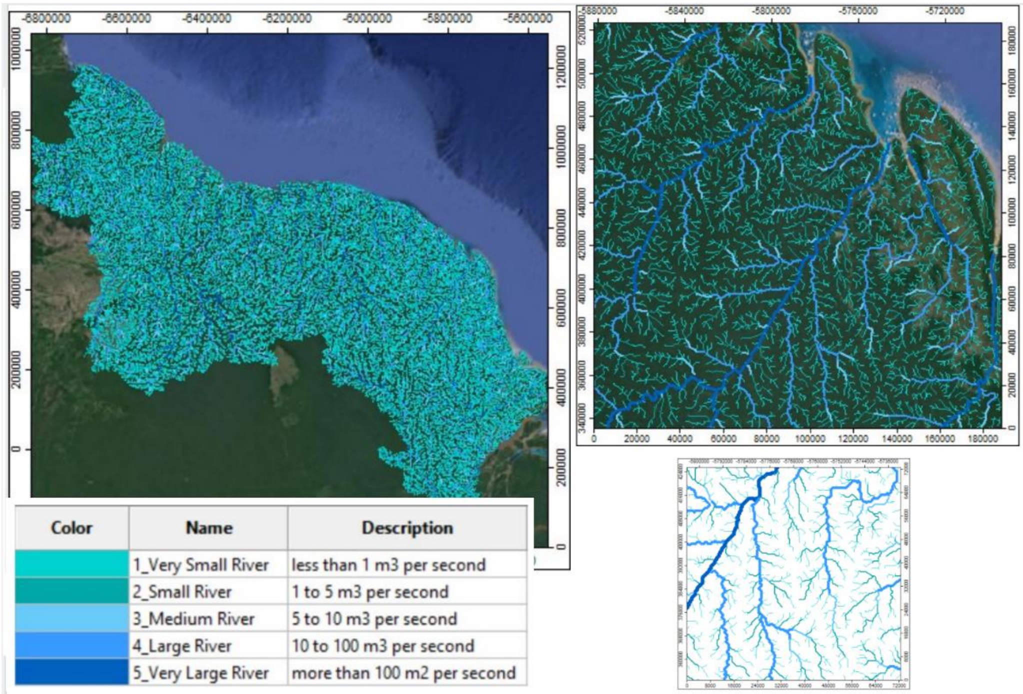


Figure 55: River extents classified in five classes based on its flows.

IV.4.3.1.2 Table II: Accessible ecosystem infrastructure potential

The ecosystem accessible infrastructure potential aims at assessing the basic capacity of ecosystems to deliver functional services. Looking at distinctive ecosystem features, the number of datasets used is limited because of availability and by the fact that complex combinations of many layers make it more difficult to understand the meaning of the indicator. Ecosystem infrastructure potential is useful for spatial comparison of ecosystems and for temporal monitoring of degradation or enhancement.

The account provides different information about the potential of each area, summarized by the **Total ecosystem infrastructure potential (TEIP)**[10], i.e. the sum of the **Net Landscape Ecosystem Potential (NLEP)** for terrestrial ecosystems and the **Net River Ecosystem Potential (NREP)** for river ecosystems[11].

Calculations of NLEP and NREP are made separately but following the same principles. In ECOSEO, both are derivate from three sub-indicators providing the same type of information (see Annex VIII.3 & 0 for more details).

1. Sub-indicator 1 gives an index on basic potential of land and river:

    a. **Green Background Landscape Index (GBLI)**. Land cover units are converted into Green Background Landscape units to compute the GBLI and then the total value (GBLV). GBLI reflects the biomass potential, independent from human cultivation. It indicates biomass sustainability. The results show that degradation mostly take place in deforested areas and low vegetation where fires occurred;

[10] There is no single formula to calculate the Total ecosystem infrastructure potential (TEIP) indicator but some principles may be followed in ENCA-QSP, having in mind the purpose of ecosystem accounting (measuring degradation in a transparent, reproducible and verifiable way), and the constraint of working with the best existing data.
[11] Net means that the indicators are the result of calculation including positive as well as negative values

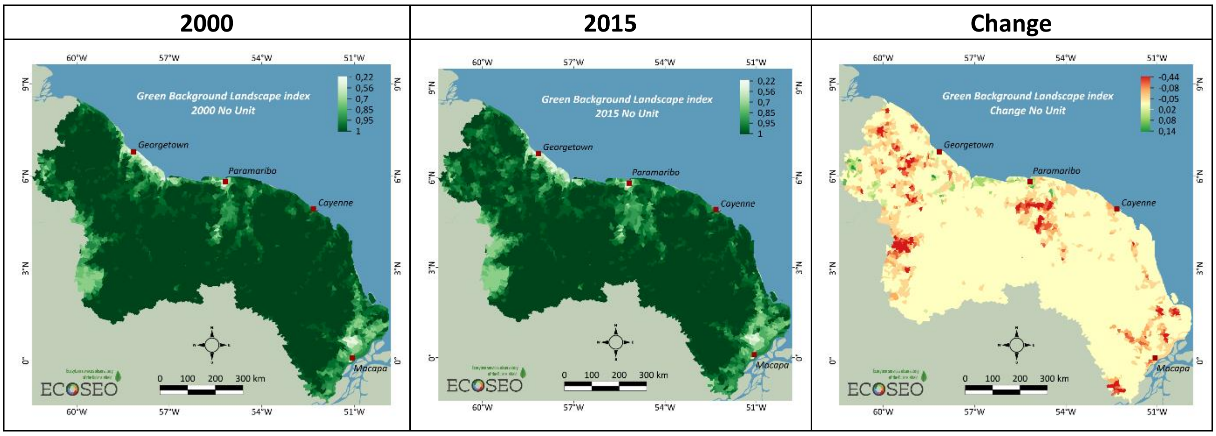


Figure 56 : Green Background Landscape Index (GBLI)

b. **River Accessibility Weighted Index (RAWI)**. River system units are weighted with a River Accessibility Potential Index calculated by km. The vector map of this index is then rasterized using the same grid system as for land cover, which gives the pixel value of RAWI. RAWI is a measurement of a potential based on rivers extent (their length) and discharge. It describes the presence of rivers and their importance for the overall functioning of ecosystem accounting units (SELUs). It can be noted that RAWI is higher in the valleys (flow effect) and in most areas considered here as high nature value index (HNVI or NATRIV) where it is probably the importance of the micro-river network that dominates. Negative changes reflects places where precipitations were lower in 2015;

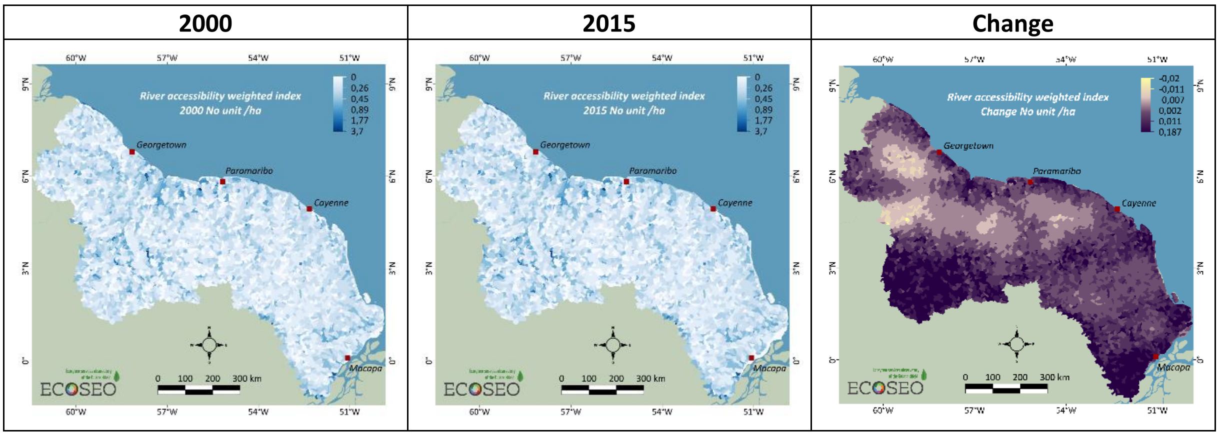


Figure 57 : River Accessibility Weighted Index (RAWI)

2. Sub-indicator 2 characterizes the High nature value, based on protected areas in ECOSEO:

Indexes of high nature value are introduced in order to adjust the previous assessment based on more quantitative considerations. High nature value is derived from what tell scientists and environmental agencies of the importance of particular ecosystems when making the decision of protecting them.

a. **Landscape high nature value index (HNVI or NATURILIS)**. NATURILIS is an indirect measurement based on available designations by science and agencies in charge of nature protection. As for the index of limitation of use due to nature protection (ILUP) presented in the carbon account, NATURILIS is based on protected areas and IUCN categories, considering such zones as high nature value areas;

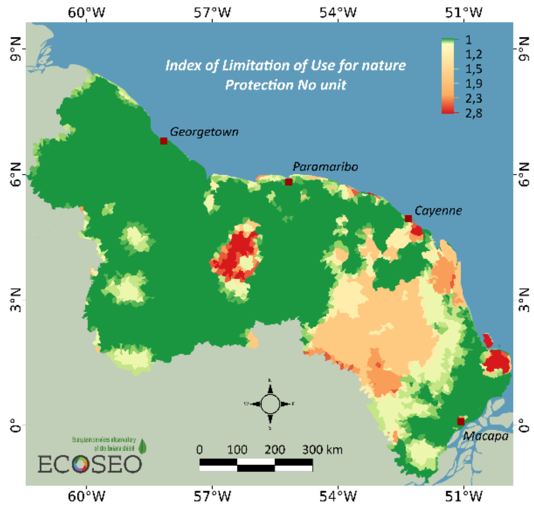


Figure 58 : Landscape high nature value index (HNVI or NATURILIS)

b. **River high nature value index (NATRIV)**. NATRIV is similar to NATURILIS, intersected with actual rivers. NATRIV gives higher nature value to rivers;

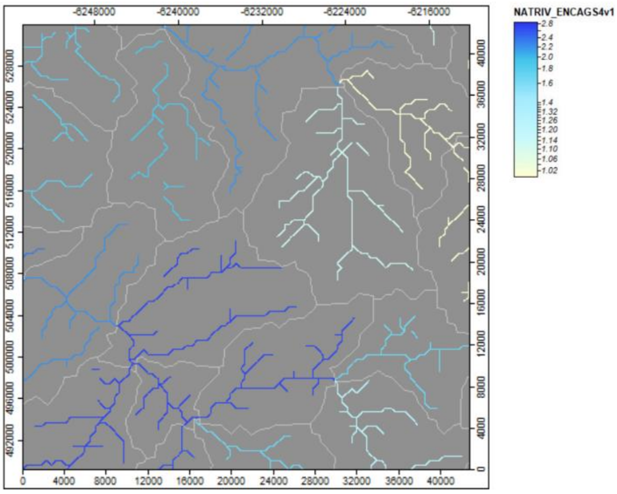


Figure 59 : River high nature value index (NATRIV)

3. Sub-indicator 3 refers to the fragmentation of landscape and rivers. Both indexes combine three spatial horizons, those of small (SELU level), medium and large river basins, with the purpose to reflect altogether local fragmentation and fragmentation of the ecological corridors of which SELUs belong.

   a. **Landscape fragmentation index (FRAG_MEFF)**. Fragmentation by artificial land cover (urban areas, mining extraction sites and large transport facilities and networks) is a major issue in landscape ecological integrity as it disrupts ecological corridors and reduces critical spawning areas. FRAG_MEFF is based on the principles of the Effective Mesh Size (Jaeger et. al, 2011). Roads having no date attributes, the Landscape fragmentation index is rather static and only changes in land cover has an impact. This point should be considered with attention in future updates as long as an economic development is always accompanied with the development of transport infrastructures;

2000	2015	Change

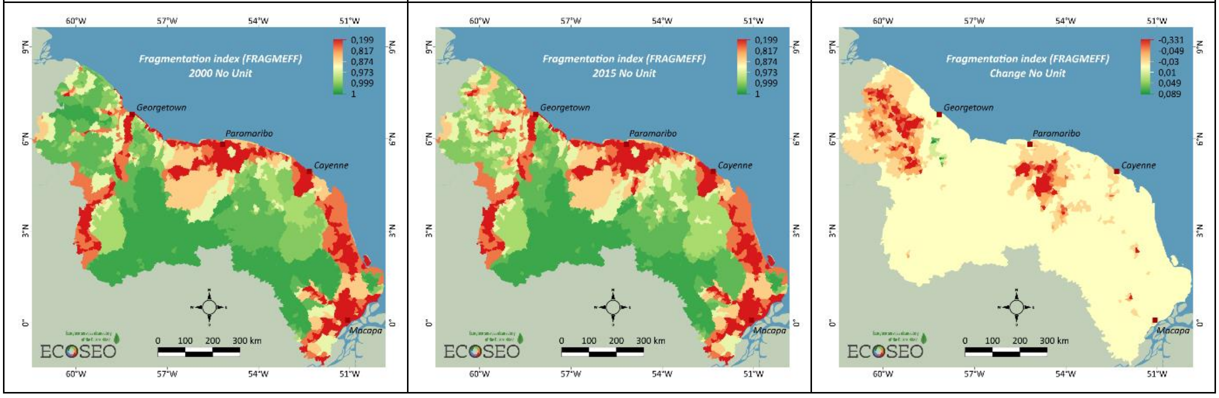


Figure 60 : Landscape fragmentation index (FRAG_MEFF)

b. **River fragmentation index (FRAGRIV)**. FRAGRIV is an index of rivers fragmentation in river basins. Dams provide access to water resource and to hydroelectricity, as recorded in the water account. However, rivers fragmentation disrupts ecological corridors, hinders fish migration and blocks sediments flows.

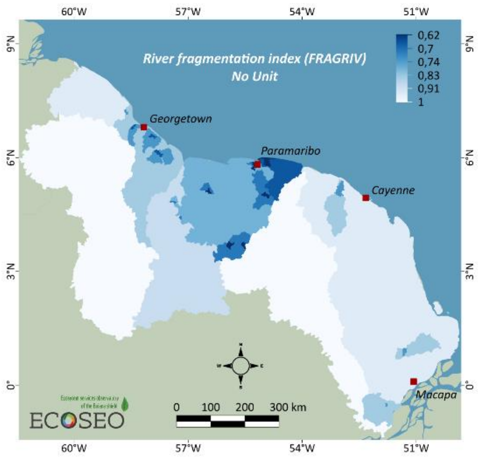


Figure 61 : River fragmentation index (FRAGRIV)

Lastly, GBLV and RAWI are weighted with High nature value and Fragmentation indexes. For landscapes, the result gives the **Net Landscape Ecosystem Potential (NLEP)**, and for rivers, the **Net River Ecosystem Potential (NREP)** (see processing steps presented before in Figure 53):

$$\boxed{NLEP = [GBLV] \times [NATURILIS] \times [FRAG\_MEFF]}$$

Eq. 13 : Net Landscape Ecosystem Potential (NLEP)

$$\boxed{NREP = [RAWI] \times [NATRIV] \times [FRAGRIV]}$$

Eq. 14 : Net River Ecosystem Potential (NREP)

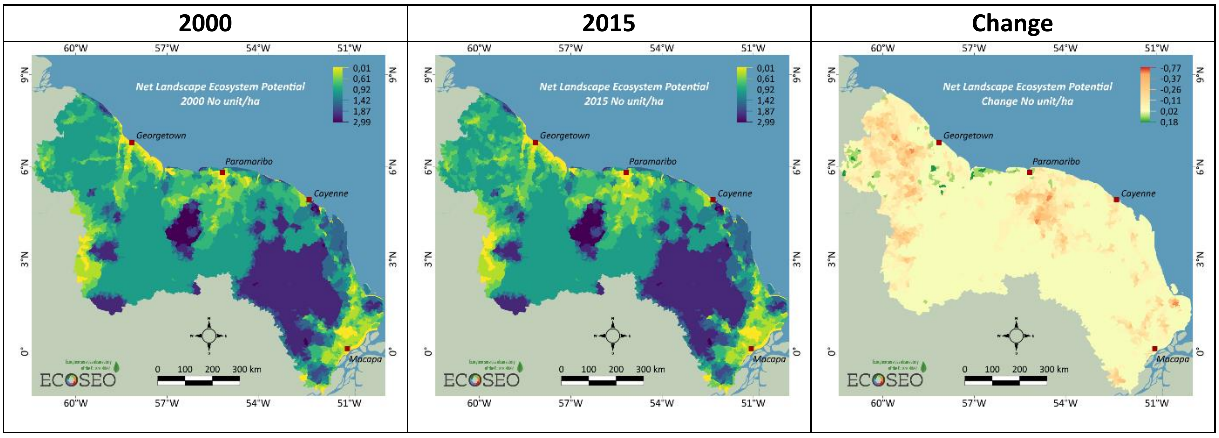


Figure 62 : Net Landscape Ecosystem Potential (NLEP)

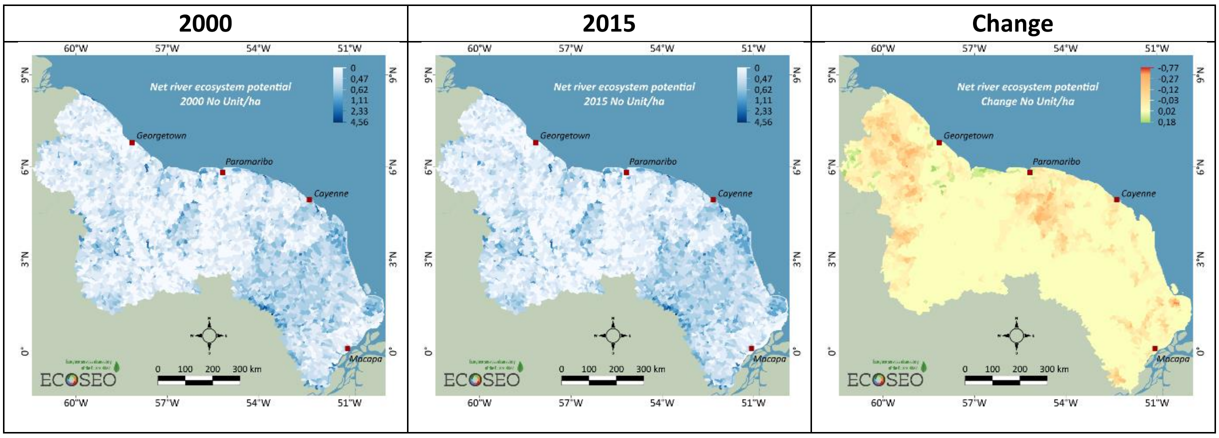


Figure 63 : Net River Ecosystem Potential (NREP)

Finally, the sum of NLEP and NREP indicates the **Total ecosystem infrastructure potential (TEIP),** based on terrestrial and river ecosystems (Figure 53):

$$\boxed{\text{TEIP} = \text{Net Landscape Ecosystem Potential (NLEP)} + \text{Net River Ecosystem Potential (NREP)}}$$

Eq. 15 : Total ecosystem infrastructure potential (TEIP)

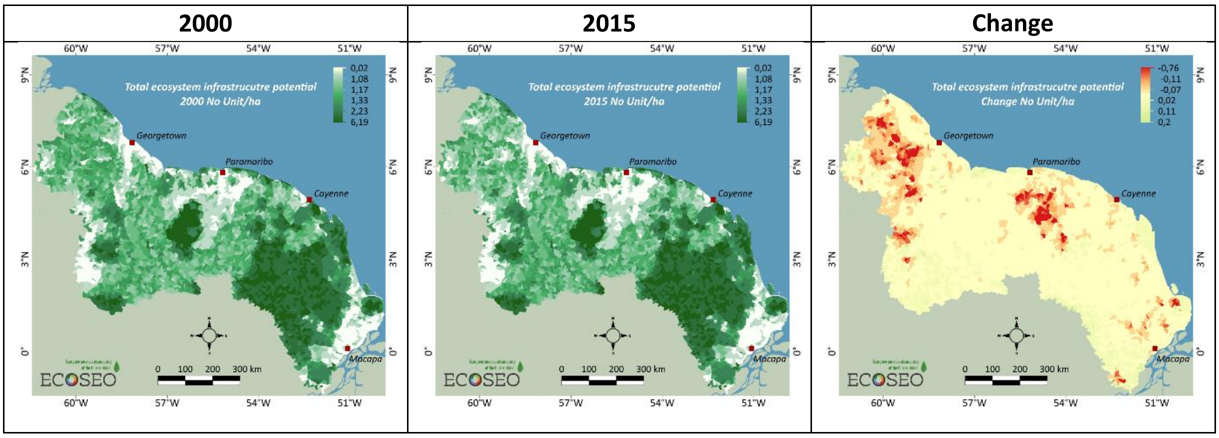


Figure 64 : Total ecosystem infrastructure potential (TEIP)

IV.4.3.1.3 Table III: Overall access to ecosystem infrastructure functional services

As mentioned in introduction of this account, ecosystem services are "the benefits people obtain from ecosystems" (MA, 2005). Provisioning services (drinking water, timber, wood fuel…) are tangible things, measured in tonnes or m^3 in the biocarbon and water accounts, that can be exchanged or traded, hence transported. Instead, regulating services (maintaining the quality of air and soil, providing flood and disease control, pollinating crops…) and socio-cultural services are intangible and linked to places. Unlike carbon and water, where the accessible resource exists independent of any actual use, **intangible functional ecosystem services need to be both accessible and actually physically accessed to exist. Therefore, they can be measured only indirectly through their accessibility to people.**

The purpose of Accounting Table III, overall access to ecosystem infrastructure functional services, is to assess access to services by bringing together supply and demand. Access is an opportunity to use. Access to services is not equivalent to users' effective demand, which has to be recorded in separate tables of ecosystem services, as its assessment requires additional data on users' behaviour and preferences and modelling. However, overall access gives a first indication of the importance of the intangible services that can be supplemented by additional analysis; one advantage for the latter being the consistent data framework on which they can rely.

The specific goal of Table III is to assess the accessibility to people of the Net Landscape Ecosystem Potential (NLEP), the Net River Ecosystem Potential (NREP) or the Total ecosystem infrastructure potential (TEIP), in order to generate different "Access Infrastructure Potential" (AIP) indicators for further analysis if needed (Figure 53).

People accessibility can be estimated via neighbourhood analysis, which shows the capacity of people to benefit from a service. One simple way of mapping potential (or probable) access to services is to use Gaussian filter technique. It transforms a crisp map into a fuzzy/smoothed map where each pixel records neighbouring population within a given radius (Figure 65). It is then possible to measure ecosystem services as the square root of either TEIP, NLEP or NREP multiplied by the smoothed population data. In ENCA, only access to ecosystem potential in the neighbourhood is considered (Long distance access through transport of persons or goods is not recorded as an ecosystem service but as an economic service).

In ECOSEO, five indicators were calculated (see Annex VIII.4 for AIP1 to AIP3 maps):

- **AIP1 - Population's local access to the Total Ecosystem Infrastructure Potential (TEIP)**
- **AIP2 - Population's local access to river services**, a sub-indicator of the previous; it does not duplicate with the water use recorded in the water account.
- **AIP3 - Population's local access to sustainable food**; this service is not identical to the food produced in SELU for two reasons: 1) only access in the neighborhood is considered and 2) the indicator is weighted by TEIP, which means production from sustainable ecosystem.
- **AIP5 - TEIP service for local/national Nature conservation**; independently of any protection, high TEIP is essential factor for nature conservation;
- **AIP6 - TEIP service international Nature conservation**; the same rationale as previously.

Tourists' local access to TEIP (AIP4) has not been computed because of missing data on tourism. As tourism is an economic activity and not an ecosystem service, what is measured in AIP4 is the attractiveness of ecosystems to tourist.

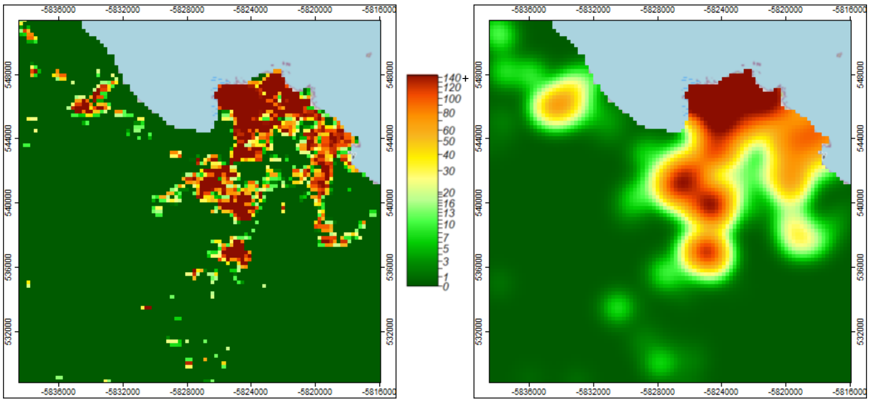


Figure 65: Example of population estimation access around Cayenne in French Guiana from the Global Human Settlement Layer datasets (left) and its smoothed version (right)

IV.4.3.2 Synthesis & analysis of Ecosystem infrastructure account

IV.4.3.2.1 Ecosystem Infrastructure Use Sustainability (EIUS)

As for Carbon and Water accounts, Table IV presents indices of intensity of use and ecosystem health. Important difference is that while carbon and water indexes of sustainable intensity of use are mainly calculated as the ratio of total annual flow of resource / total annual flow of uses, the sustainable intensity of use of the ecosystem infrastructure is calculated from stocks in reference to a target. For ECOSEO, as the monitoring is between 2000 and 2015, the chosen baseline year is 2000, the first year of accounting. The meaning of this choice is to define a target of no net ecosystem degradation (net loss of Total Ecosystem Infrastructure Potential) as compared to 2000. In other terms, we propose here the hypothesis that for the region, boundary on ecosystem capability has been met on year 2000 and should not be bypassed. This kind of indicator is very similar to the Land Degradation Neutral Development defined by the UN Convention to Combat Desertification and adopted as one Sustainable Development Goal (SDG) indicator.

The Ecosystem Infrastructure Use Sustainability (EIUS) index is therefore calculated as follow:

$$\boxed{\text{EIUS = Total ecosystem infrastructure potential (TEIP) present year / TEIP baseline}}$$

Eq. 16 : Ecosystem Infrastructure Use Sustainability (EIUS)

In this case, EIUS for 2015 reflects the change of Total ecosystem infrastructure potential (TEIP) (Figure 66) and highlights hotspots of net loss of TEIP.

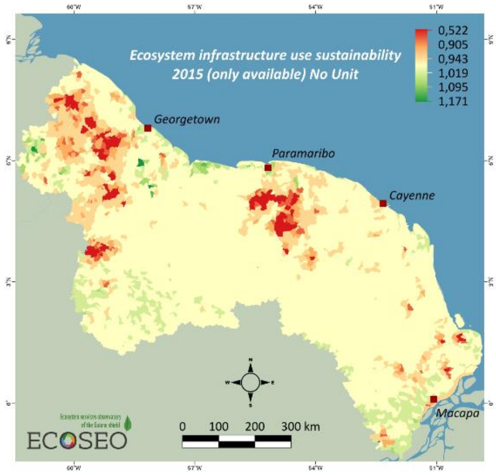


Figure 66 : Ecosystem Infrastructure Use Sustainability (EIUS) for 2015 as compared with 2000 (only available)

IV.4.3.2.2 Ecosystem Infrastructure health (EIH)

<u>The Ecosystem Infrastructure health (EIH) index</u> gives an important place to biodiversity. In ENCA-QSP, species biodiversity and its change are an important component of ecosystem health diagnosis, which is needed to fine-tune, confirm or challenge the assessment carried out in the Total Ecosystem Infrastructure Potential accounts based on spatial data. However, access to biodiversity change data, which is an essential indicator of the present and future state of an ecosystem, remains the main challenge. Ideally, consistent time-series should be available and when such series exist, the sensitivity and temporal stability of the indicators need to be checked. Moreover, standard statistics of species abundance or diversity are not sufficient to inform on biodiversity at the Ecosystem accounting scale (SELUs). Data, models and expert judgments are necessary to develop meaningful indicators. The ENCA-QSP manual discusses in detail and gives recommendations for the inclusion of biodiversity in the ecosystem capital accounting framework (Weber, 2014 – Chapter 7.1.3, p180).

Biodiversity change has to be understood as an indicator of ecosystem degradation during the period of accounting and not as the gap between a theoretical situation and the present one. Species biodiversity is strongly influenced by habitat condition. In the Ecosystem Infrastructure account, change in habitats extent and condition is explicitly recorded in TEIP. Total Ecosystem Infrastructure Potential Therefore, the added value of the species biodiversity change indicator has to be clear in order to avoid redundancy with landscape/riverscape biodiversity change.

Although important sources exist, they do not provide immediately the kind of indicators needed and further processing is needed. Data source to consider are in particular the IUCN data and the Global Biodiversity Information Facility (GBIF) database, and recent developments in the context of the Group on Earth Observations Biodiversity Observation Network (GEO-BON) or project like the Local Biodiversity Intactness Index (LBII). Exploiting them for producing reliable indicators of species biodiversity change for SELUs is a task going far beyond what statisticians/accountants can do and should involve the scientific community. For accounting, the purpose is not to reflect the details of the large variety of conditions and species, but to have diagnoses based on the best knowledge. As long as this knowledge is incomplete, thematically, spatially and historically, experts' judgments are necessary to interpreting raw data. Recent development of the PREDICTS/Land Biodiversity Intactness Index is an example of ongoing progress. At this stage, the reference to remote historical condition limits the interest of the index for accounting but the delivery of annual data is announced, which would provide important new data.

For this application in ECOSEO, the ambition regarding biodiversity has been to highlight the importance of the issue using two indicators produced by IUCN and made available on the World Bank website, i.e. Biotope vulnerability (EIH3) and Extinction risks (EIH5), which do not provide change information (see Annex VIII.5). These are completed by change data on rivers water pollution due to gold mining activities and groundwater salinity (EIH8).

Available data from water monitoring networks have been either difficult to access or too much limited to a few monitoring stations to be used. Main cities in the region are coastal or alongside large rivers (Amazon, Maroni, Courantyne or Essequibo rivers…). As long as available data is limited and considering that the accounts do not presently address the marine coastal ecosystems and that the Amazon River is outside of the scope, the assumption done is that urban wastewater do not affect the rivers of the region. However, a well-known river pollution with impacts on ecosystem and people health is the consequence of gold mining activities (water turbidity and pollution with heavy metals such as mercury - Rahm et al., 2020b). An estimation of this pollution has been carried out based on the assumption that the pollution of a river in a SELU is proportional to the area of gold mining upstream. Stating point, an estimation of the pollution of downstream SELUs has been done using the property that SELUs are connected by the hydrological model of Hydroshed. For taking into account the sedimentation of pollutants alongside the river stream, the pollution value has been carried over the next three downstream hydrographic basins only. The level 10 HYBAS having an average area of circa 100 to 150 km^2, the sedimentation model leads probably to an underestimation of the pollution from gold mining. In a next step, these theoretical estimations should be crosschecked with water monitoring data as well as with population health data.

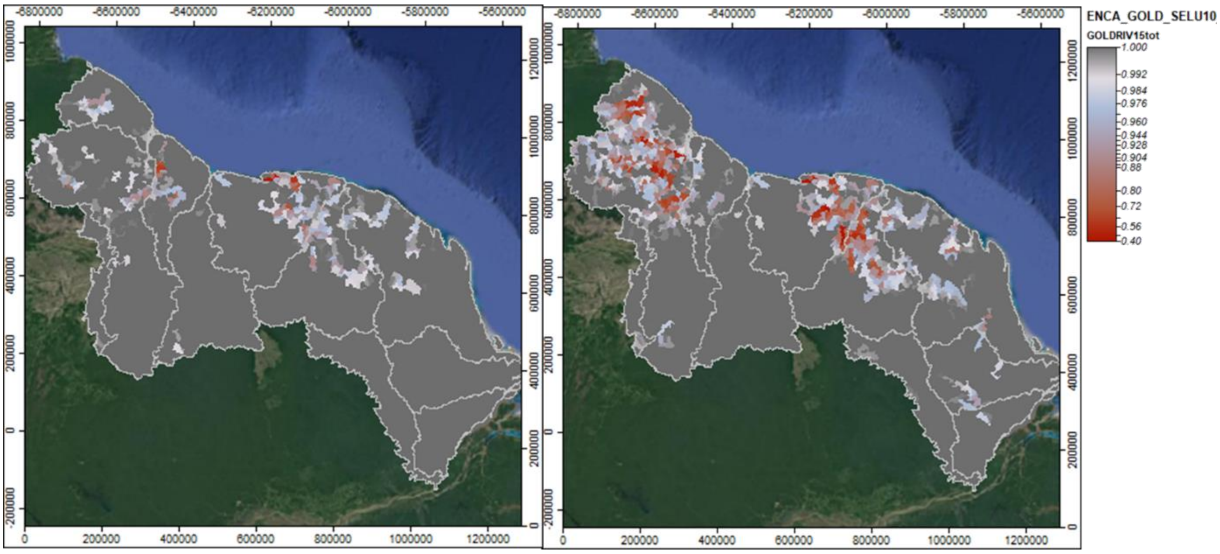


Figure 67: Rivers water quality due to gold mining index, mean value by ecosystem accounting unit (SELU) in 2000 (left) and 2015 (right)

Eventually, the **Ecosystem Infrastructure Health (EIH) index** compile this information by multiplying the mean value per SELU of all available indices:

EIH = Biotope vulnerability (EIH3) x Extinction risks (EIH5)x Water pollution due to gold mining activities and groundwater salinity (EIH8)

Eq. 17 : Ecosystem Infrastructure Health (EIH) index

As **no change data are available for EHI3 and EHI5, changes in Ecosystem Infrastructure Health (EIH) come from river water quality due to gold mining** (Figure 68).

When more biodiversity data exist at the country scale, and/or for particular areas such as protected areas benefitting of studies and monitoring, more appropriate species biodiversity change index can be produced as proposed in the CBD-ENCA-QSP report (Weber, 2014)., but there were not included here.

2000	2015	Change

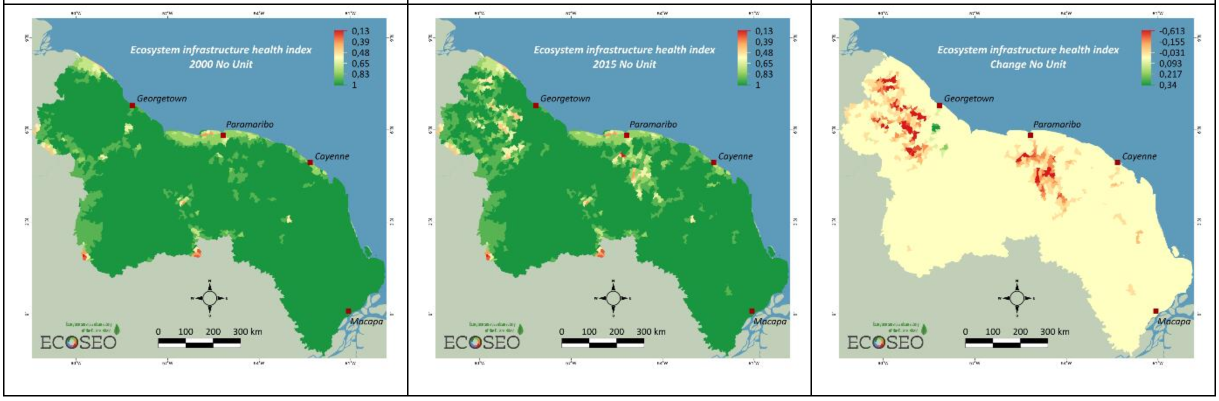


Figure 68 : Ecosystem Infrastructure Health (EIH) index

IV.4.3.2.3 Ecosystem infrastructure internal ecological unit value (EIIUV)

Finally, combining change in impact of ecosystem infrastructure use intensity with the composite ecosystem health index provides a measure of the change in ecosystem ecological integrity. The calculation can be a simple average of the two indicators or can be tuned according to their relative sensitivity.

In ECOSEO, as for carbon and water accounts, the **Ecosystem infrastructure internal ecological unit value (EIIUV)** is the arithmetic average of the quantitative index of Ecosystem infrastructure use sustainability (EIUS) and the other qualitative index of Ecosystem infrastructure health (EWH):

$$\boxed{\text{EIIUV} = (\text{EIUS}+\text{EIH})/2}$$

Eq. 18 : Ecosystem infrastructure internal ecological unit value (EIIUV) index

From the standpoint of ecosystem infrastructure, it is a condition indicator between 0 and 1, which aggregates, combines and summarizes quantitative and qualitative information estimated previously in Tables I to IV. This index of change in ecosystem ecological integrity is equivalent to an ecological price; at this stage, it is still an internal price since biomass/biocarbon and water accessibility are not reflected in its definition. In ENCA-QSP, these factors (i.e. biomass/biocarbon and water accessibility) will be incorporated into the calculation of the Total ecosystem capability (TEC) with its specific unit-equivalent, the Ecosystem capability unit (ECU) (see next section IV.5).

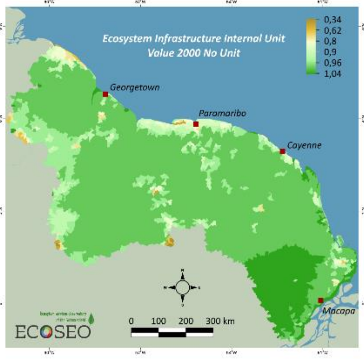
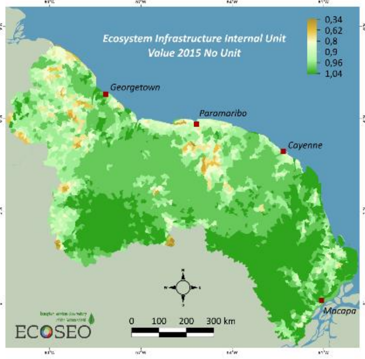
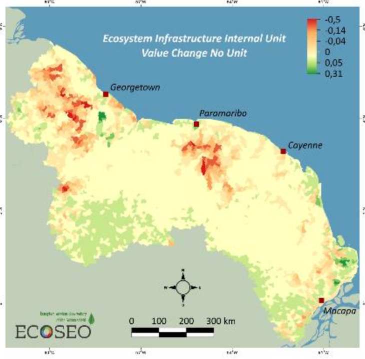
2000	2015	Change
		

Figure 69 : Ecosystem Infrastructure internal unit value (EIIUV) index

IV.5 Total Ecosystem Capability account

The total ecosystem capability account aims at producing an aggregate summarizing the various quantitative and qualitative changes recorded in the accounts of ecosystem carbon, ecosystem water and ecosystem infrastructure. It measures the capacity of the ecosystems to deliver multiple services in a sustainable way. The aggregate has to reflect the real availability of each resource for use, and possible depletion or degradation, but accounting for each individual natural asset separately does not provide a full picture since they are part of systems, i.e. ecosystems. Natural assets interact with each other but also with human communities, and what happens to one is generally of consequence to all.

IV.5.1 Accounting for ecological value

Accounting for ecosystems as natural capital is an attempt to bring together multiple data in a way that can be used for decision-making. Ultimately, these data will express values, the values of nature that may be economic values, benefits and costs, but not only those. Other values can and should be considered and expressed in a way that makes them easy or easier to integrate into decision-making processes.

Ecological value is a broadly used concept, although not normalized. The ENCA-QSP considers the ecological value of the ecosystem capital, not of ecosystems in general. It is close to the definition given in the TEEB Glossary of terms, where ecological value is distinguished from economic valuation:

- Ecological value: non-monetary assessment of ecosystem integrity, health, or resilience, all of which are important indicators to determine critical thresholds and minimum requirements for ecosystem service provision;
- Economic valuation: the process of expressing a value for a particular good or service in a certain context (e.g. of decision-making) in monetary terms.

ENCA-QSP proposes calculation of the ecological value of ecosystem capital in terms of its capability, which encompasses the multiple options offered (not necessarily particular services) and their sustainability over time. **The unit/currency proposed is the Ecosystem Capability Unit - ECU**, which allows quantification of ecosystem degradation or enhancement. In that way, a shift is made possible in decision making from specific adjustments based on stand-alone indicators to a macro approach for balancing the macro-economic indicators (Figure 70). The rationale, calculation principle and use of ECU for accounting is presented in detail in chapter 2 of the ENCA-QSP manual (Weber, 2014).

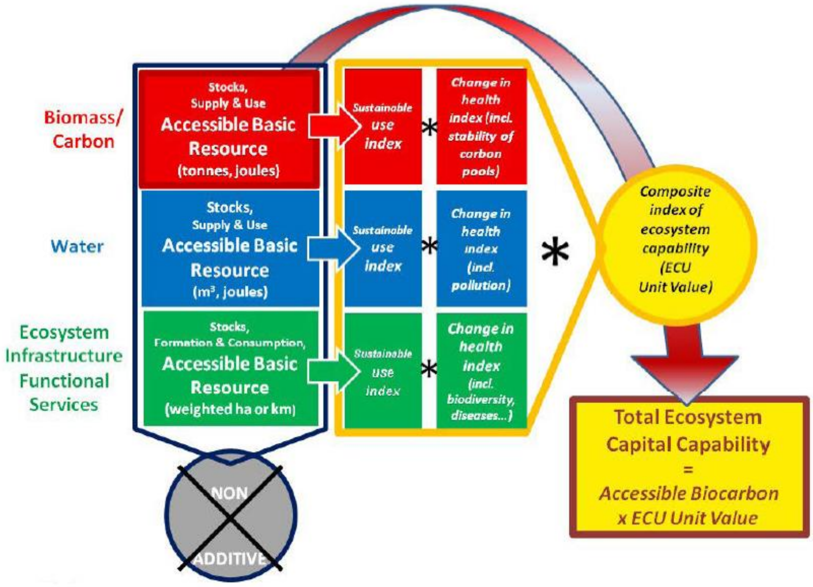


Figure 70 : Calculation concept of ecological value of ecosystem capital in ECU

The ECU unit value is similar to a social price giving in a conventional way the importance given to ecosystems' maintenance. In ENCA, this unit value (or price) is determined by the arithmetic average of the internal unit values of the three components accounts, previously calculated in their respective Table IV (CIUV for Carbon, WIUV for Water & EIUV for Ecosystem infrastructure) (Figure 71):

$$\boxed{\text{ECU price} = (\text{CIUV} + \text{WIUV} + \text{EIUV})/3}$$

Eq. 19 : Ecosystem Capability Unit (ECU) price

The purpose is finally to reveal costs that are presently unpaid as long as they relate to the use and degradation of the ecosystem. As stated earlier in this report, the step taking place after the completion of ecosystem capital accounts in ECU and the establishment of ecological balance sheets for economic sectors and agents (in ECU again) is the calculation of the related monetary costs. The calculation of these costs, which is out of the scope of this study, is based on restoration, avoidance or compensation of the degradation.

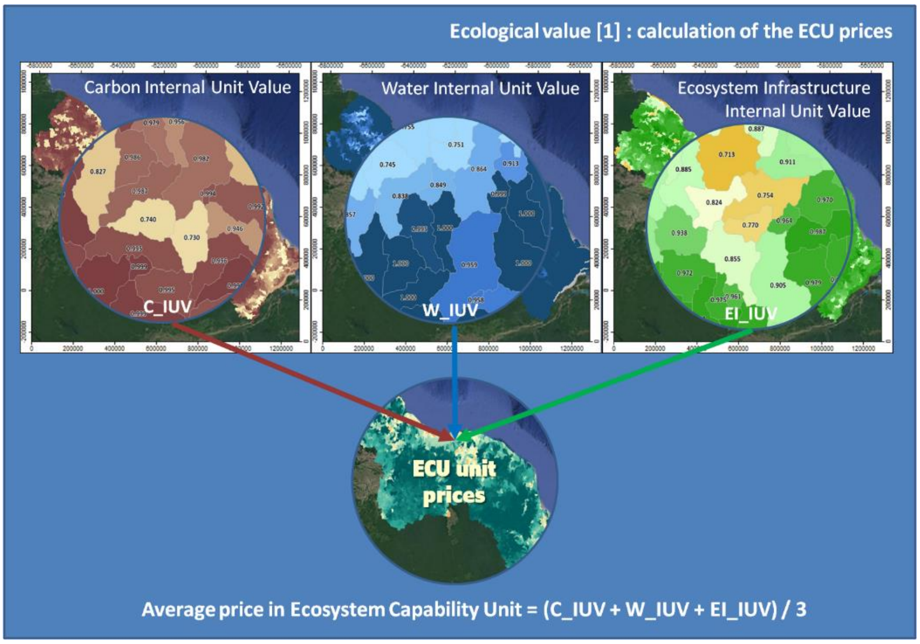


Figure 71 : Calculation of the ECU prices (J-L Weber, 2020)

The unit values or prices in ECU rate the estimated "behaviour" and resilience of systems. Once estimated per ecosystem accounting unit (SELU), it is technically possible to calculate average ECU-prices at different levels, such as LULC units, larger river basins or administrative divisions. In the case of land cover units, this price will reflect the overall SELU context of the land cover unit, not only its individual properties. Figure 72 illustrates the ECU values estimated for 2000 and 2015, as well as the change in ECU between 2000 and 2015. Most of the ECU losses represented by yellow, orange and red colours are located in hotspot areas of mining activity, i.e. on the border between Suriname and Guyana, as well as in northern Guyana. Most of the loss in ECU value occur within areas where gold mining. There are also losses in ECU value in the southeast of Amapá, linked to carbon losses (see Carbon internal unit value (CIUV) index). These carbon losses come from the combined effect of fires and the erosion of soil organic carbon. In contrast, we find increases in the value of the ECU between 2000 and 2015. These represented in green and being found mainly in the southeast of Guyana and in the east of Amapá, come mostly from the gain of carbon following fires that occurred in 2000. By combining the internal values of carbon, water and ecological infrastructure, the values in ECU make it possible to highlight the main combined impacts on ecosystems.

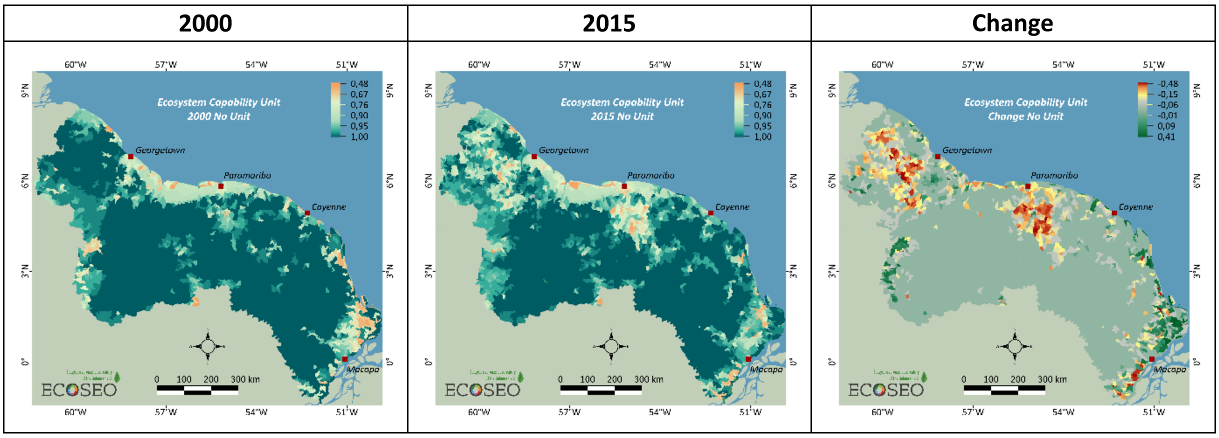


Figure 72 : ECU prices

IV.5.2 The ecosystem capital capability account

The ECU price is then used to calculate, for each ecosystem accounting unit (SELU), the ecosystem capability (i.e. the capacity of the ecosystem to deliver its services) in terms of carbon, water and ecosystem infrastructure, plus the Total ecosystem capability, which combines all three: (Figure 73):

1. **The Carbon Ecosystem Capability (C_EC)**:

C_EC = Net Ecosystem Accessible Carbon Potential (NEACP, in tonnes of carbon) x ECU price

Eq. 20 : Carbon Ecosystem Capability (C_EC), in ECUs

2. **The Water Ecosystem Capability (W_EC)**:

W_EC = Net Ecosystem Accessible Water Potential (NEAWP, in 1000 m^3) x ECU price

Eq. 21 : Water Ecosystem Capability (W_EC), in ECUs

3. **The Ecosystem Infrastructure Capability (EI_EC)**:

EI_EC = Total Ecosystem Infrastructure Potential (TEIP) x ECU price

Eq. 22 : Ecosystem Infrastructure Capability (EI_EC), in ECUs

4. **The Total Ecosystem Capability (TEC)**:

Total Ecosystem Capability (TEC) = C_EC + W_EC + EI_EC

Eq. 23 : Total Ecosystem Capability (TEC), in ECUs

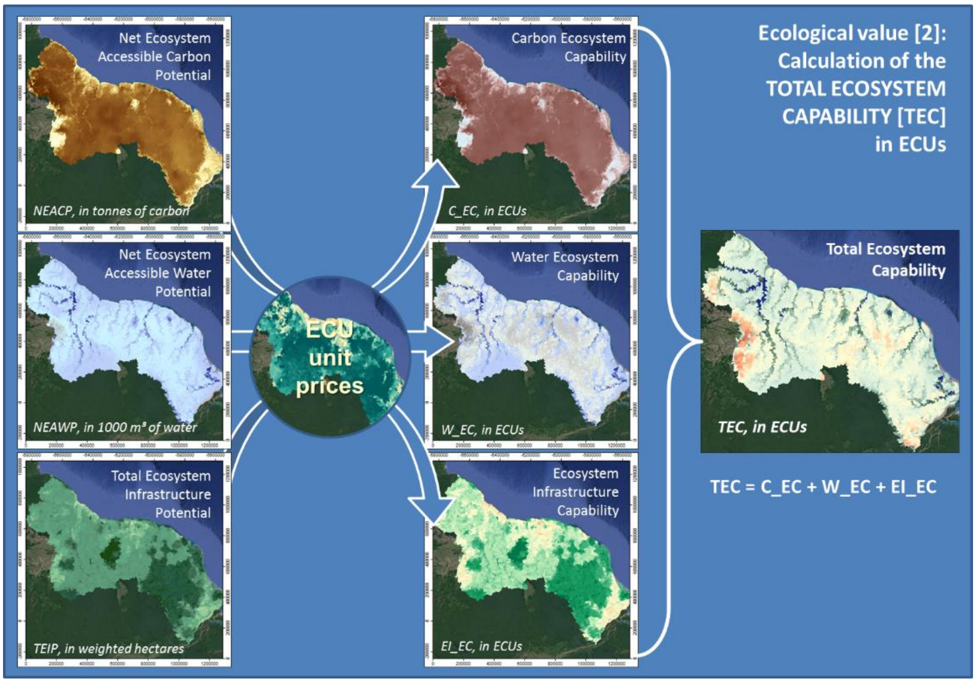


Figure 73 : Calculation of the Total Ecosystem Capability [TEC], in ECUs (J-L Weber, 2020)

In the same way as economic value (quantity x money price) of things of different nature (e.g. 1 kg of bread + 1 litre of milk + 1 month of internet subscription) can be added , the capabilities of the three components can be added when they are priced in ecological value (ECU).

The Ecosystem capability (i.e. its capacity to deliver services) can be analysed by component (Carbon, Water & Ecosystem infrastructure) or in aggregate taking into account the full ecological context through The Total Ecosystem Capability (TEC) index. Figure 74 to Figure 76 below show the ecosystem capability of the three components, while Figure 77 illustrates the Total Ecosystem Capability (TEC). it is important to stress that the TEC is one indicator amongst others; Others can be used to take decisions if more relevant for the situation (or if you are not comfortable with it). TEC is an attempt to combine all components as best as possible in order to provide integrated information.

2000	2015	Change

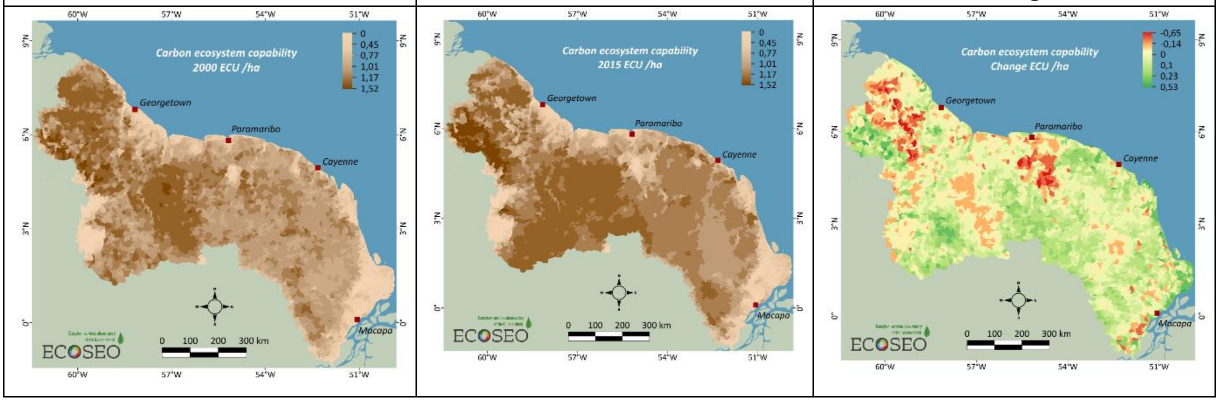


Figure 74 : Carbon Ecosystem Capability (C_EC), in ECUs

2000	2015	Change

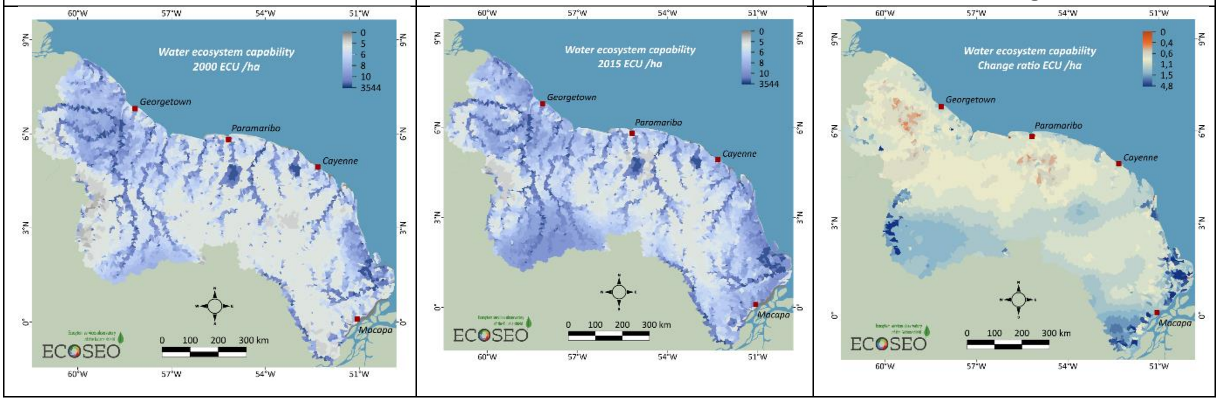


Figure 75 : Water Ecosystem Capability (W_EC), in ECUs

2000	2015	Change

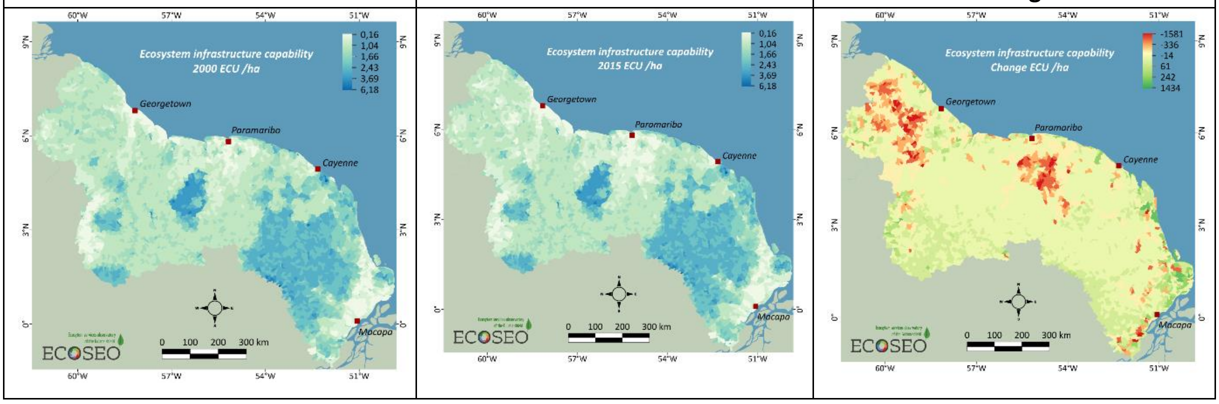


Figure 76 : Ecosystem Infrastructure Capability (EI_EC), in ECUs

ECOSEO

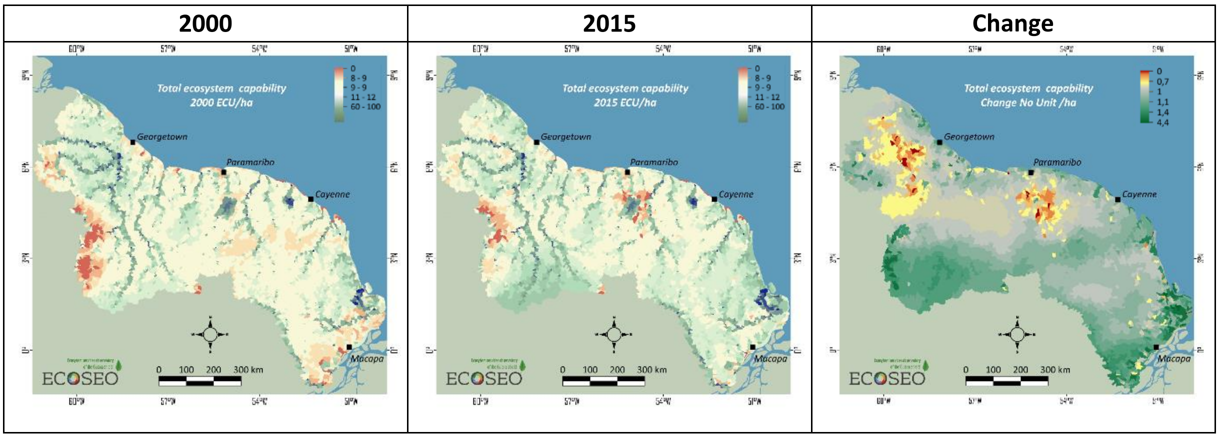


Figure 77 : Total Ecosystem Capability (TEC), in ECUs

As compared to the maps of ECU prices (Figure 72) changes in Total Ecosystem Capacity seem less important in some areas. This is mainly the effect of Water and Biomass Accessible potentials higher on the average in 2015 than in 2000 due to precipitations. Hence, the ECU degradation is mitigated or hidden by the quantitative balances. This corresponds to a one-year reality but it has to be taken into account when interpreting the results, in the same way as the price indexes are used to interpret economic indicators such as production, consumption and income.

<u>The Total Ecosystem Capability (TEC)</u> of ENCA is considered as an aggregate which can be compared to the Gross domestic product (GDP) in terms of change and provide an essential sustainability indicator telling if or if not GDP growth is correlated to ecosystem capital degradation. Nevertheless, it is important to stress that, as for GDP, the TEC is one indicator amongst others; if more relevant for the situation, other sub-indicators can be used to take decisions. TEC remains an attempt to combine all components as best as possible in order to provide integrated information

V | Discussion

Located within the Guiana Shield, the study area remains one of the regions of the world least impacted by human activities. Qualified as “High Forest Low Deforestation” (HFLD) areas, the rate of forest cover is one of the highest with the majority of natural forests in pristine state, sheltering an exceptional biodiversity. The region is also renowned for containing approximately 10-15% of the world’s freshwater volume, with the Guianas (Guyana, Suriname and French Guiana) leading the top five water surplus countries (FAO- AQUASTAT, 2010)[12]. This wealth of natural capital, coupled with low population pressure, fulfills the conditions favorable to the development of a green and sustainable economy in the region (WWF Guianas, 2012, Deloitte, 2018).

V.1 Limitations of the study

The results allowed spatializing the hotspots and the major trends in degradation of ecosystem capability at the scale provided by the input data and the accounting unit selected accordingly (SELU), i.e. watershed of level 10. However, as mentioned before, **the results must be analysed with caution and hindsight considering the experimental character of the method, the availability and accuracy of input data, and the scale of analysis.**

Indeed, this is one of the first in-depth applications of the Ecosystem Natural Capital Accounting (ENCA) method. Developed on the basis of the ‘System of Environmental-Economic Accounting– Ecosystem Accounting’ (SEEA-EA) that has just been adopted this year by the UN Statistical Commission as a new statistical standard, the interest for such method is recognized but its operational implementation still needs to be confirmed. For our study, given the lack of consistent data at the regional level, most of the data used are global data sets, whose accuracy is limited. Moreover, to compensate the lack of data and complete the analysis, some additional information had to be extracted from data extrapolation or from the crossing of spatial data with statistical information. Despite these cross-analyses that increase the uncertainties, critical data for estimating the state of ecosystems remain absent and in their absence, some phenomena inevitably remain ignored. The result of the study must also be analysed considering the Ecosystem accounting unit that was selected, i.e. watersheds of around 100-150km^2, which provide aggregated results that can mask localized phenomena.

In addition, the monitoring of changes required to assess degradation levels has consequences. **The monitoring was carried out here on two dates only over a 15 years period, while ENCA recommends an annual monitoring.** Such a two-date analysis is particularly sensitive to extreme weather events. In addition, it provides an inventory on two dates but cannot reflect a real regional trend over 15 years that need to be confirmed by more frequent monitoring. The low monitoring frequency limit the possibility to attenuate or smooth out exceptional phenomena such as meteorological effects which can influence the results if not adjusted. However, the monitoring of changes at high frequency which is mandatory to assess the evolution of the state of ecosystems also limits the amount of data available. As mentioned above, very few homogeneous spatialized data on change is available in certain domains. The lack of homogeneous or available statistic data on timber extraction, biodiversity, water quality, etc. have limited the integration of information in this study, especially for the water and ecosystem infrastructure accounts. This can be mitigated somewhat in ENCA, which integrates qualitative criteria that can take many forms but it requires holding specific workshops with national experts from various fields to define best ecosystem health or usage restrictions indicators, in order to strengthen the results and / or to compensate for the lack of quantitative data. In this study, with the exception of some, most of these qualitative indicators have been roughly produced from cross-referencing, data extrapolation or thresholds defined by the authors to complete the information and

[12] The top five surplus countries are Greenland, French Guiana, Iceland, Guyana, and Suriname

try to capture more phenomena. Some indicators could have been discussed during workshops but time and resources as well as the appropriation of the method limited the exercise.

V.2 Interpretation of the main regional trend of total ecosystem capability

Despite the aforementioned limitations and precautions for analyzing the results, the results of this study show that the region has so far succeeded in largely conserving the integrity of its ecosystems, which demonstrates its status of one of the most intact regions in the world. Almost the entire southern part of the region has ecosystem capability levels in 2015 that are comparable to 2000, with even an increase in this capability for some watersheds. This slight increase is, however, mostly due to a higher Net primary production (NPP) linked to a higher level of precipitation in 2015 than in 2000. For some ecosystem accounting units (SELUs), located mainly in the south-west of Guyana and in the north and east of Amapá, the results even show greater increase in total ecosystem capability (dark green areas), which in fact reflects the scars of bush fires that occurred in 2000. Despite the greater difficulties of access in the south and the center of the territories of the study area, the results suggest the positive role of protected areas in the conservation of the ecosystem capability.. The main protected areas where watersheds with a loss of capability can be found are: in Guyana, the Kaieteur National Park and the Iwokrama Forest Reserve; in Suriname, the Brownsberg nature park heavily impacted by mining activity and the Brinkheuvel nature reserve; In French Guiana, the integral biological reserve of Lucifer / Dékou-Dékou and lightly, the north-west of the Amazonian park, both affected by mining activity; In Amapá: the Ramsar site in the south-east of the territory affected mainly by fires.

However, despite these positive results, this study also shows that the capacity of the region's ecosystems to provide their provisioning, regulation and supporting services has decreased in some areas, following different degradation intensities (Figure 78):

- Dark red indicates SELUs with 35 to 50% degradation of the Total ecosystem capability (TEC) between 2000 and 2015;
- Dark orange 25-35% degradation;
- Light orange 15-25%;
- Yellow 5-15%;
- Lightest green/yellowish less than 5%, which can be considered as stable areas given data uncertainties.

Degradation of the total ecosystem capability (TEC) is mostly related to artificial (infrastructures and mining) and agriculture development, which are the main drivers of deforestation in the study area. This highlights the direct and indirect key role of forest ecosystems to human well-being. Forests provide a multitude of benefits in terms of climate regulation, water supply and regulation, timber, energy, habitat for biodiversity, clean air, erosion control and many others. This preponderant role of forest ecosystems is consistent with the recent analysis carried out in parallel by Sieber et al. (2021) at the border of French Guiana and Suriname, as part of the ECOSEO project. Following expert-based ecosystem services (ES) supply matrices, the study reveals that forest ecosystems have the highest ES capacities, followed by aquatic and marine ecosystems; whereas agricultural and urban land cover have weak to moderate capacities.

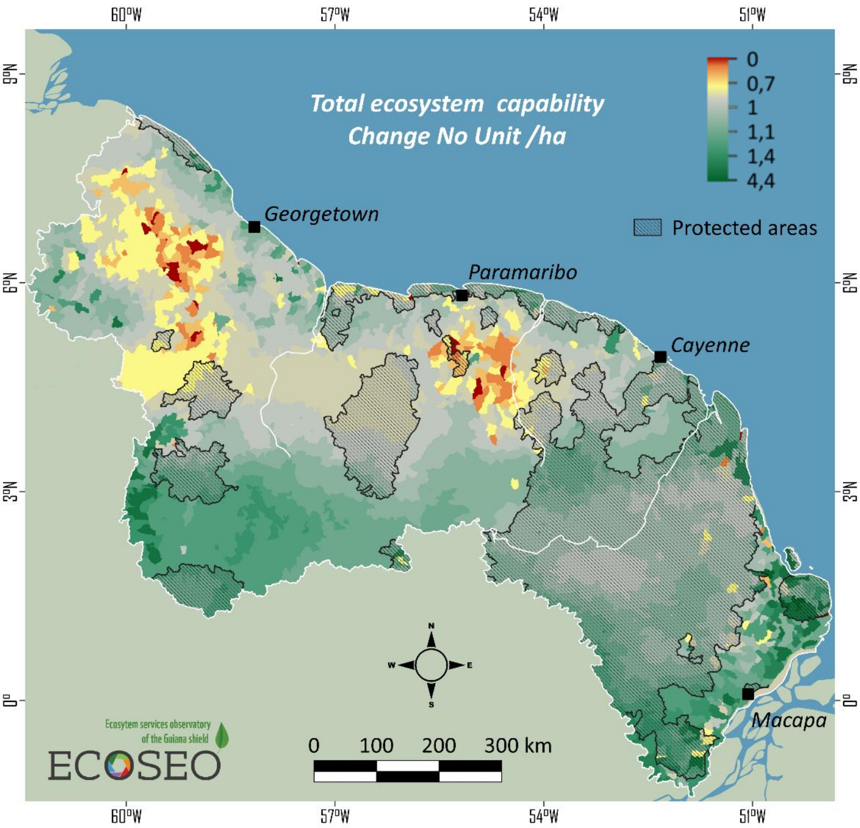


Figure 78 : Change in Total Ecosystem Capability (TEC) in ECUs, overlapped with protected areas[13]

Pressures on forests ecosystems vary from one territory to another and gold mining activities, which is the second driver of deforestation in the study area and the first in the Guianas (Guyana, Suriname and French Guiana), affects the most ecosystems capability. This effect is also reinforced by the fact that the only integrated data on river pollution have been extrapolated from this activity. This could be improved in the future by integrating more data on water quality if available. Nevertheless, the tropical forests of the Guiana Shield are currently the most affected by gold mining in South America, with gold mining accounting for 41% of total forest loss in the region (Alvarez-Berrios and Mitchell Aide, 2015; Dezecache et al., 2017).

In general, we note that for the vast majority of ecosystem accounting units (SELUs), French Guiana and Amapá retain their ecosystem capability. For French Guiana, the main degradations to be noted are located in the west of the territory, along the Maroni River that separates it from Suriname. This area is also the most impacted on the Suriname side, where we find a concentration of the most degraded watersheds of the country and which corresponds to a hotspot of mining activity. These degradations on each side of the border mutually affect the integrity of ecosystems, implying the need for dialogue and co-management. In Guyana, the loss of ecosystem capability is confined to the northern part of the country in a more dispersed manner than in Suriname for example, which also reflects the wider spatial distribution of mining activity. Degradations are also visible in the center-west in grassland and agricultural development areas, caused mainly by the cumulative loss of ecosystem capability in terms of carbon, water and ecosystem infrastructure. This area would deserve more frequent monitoring to better understand the underlying causes of the loss of capability and to ensure that it is not an exceptional climatic effect linked to an analysis at two dates only (e.g. difference in precipitation observed in 2000 and 2015).

[13] A buffer has been applied to protected areas to fit with watershed of level 10 (HYBAS10) definition

The evolution of the transition zone between grassland/savannah and forest stretching from the west to the southwest of Guyana is particularly interesting and important to follow over time, given the low level of the total ecosystem capability in 2000 and 2015. According to Bovolo et al. (2018), the Rupununi-Rio Branco savannah (Figure 79), running through northern Brazil to southern Guyana, is particularly vulnerable and natural or anthropogenic activities could easily lead to expansion of the savannah boundaries. The forest-savannah boundary is abrupt, and marks a general change in rainfall regime from a two wet season maritime climate over the coastal forests, to a continental climate with one wet season over the savannahs. In such mesic environments, savannah or 'treeless states' might represent stable alternatives to tropical forests (Hirota et al 2011, Staver et al 2011). The presence and maintenance of forest or savannah may be related to disturbances such as fire, and tree shade-fire suppression feedbacks (Hoffmann et al., 2012). This effect is visible from data on loss of biocarbon due to fires of natural or multiple origin (Figure 21), which also shows an increase in the intensity of fires in 2015 compared to 2000. More frequent and widespread fire events added by anthropogenic pressures such as mining and logging along with climate-related changes such as altered rainfall regimes, length of dry season, increasing temperatures and rising CO2 levels, might act to push the system towards one particular state (Oliveras and Malhi 2016).

Figure 79 : Map of South America showing the location of the Guiana Shield, the Amazon River basin and La Plata Basin, as well as major rivers and the approximate location of the Rupununi-Rio Branco Savannah (Source: Bovolo et al., 2018)

The results of the study from Bovolo et al. (2018) also highlights the key role of the forests of the Guiana shield that could be considered as guardians of South American climate. The Guiana Shield is located at the start of two major 'atmospheric rivers': the Caribbean low-level Jet and the South American low-level jet (SALLJ).rivers which carry moisture across South America. Based on deforestation scenario where 28% of Guiana Shield rainforest are replaced by the expansion of the Rupununi-Rio Branco savannah and existing or planned mining blocks, the study shows that the initial phase of the two atmospheric rivers might be disrupt and lead to hydro-climatic impacts 1000 km west and 4000 km south. Such multi-scale perturbations can severely affect biodiversity and ecosystem services across South America, including agriculture in La Plata River Basin (LPB).

VI | Conclusion

This study is the first application of the experimental method of Ecosystem natural capital accounting (ENCA) at such a large spatial scale, with such level of details. It allowed to test and illustrate the different stages of the production chain and to identify the data required for its implementation. This first application was a challenge given the experimental nature of the method, but it has greatly contributed to improving and developing it. The ENCA_QSP_FTI model, which describes in a detailed and transparent manner all the input data as well as the relationships between the different accounting lines in the tables, has been refined and consolidated, which will facilitate the future implementation of the method.

Beyond contributing to the demonstration and improvement of the ENCA ecosystem accounting method, this study provides a first assessment of the evolution of ecosystem capability (i.e. the capacity of ecosystems to deliver their services) in an integrated manner. The combined impacts on carbon, water and ecosystem infrastructure (including biodiversity) resources were used to assess changes in the Ecosystem capability unit (ECU) and the Total Ecosystem Capability (TEC). TEC quantifies in ECU (Ecosystem capability unit) the increase or decrease of the capacity of ecosystems to provide their provision, regulation and supporting services.

However, as detailed in the previous section, these first results produced on a transnational scale have many limitations and should be considered as indicative for their future improvement. Despite the use of detailed land cover (LULC) change data produced under the project, which forms the building block of ENCA, all other inputs come from global datasets, the accuracy of which may be limited at the local or even national level. An application on a finer scale from national or local data would permit to test and confirm the operational nature of the method to respond to a given problem, if the necessary input data are available and if validation / verification can be carried out.

In view of this experience, it appears that today the territories in the region suffer from a lack of data to meet their international commitments to the Convention on Biological Diversity (CBD) on the subject of natural capital accounting (Aïchi Target 2). Indeed, a minimum of local data and information on the changes in time are necessary to account for the evolution of the state and capability of ecosystems with an enhanced level of confidence. The lack of available data represented the main obstacle to the implementation of the method at the transnational level. Many data had to be extrapolated or cross-referenced to obtain the necessary information to account for this or that phenomenon. As the method is flexible, it is possible to ignore those phenomena considering that it does not occur or to replace quantitative information with qualitative ones based on expert opinion. Anyway, in both cases, this has an impact on the level of detail and confidence of the results. This lack of data was revealed on the three accounting components of the analysis, i.e. on carbon and in particular on water and biodiversity. In connection with data acquisition, the results demonstrate also the need for more frequent monitoring to limit changes due to climatic hazards for example, but also to ensure closer monitoring of the situation in order to intervene in time when necessary. The simple two-date comparison of the situation between 2000 and 2015 carried out in this study is not sufficient to establish a real trend over the fifteen years nor to mitigate exceptional climatic effects that could influence the results (e.g. precipitation of 15% above average in 2015). Therefore, to ensure the achievement of the objectives set by the international community with regard to natural capital accounting, it is above all essential to support countries in the production of relevant data for monitoring, as well as to build capacities on the implementation of the method. National ownership requires in-depth capacity building needs and the establishment of a pool of experts from different fields (biodiversity experts, hydrologists, foresters, statisticians, etc.).

As for the results in the region, it recalls the capital importance of maintaining the integrity of the forest ecosystem of the region in order to avoid cascading effects that could have disastrous consequences at the local level but also at the scale of the entire South American continent. The Total Ecosystem Capability of several watersheds has already been degraded more or less severely and some areas seem particularly vulnerable to savannization. These areas should be monitored closely and it is up to each territory to decide the future of the ecosystems present in these watersheds. The restoration of degraded sites if it is not already too late would perhaps allow the ability of ecosystems to go back in time, if these restorations are coupled with activities using the ecosystem's resources in a sustainable manner. As such, the next step of the ENCA method integrates the monetary evaluation of the restoration costs to assess the cost-benefits of the operation. For areas that seem particularly vulnerable such as southwest Guyana, close monitoring of activities in the transition zone is necessary to avoid the advance of the savannas. The protection of these key areas could prove useful to prevent the advance of these fronts in the future.

In the southern part of the region, the network of protected areas combined with limited access conditions have maintained an almost intact continuous block of forest. Nonetheless, LULC data shows that with the development of infrastructure and the resulting accessibility, mining activity is spreading more and more southwards in Suriname along the Maroni and in Guyana approaching the southwest's vulnerable savannah / forest transition zone. Maintaining the integrity of this ecological corridor emerges as one of the priorities for the preservation of the many services provided by forests, such as the maintenance of biodiversity, the storage of carbon in above and below ground, the protection against soil erosion and fires, the regulation of the water cycle and climate, etc. Actions have already been taken in this direction in Suriname (Ramirez-Gomez at al., 2016) in order to ensure the continuity of the network of protected areas formed by the Tumucumaque Brazilian National Park and the French Guiana Amazonian park. The TWTIS project (former South Suriname Conservation Corridor -SSCC) lead by Conservation International follows the objective to put under legal protection 7.2 million hectares of pristine tropical forest in the south of Suriname (40% of Suriname's land surface). By signing an Indigenous Declaration for the protection of the area, the indigenous communities declared the Southern Suriname Conservation Corridor on March 5, 2015. However, this project has not been concretized since the current Nature Protection Laws of Suriname from 1954 need to be revised for legal recognition of the SSCC. In Guyana, efforts in this direction were also made and concretized by the creation in 2017 of the Kanashen (or Konashen) Community Owned Conservation (COCA), at the extreme south of the country along the Essequibo River. It covers 6485.67 km² of land and represents Guyana's first community-owned area that is legally protected. Actions are therefore underway but they must be more supported at the political level and reinforced by the means of the international community given the key role of the region in the fight against the erosion of biodiversity, climate change and desertification.

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VIII | Annexes

VIII.1 Details of Land cover Ecosystem functional classes

LCEFU: Land Cover Ecosystem functional classes	LCEFU contents: main and other land cover type	
01 Urban and associated developed areas	**LCT.1**	
011 Urban fabric and associated developed areas	LCT.01.b	
012 Dispersed human settlements	LCT.01.a	
02 Homogeneous herbaceous cropland	**LCT.02.c and LCT.02.d**	**continuums of LCT.02.a and LCT.02.b**
021 Rainfed homogeneous herbaceous cropland	LCT.02.c	continuums of LCT.02.a
0211 Medium to large size fields of herbaceous crops rainfed	*LCT.02.c*	
0212 Small size fields of herbaceous crops rainfed	*continuums of LCT.02.a*	
022 Irrigated or aquatic homogeneous herbaceous cropland	LCT.02.d	continuums of LCT.02.b
0221 Medium to large size fields of herbaceous crops irrigated or aquatic	*LCT.02.d*	
0222 Small size fields of herbaceous crops irrigated or aquatic	*continuums of LCT.02.b*	
03 Agriculture plantations, permanent crops	**LCT.03.b**	**continuums of LCT.03.a**
031 Agriculture plantations, permanent crops, rainfed	*part of LCT.03.b*	*part of continuums of LCT.03.a*
0311 Medium to large size fields of woody crops rainfed	*part of LCT.03.b*	
0312 Small size fields of woody crops rainfed	*part of continuums of LCT.03.a*	
032 Agriculture plantations, permanent crops, irrigated	*part of LCT.03.b*	*part of continuums of LCT.03.a*
0311 Medium to large size fields of woody crops rainfed	*part of LCT.03.b*	
0312 Small size fields of woody crops rainfed	*part of continuums of LCT.03.a*	
04 Agriculture associations and mosaics	**discontinuous LCT.02.a, LCT.02.b, LCT.03.a, LCT.05.b**	**LCT.4**
041 Multiples crops and small size pastures	*part of LCT.4*	
042 Layered crops	*part of LCT.4*	
043 Mosaics of small agriculture and natural plots	discontinuous LCT.02.a, LCT.02.b, LCT.03.a, LCT.05.a, and natural classes	
05 Pastures and natural grassland	**part of LCT.5**	
051 Pastures	continuums of LCT.05.b	
052 Natural grassland	LCT.05.a	
06 Forest tree cover	**part of LCT.06.b & LCT.06.c**	**LCT.7**
061 Forest broadleaves tree cover	part of LCT.06.b & LCT.06.c	
062 Forest deciduous tree cover	part of LCT.06.b & LCT.06.c	
063 Forest mixed tree cover	part of LCT.06.b & LCT.06.c	
064 Mangroves	LCT.7	
07 Shrubland, bushland, heathland	**LCT.8**	
08 Sparsely vegetated areas	**LCT.10**	
09 Natural vegetation associations and mosaics	**discontinuous LCT.05.a, LCT.6, LCT.8**	
10 Barren land	LCT.11	
11 Permanent snow and glaciers	LCT.12	
12 Open wetlands	LCT.9	
13 Inland water bodies	LCT.13	
131 Rivers and canals	LCT.13 part	
132 Lakes and reservoirs	LCT.13 part	
14 Coastal water bodies and inter-tidal areas	**LCT.14**	
141 Estuaries	LCT.14.a part	
142 Lagoons	LCT.14.a part	
143 Coastal flats (beaches and mudflats)	LCT.14.b part	
144 Coral reefs	LCT.14.b part	
Sea (interface with land)	-	-

Source: Jean-Louis Weber (2014). Ecosystem natural capital accounts: A quick start package, CBD Technical Series No. 77, Secretariat of the Convention on Biological Diversity, Montréal, 288 pp.

Land Cover Types detailed classification	
LCT.1	**Artificial surfaces (including urban and associated areas)**
LCT.01.a	Artificial surfaces from 10 to 50 %
LCT.01.b	Artificial surfaces from 51 to 100 %
LCT.2	**Herbaceous crops**
LCT.02.a	Small size fields of herbaceous crops rainfed
LCT.02.b	Small size fields of herbaceous crops irrigated or aquatic (rice)
LCT.02.c	Medium to large fields of herbaceous crops rainfed
LCT.02.d	Medium to large fields of herbaceous crops irrigated or aquatic (rice)
LCT.3	**Woody crops**
LCT.03.a	Small size fields of woody crops
LCT.03.b	Medium to large fields of woody crops
LCT.4	**Multiple or layered crops**
LCT.5	**Grassland**
LCT.05.a	Natural grassland
LCT.05.b	Improved grassland
LCT.6	**Tree covered area**
LCT.06.a	Tree covered area from 10 to 30-40 %
LCT.06.b	Tree covered area from 30-40 to 70 %
LCT.06.c	Tree covered area from 70 to 100 %
LCT.7	**Mangroves**
LCT.8	**Shrub covered area**
LCT.08.a	Shrub covered area from 10 to 60 % (open)
LCT.08.b	Shrub covered area from 60 to 100 % (closed)
LCT.9	**Shrubs and/or herbaceous vegetation aquatic or regularly flooded**
LCT.09.a	From 2 to 4 months
LCT.09.b	More than 4 months
LCT.10	**Sparsely natural vegetated areas**
LCT.11	**Terrestrial barren land**
LCT.11.a	Loose and shifting sand and/or dunes
LCT.11.b	Bare soil, gravels and rocks
LCT.12	**Permanent snow and glaciers**
LCT.13	**Inland water bodies**
LCT.14	**Coastal water bodies and inter-tidal areas**
LCT.14.a	Coastal water bodies (lagoons and/or estuaries)
LCT.14.b	Inter-tidal areas (coastal flats and coral reefs)

Source: Jean-Louis Weber (2014). Ecosystem natural capital accounts: A quick start package, CBD Technical Series No. 77, Secretariat of the Convention on Biological Diversity, Montréal, 288 pp.

VIII.2 ECOSEO LULC flow classification

Adapted from Weber (2014):

lf1	Artificial development	
	lf11	Artificial development over agriculture
	lf12	Artificial development over forests
	lf13	Artificial development of other natural land cover
	lf14	Water bodies creation
	lf19	Other …
lf2	Agriculture development	
	lf21	Conversion from small scale/mosaic to large scale agriculture
	lf22	Conversion from grassland to agriculture
	lf23	Conversion from forest to agriculture
	lf24	Conversion from marginal land to agriculture
	lf29	Other …
lf3	Internal conversions, rotations	
	lf31	Internal conversion of artificial surfaces
	lf32	Internal conversion between agriculture crop types
	lf33	Internal conversion between forest types
	lf34	Internal conversions of natural land
	lf39	Other …
lf4	Management and alteration of forested land	
	lf41	Management, felling and replantation
	lf42	Fires, epidemics and other
	lf49	Other …
lf5	Restoration and development of habitats	
	lf51	Conversion from crops to set aside, fallow land and pasture
	lf52	Withdrawal of farming/ Landscape restoration
	lf53	Forest creation, afforestation of agriculture
	lf54	Forest creation, afforestation of marginal land
	lf55	Forest recruitment
	lf56	Restoration of degraded land
	Lf57	Forest creation, afforestation of mining
	lf59	Other …
lf6	Changes of land-cover due to natural and multiple causes	
	lf61	Climatic anomalies
	lf62	Climatic and other hazards
	lf69	Natural transitions n.e.s.
Lf7	Other land cover changes n.e.c. and reclassification	
Lf8	Mining development	
	lf71	Conversion from agriculture to mining
	lf72	Conversion from grassland to mining
	lf73	Conversion from forest to mining
	lf74	Conversion from marginal land to mining
	lf75	Other …
lf0	No observed land-cover change	

VIII.2.1 Lf1 – Artificial development

Artificial development includes sprawl or extension of urban and associated areas, transport infrastructures, economic activity areas, and associated areas such as green urban areas and sports facilities, and quarries and waste landfills.

Creation of water bodies that change land cover dramatically is also lf1.

The main categories of lf1 are:

- Artificial development over agricultural land;
- Artificial development over forests;
- Artificial development of other natural land cover.

Conversions within urban areas are not included here but recorded in lf3.

VIII.2.2 Lf2 - Agriculture development

Agriculture development includes conversion of forests, and natural and semi-natural land to agriculture. Conversion from small-scale agriculture, with associations of crops, mosaics and small linear features, to homogeneous cropland (farmland restructuring) is lf2.

If2 can be described according to the land-cover types consumed, for example as:

- Conversion from small-scale/mosaic farmland to large-scale agriculture;
- Conversion from grassland to agriculture;
- Conversion from forest to agriculture;
- Conversion from marginal land to agriculture.

Conversions between crops are internal to agriculture and are not included here but recorded in lf3.

VIII.2.3 Lf3 – Internal conversions and rotations

Internal conversions and rotations (lf3) are changes which can be observed within land-cover classes: artificial, urban, forest and other types. They require observation of detailed land-cover classes.

Internal conversions can be detailed according to specific changes in the areas:

- Internal conversion of artificial surfaces: reclamation of brown-field sites, development of green urban areas, or conversion of dwellings to offices or industrial buildings into apartments;
- Internal conversion between agriculture crop types: extension of irrigation systems, conversion between herbaceous and shrub/tree permanent crops. Crop rotations can be recorded as lf3; Conversions between homogeneous cropland and agricultural mosaics or pasture/grassland are not recorded in lf3 but in lf2 (intensification of use) or lf5 (extensification);
- Internal conversion between forest types: conversions between evergreen and deciduous, shifts between mono-specific and homogeneous stands;
- Internal conversions of natural and semi-natural land types, which can be observed at a detailed level.

lf3 will appear in land-cover accounts when detailed data are aggregated into broader classes, in which case they are recorded in the diagonal of the change matrix. In accounts directly generated from the LCEU 15 classes, lf3 will only be used in a first step to record changes between herbaceous and woody agricultural cropland. However, lf3 can also be introduced into the accounting tables based on additional statistical information, in which case accounts are balanced with a reduction of no observed change (lf0) equal to the introduced lf3. For these reasons, ENCA presents two different change matrices: the computational matrix which results from the processing of two land-cover maps, and the accounting matrix where actual no changes are recorded not in the diagonal (reserved for lf3 aggregations) but in rows and columns.

VIII.2.4 Lf4 - Management and alteration of forested land

Forest management refers to long time-spans with a succession of steps. Depending on the frequency of accounting, all steps are described (annual accounts) or intermediate steps are consolidated. In addition, forests are socio-ecological systems that include areas with forest-tree cover (LCF06) and other areas that are managed by foresters and are considered as part of forests in a land-use sense. This distinction is reflected in land-cover accounts. Processes involving forests are recorded in all land-cover aggregated flows.

It includes the effects of regular forest management, in particular tree felling whether or not followed by replanting. It is observed as a shift from tree cover to various classes of used (artificial and agriculture) or non-used land cover (bare soil, grass, shrub, etc.), in the latter case temporarily considered as still part of forests in a land-use sense. Forest creation on (non-forest) marginal land and recruitment from the growth of young trees, which are part of the forested land, are both recorded in the same class (lf5).

Forest management includes protection from hazards and restoration after damage. Forest tree-cover degradation by fire, wind and pests is therefore recorded in the same aggregated class as tree felling[14].

VIII.2.5 Lf5 – Restoration and development of habitats

Restoration and development of habitat groups represents flows resulting from anthropogenic processes. The main items are:

- conversion from crops to set-aside, fallow land and pasture;
- conversion from cropland to sparse and other natural vegetation in the context of shifting cultivation;
- landscape restoration (hedgerows replanting, etc.);
- withdrawal of farming;
- forest creation, afforestation of agricultural land;
- forest creation, afforestation of marginal land;
- forest recruitment.

VIII.2.6 Lf6 - Changes of land cover due to natural and multiple causes

In many cases, land-cover flows cannot be clearly allocated to a particular human activity. This is the case with change driven by climate change regarding temperature, rainfall regime and hazards such as

[14] There is a difference here from the approach of IPCC/LULUCF where fires that are independent of any anthropogenic cause are excluded. The point will be taken in the biomass/carbon account where the two types of fire will be distinguished.

storms. For managed forests, damage is classified as lf4 (management and alteration of forested land) and development as lf5 (restoration and development of habitats). Unmanaged natural transitions are recorded in lf6. Main lf6 flows are:

- effects of climatic anomalies: droughts, seasonal regimes, etc.;
- effects of climatic and other hazards (except effects on forests): storms, floods, landslides;
- coastal erosion;
- melting of permanent snow and glacier;
- volcanic eruptions, earthquakes, tsunamis;
- indirect effects of overexploitation of natural resource (e.g. progressive degradation by overgrazing or slash-and-burn agriculture);
- natural transitions in unmanaged land.

VIII.2.7 Lf7 - Other land-cover changes not elsewhere classified (n.e.c.) and revaluation

This class records unlikely changes such as conversion of urban areas to agriculture or forest. Revaluation is also recorded in lf7. It corresponds to changes in classification due to potential errors in the initial database. As long as the initial database is not revised and upgraded, such false change is recorded as revaluation. Once revision is done, revaluation will be reclassified, generally as no observed change.

VIII.2.8 Lf8 - Mining development

Mining development includes conversion of forests, and natural and semi-natural land to agriculture.

If2 can be described according to the land-cover types consumed, for example as:

- conversion from agriculture to mining;
- conversion from grassland to mining;
- conversion from forest to mining;
- conversion from marginal land to mining.

VIII.3 Net Landscape Ecosystem Potential (NLEP) sub-indicators

As shown previously, NLEP is built by the product of the GBLI, NATURILIS and FRAG_MEFF that are quickly described hereafter:

VIII.3.1 The Green Background Landscape Index (GBLI)

The Green Background Landscape Index (GBLI) reflects on the one hand the biomass potential and on the other hand its autonomy from human cultivation. GBLI is an indication of biomass available for nature itself. It ranges from 1 to 100. The rating scale should reflect relative values in order to monitor realistic changes. The limit of possible rating is the detail of land cover data (Figure 80).

Box 1 : GBLI rating process for ENCA Guiana Shield (version 1)

In the case of the ENCA-QSP of the Guyana shield, the grid has been submitted to a workshop of experts of the various countries with the purpose of estimating weighting factors for land cover classes on a scale from 1 to 100. Experts were guided with a grid making explicit the two dimensions of GBLI: the biomass potential (the productivity) and the biotic regulation (the capacity of reproduction without anthropogenic inputs).

GBLI = [P_x]*[R_y]

Biotic regulation [

10	10	20	50	80	100
8	8	16	40	64	80
5	5	10	25	40	50
2	2	4	10	16	20
1	1	2	5	8	10
0	**1**	**2**	**5**	**8**	**10**

Biomass potential [P]

The first round of assessment resulted in these values:

- Pristine forest, wetland: P10*R10 = 100
- Urban/artificial areas: 1 to 10 = 5
- Production forest (according to age): 35 to 70
- Open forest: 50 to 70
- Forest transitions, trees plantations: 10 to 35
- Large scale agriculture (annual crops): P5*R2 = 10
- Large scale agriculture (permanent crops, plantations): P7*R2 = 14
- Agriculture x Nature mosaics: P8*R8 = 64
- Grassland: P5*R10 = 50
- Shrubs: P6* R7 = 42
- Steppes: P2*R5 = 10
- Rocks, sand: P1*R1 = 1
- Inland Water: 40 to 80
- Coastal water: 10 to 100

Discussions between experts lead to revising some of these numbers regarding both their relative value and the availability of data. In particular, the distinction of GBLI by forest types was not possible. Finally, it appeared that the rating resulting from the experts' discussion was very close to the theoretical scale suggested in the CBD ENCA manual. Therefore, as a provisional solution for Fast Track Implementation accounts, it was decided to simply use the default values of the manual.

The ENCA-QSP GBLI rating grid for land cover which has been used by default for the fast track implementation and adapted to the ECOSEO land cover classification as follows:

Land cover code	Land cover name	note GBLI [0-100]	note GBLI [0-1]
11	Artificial surfaces	10	0.10
12	Transport infrastructure	10	0.10
13	Minerals extraction sites	10	0.10
21	Agriculture herbaceous crops	20	0.20
22	Woody crops_plantations	30	0.30
23	Mixed or shifting nature-agriculture	50	0.50
30	Pastures & natural grassland	50	0.50
41	Forest tree cover	100	1.00
42	Mangroves	100	1.00
50	Shrubland, bushland, heathland	70	0.70
60	Barren land	30	0.30
71	Open wetlands_marshes	100	1.00
72	Inland water bodies	80	0.80
73	Coastal water bodies, lagoons, estuaries	80	0.80
74	Intertidal zones	80	0.80

Figure 80 : ENCA-QSP GBLI rating grid for land cover

GBLI notes have been assigned to 1 ha pixels. The resulting grid is finally smoothed using a Gaussian filter in order to reflect the landscape character of the index, namely the mutual influence of neighbouring pixels. The resulting outcome is, for example, as on the extract of the 2015 map:

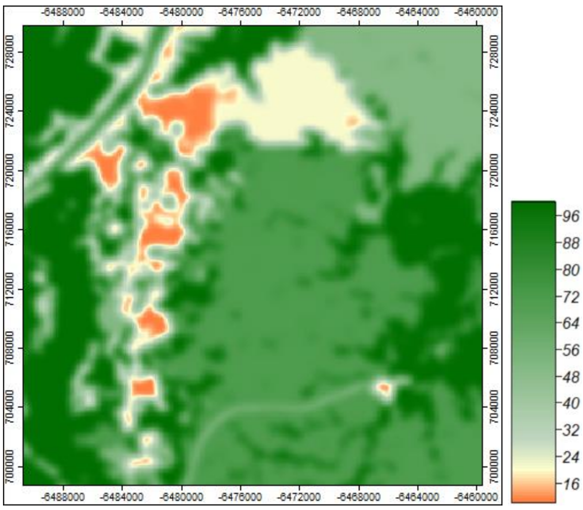

Figure 81 : Extract of the GBLI map 2015

VIII.3.2 Landscape high nature value index (HNVI or NATURILIS)

The High Nature Value Index (HNVI, or NATURILIS) is an indirect measurement based on available designations by science and agencies in charge of nature protection. Available information is combined and then smoothed for reflecting the fact that HNVI influences positively is neighbourhood and, on the contrary, is negatively impacted by surrounding artificial land use. Another interest of Gaussian smoothing is that it agglomerates archipelagos of small protected areas into larger sets. The version 1 of HNVI is only based on WCMC' World Database of Protected Areas (WCMC - WDPA) and IUCN categories only. It should be upgraded with other relevant international datasets as well as national datasets.

The rating of protected areas is based on coefficients assigned to IUCN classes and to the idea that several protections in the same place reveal high value and therefore should be added-up.

The rating of IUCN classes is as in the following table:

UICN_CAT_label	Note_0_1
Ia	1.00
Ib	0.90
II	0.70
III	0.60
IV	0.50
V	0.60
VI	0.60

All protected and non-protected areas are given the note 1 and then, points or decimals are added-up. Here, the total of the marks given makes circa 5, which means that the maximum note could be of 6. This note will be multiplied with the Green Background Landscape Index (GBLI) value (see Annex VIII.3.1).

If other protections are documented and mapped, they can be added in the same way. Other designations of nature value or biodiversity importance are eligible as long as they are validated. Would it have been accessible for free, the Key Biodiversity Areas of IUCN should have been considered with a high rating of at least 1. It is recommended that this is done for a future upgrade of ENCA. In the same way, national and local protections not recorded in WDPA should be integrated as well. It would lead to a scale of HNVI marks up to 10. In any case, the present approach has to be considered as a starting point aimed at highlighting the issue. The range of HNVI itself can be modified as long as it expresses finally a social value based on verifiable scientific knowledge. A different scale can be adopted as the result of scientific and institutional discussions on the range of values which would best inform policy making.

HNVI is not an assessment of protection efficiency but an indirect way to assess the higher nature value of particular ecosystems based on what is stated by scientific and environmental protection agencies. A legal declaration is a clue that there is something to protect. If this protection is not implemented in facts, it does not mean that the area has no high nature value.

Giving high weight to areas has a consequence because when it is degraded, the degradation will appear as more important. Much more than for more common areas. Note that if another protected area is created, there is no increase of HNVI over time as long as this designation will be taken from the first year of accounting.

VIII.3.3 Landscape fragmentation index (FRAG_MEFF)

Fragmentation by artificial land cover (urban areas, mining extraction sites and large transport facilities and networks) is a major issue in landscape ecological integrity as it disrupts ecological corridors and reduces critical spawning areas. FRAG_MEFF is based on the principles of the Effective Mesh Size (Jaeger et. al, 2011). It is implemented as a combination of three fragmentations indices computed for hydrological basins level 10 (HYBAS10 local impact of fragmentation), HYBAS7 (medium scale impacts) and HYBAS4 (impact on large basins).

Therefore, for each river basin the different element were computed as illustrated by Figure 82 :

- mesh_area = Intersect_area – urban_area
- meff =(∑ (mesh_area)^2) / riverbasin_area
- frag = meff / riverbasin_area

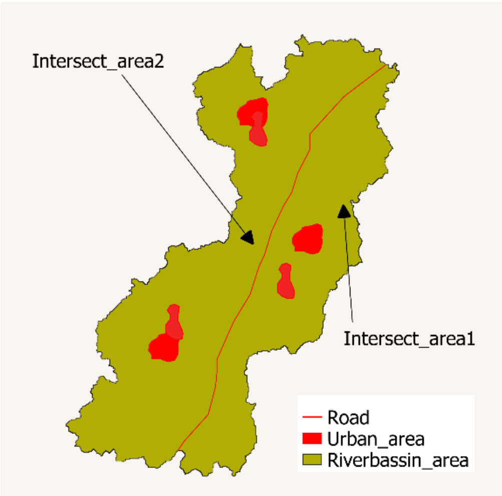

Figure 82: Schema to understand how is computed land fragmentation indicator: Example in one river basin.

Net River Ecosystem Potential (NREP) sub-indicators

The analogue to the Net Landscape Ecosystem Potential (NLEP) for the river is the Net River Ecosystem Potential (NREP) index. NREP is computed based on the RAWI (equivalent to the GBLI of the land component), NATRIV (equivalent to the NATRILIS of the land component) and the FRAGRIV (equivalent to the FRAG_MEFF of the land component).

VIII.3.4 River Accessibility Weighted Index (RAWI)

Illustrated by Figure 57, RAWI, the River Accessibility Weighted Index is a measurement of a potential based on rivers extent (their length) and discharge. It describes the presence of rivers and their importance for the overall functioning of ecosystem unit (SELU). The water accounts take into account water accessibility and one of its variable describes stocks of rivers in standardized river measurement units (SRMU), defined as 1 km x $1m^3$ x 1 $second^{-1}$. SRMU measurements address all rivers but give important weight to the water runoff. From the point of view of ecosystem functioning, small rivers and even very small streams are very important. In addition, medium, large and very large rivers are not so much different from each other. The solution proposed for RAWI is therefore to normalize it by calculating it as the natural log of SRMU measurements. Once computed, RAWI can be converted to hectares and combined with GBLI of which it is a parent indicator.

VIII.3.5 River high nature value index (NATRIV)

NATRIV is based on the non-smoothed version of NATURILIS, which is intersected with actual rivers. NATRIV gives higher nature value to rivers.

VIII.3.6 River fragmentation index (FRAGRIV)

FRAGRIV, illustrated by Figure 83 is an index of rivers fragmentation in river basins. Dams provide access to water resource and to hydroelectricity, as recorded in the water account. However, rivers fragmentation disrupts ecological corridors, hinders fish migration and blocks sediments flows. Fragmentation by dams is assessed at three specific scales: small hydrological basins (HYBAS10, the SELUs level), medium basins (HYBAS7) and large basins (HYBAS 4). Data used for dams come from the merge of international data sets that are obviously incomplete, which will require upgrade with national data.

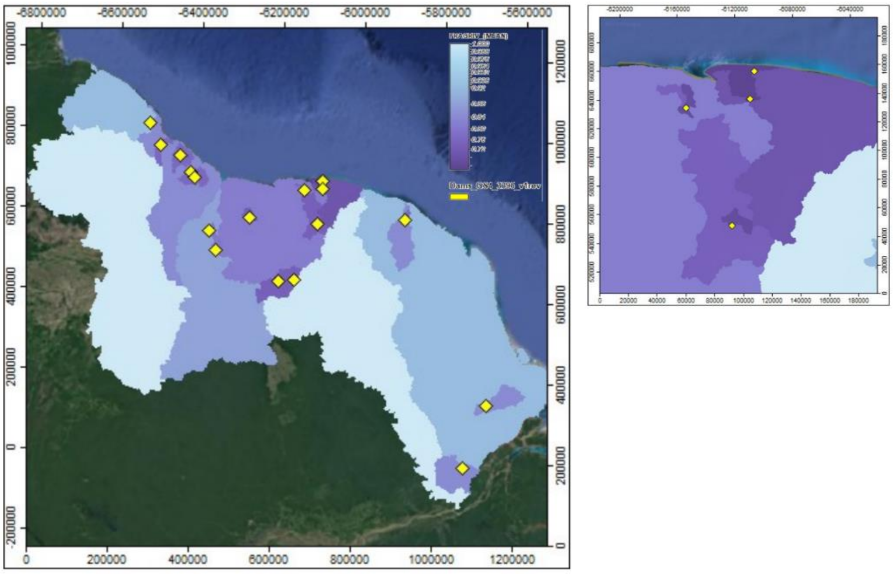

Figure 83: FRAGRIV: Rivers fragmentation of hydrological.

VIII.4 Overall access to ecosystem infrastructure functional services

VIII.4.1 AIP1 - Population's local access to TEIP

AIP1 is built by multiplying the population access raster to the Total Ecosystem Infrastructure Potential (TEIP) of 2000 and 2015.

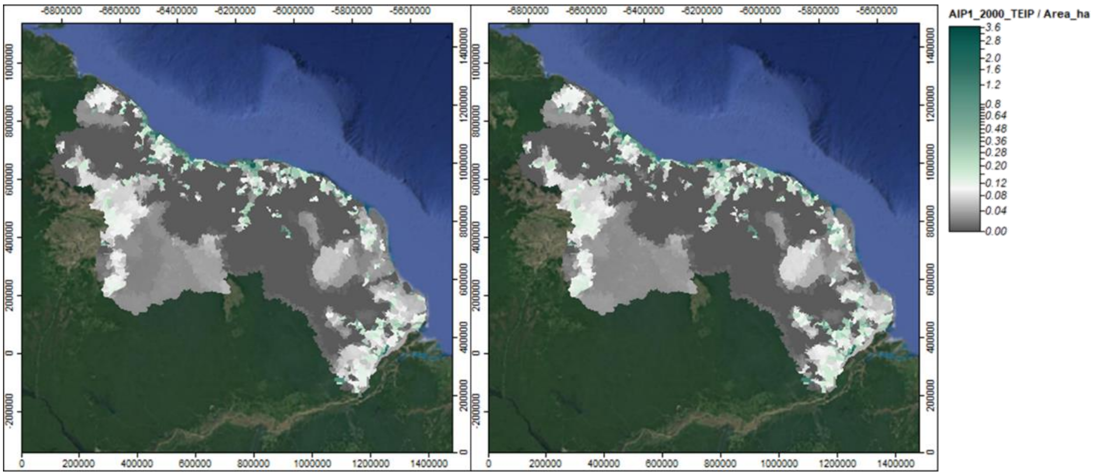

Figure 84 : AIP1 - Population's local access to TEIP in 2000 (left) and 2015 (right)

VIII.4.2 AIP2 - Population local access to river services

AIP1 is built by multiplying the population access raster to the Net River Ecosystem Potential (NREP) of 2000 (left) and 2015 (right):

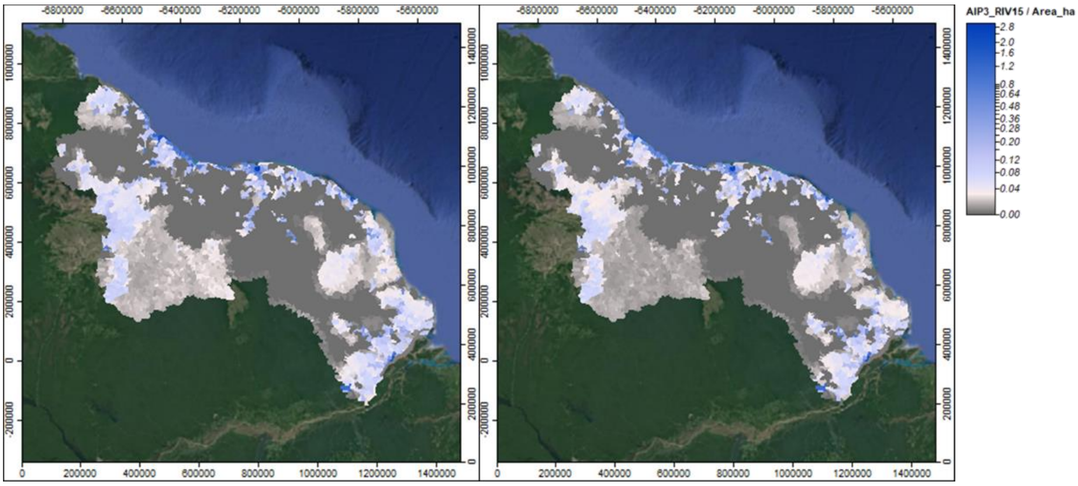

Figure 85 : AIP2 - Population local access to river services in 2000 (left) and 2015 (right)

VIII.4.3 AIP3 - Population local access to sustainable food

AIP3 - Population local access to sustainable food is built based on AIP31 Gridded agriculture harvest statistics and AIP32 Food sustainable ecosystem potential

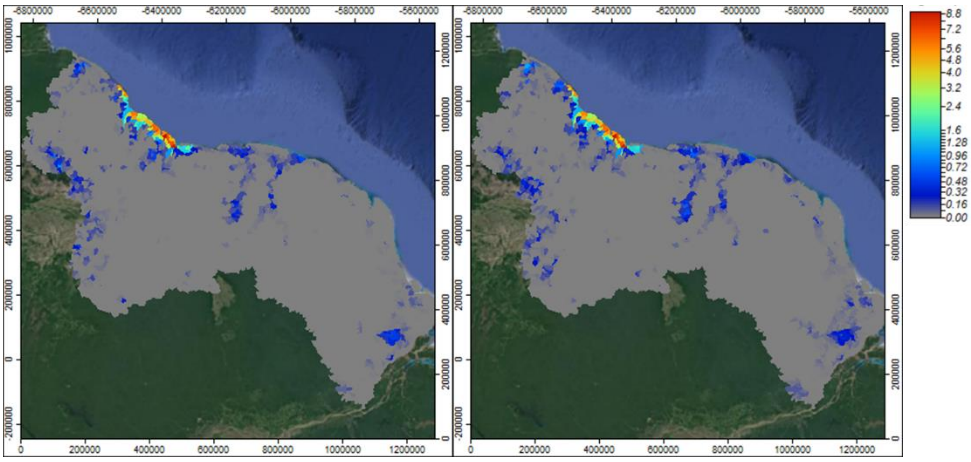

Figure 86 : AIP31 - Gridded agriculture harvest statistics in 2000 (left) and 2015 (right)

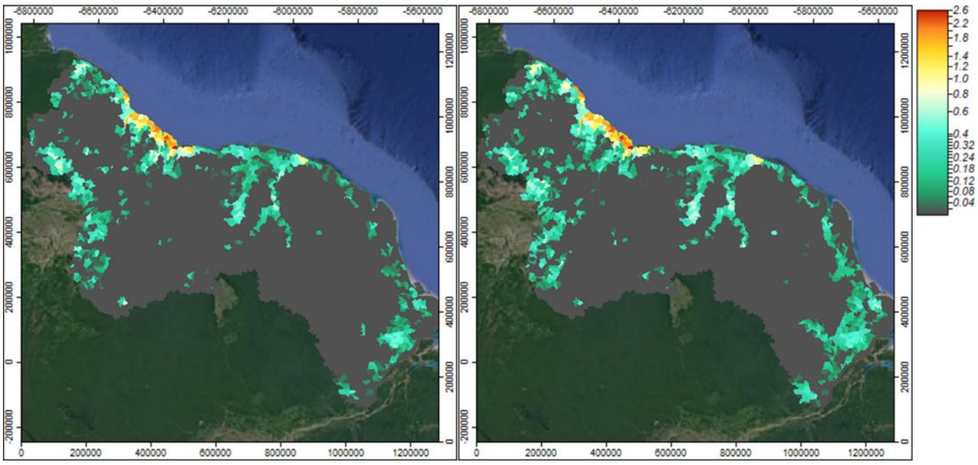

Figure 87 : AIP32 - Food sustainable ecosystem potential in 2000 (left) and 2015 (right)

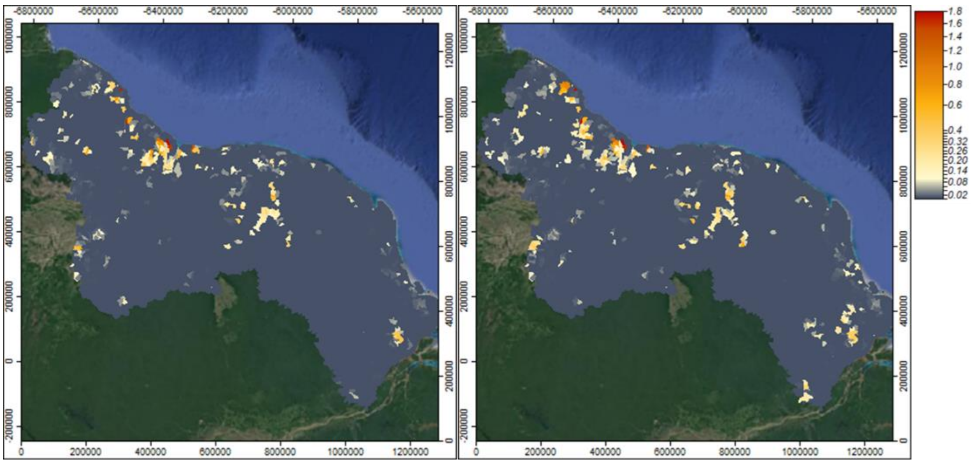

Figure 88 : AIP3 - Population's local access to sustainable food in 2000 (left) and 2015 (right)

VIII.5 Ecosystem Infrastructure Health (EIH) sub-indices

This annex illustrates and gives more information about the source or calculation of the sub-indices that compose the Ecosystem Infrastructure Health (EIH) index.

VIII.5.1 Biotope vulnerability (EHI3)

Biotope vulnerability index (EHI3 - Figure 90) is computed by IUCN for the Terrestrial Ecoregions of the World produced by the WWF that provide a map of terrestrial biodiversity that gives enough detail to be useful in global and regional conservation priority-setting and planning efforts (see input data table). Due to lack of change data this indicator is the same for both dates.

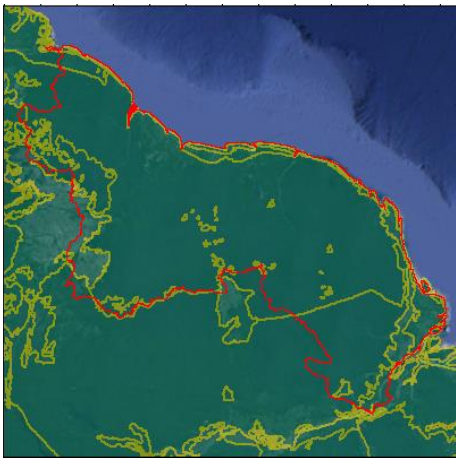

Figure 89: Terrestrial Ecoregions of the World (TEOW) – yellow lines

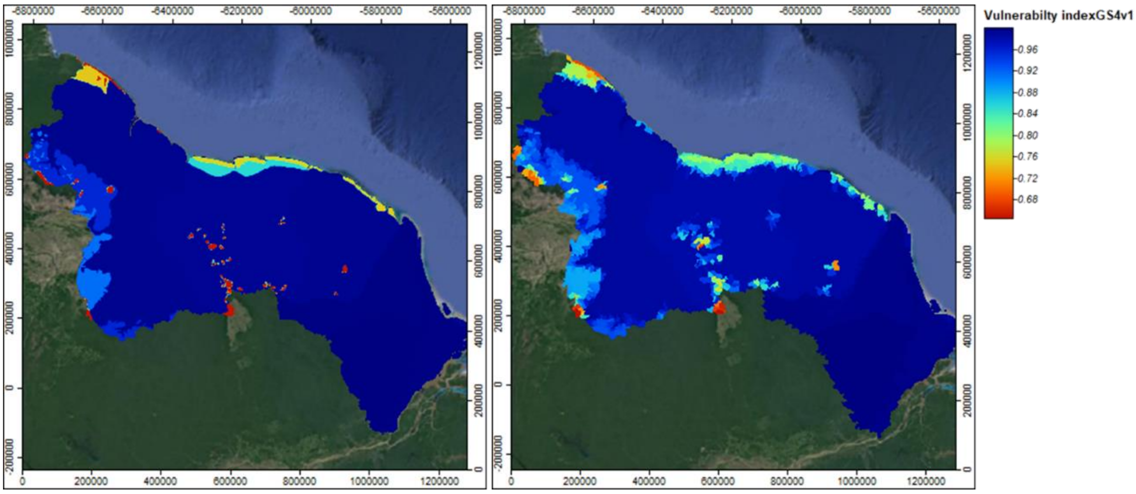

Figure 90:EHI3 Biotope vulnerability index for both 2000 and 2015. At left the raw data and at right the average value per SELU. Dark blue in Amapá means no data, i.e. no vulnerability (= 1).

VIII.5.2 Extinction risk index (EIH5)

The extinction risk index is based on the EDGE score by Isaac et al. (2007) that measures the contribution made by different species to phylogenetic diversity and show how the index might contribute towards species-based conservation priorities.

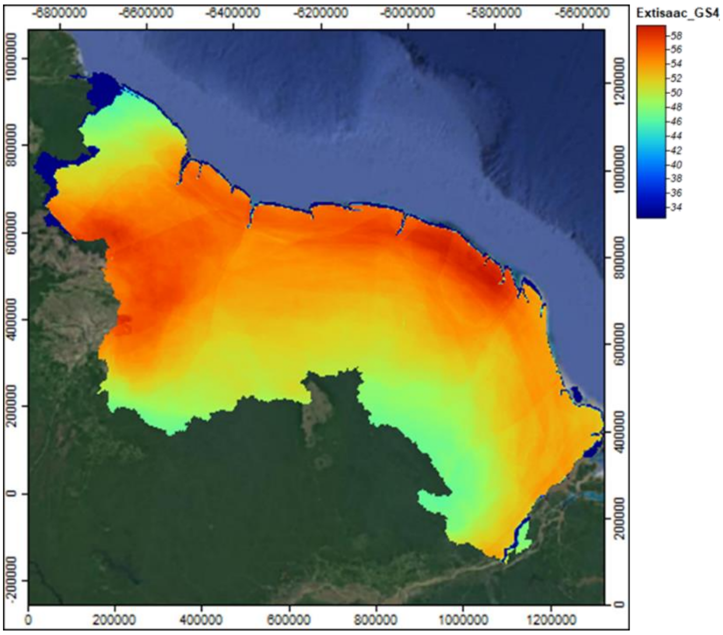

Figure 91:EIH5: Extinction risk index both 2000 and 2015 (No change data is available).

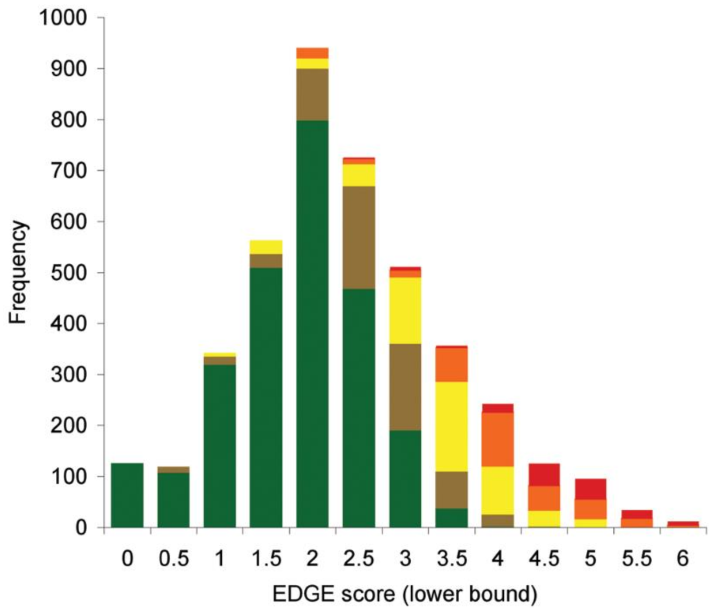

Figure 92 : Histogram of EDGE scores for 4182 mammal species, by threat category. Colours indicate the Red List category: Least Concern (green), Near Threatened and Conservation Dependent (brown), Vulnerable (yellow), Endangered (orange) and Critically Endangered (red)

(Source: Isaac et al., 2007 - https://doi.org/10.1371/journal.pone.0000296.g003)