Biophysical Modelling and Analysis of Ecosystem Services in an Ecosystem Accounting Context

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Author: Lars Hein[1]

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Contents

1. Introduction

This document provides guidance on the biophysical modelling and analysis of ecosystem service flows and assets for the purpose of experimental ecosystem accounting. The document is prepared in the context of the overall SEEA-Advancing Experimental Ecosystem Accounting project, building upon and expanding earlier work in this field, and intends to provide a summary and review of approaches, data, tools and results of existing and previous ecosystem accounting work focusing on biophysical modelling. Compared to previous work eliciting how models can be used for ecosystem accounting, this document provides an updated and extended analysis of how models can be applied. The document pays specific attention to ensuring consistency with SNA principles, discusses both temporal and spatial modelling approaches, discusses explicitly modelling for the purpose of asset accounting, and includes a chapter (Chapter 4) that describes available data sources for ecosystem modelling in an accounting context. This chapter includes a summary and review of how existing global and national spatial datasets, including remote sensing imagery, such as the new Sentinel satellites, can be applied in support of experimental ecosystem accounting.

Ecosystem accounting aims to analyze ecosystem services and ecosystem capital in a way that is consistent with the national accounts. There is an increasing national and international interest in ecosystem accounting, as expressed at the Rio plus 20 Conference and in a recent statement by the European Union (EC, 2011). A first major step in the development of ecosystem accounting procedures and guidelines was the ‘SEEA Experimental Ecosystem Accounting Guideline’ (EC/OECD/UN/World Bank, 2013). These guidelines lay out the basic concepts, the relation between ecosystem accounting and environmental economic accounting and national accounting, as well as remaining challenges in the development of ecosystem accounts. This document builds upon the SEEA EEA guidelines, on the basis of experiences gathered with spatial and biophysical modelling of ecosystem services as described in the scientific literature as well as national and global assessments such as MA (2005), TEEB (2010), EC (2011), UK NEA (2011), SSCB (2014) and the recent IPBES documents that are now becoming available.

Chapter 2 of the report first describes the general concepts underlying biophysical analysis of ecosystem services in an accounting context. Chapter 3 focuses on the modelling of ecosystem services. Finally, Chapter 4 analyses available global spatial datasets and how they, and the new Sentinel satellites and other remote sensing resources, can be used in support of ecosystem accounting.

2. Biophysical accounting for ecosystem services

2.1 Introduction

Ecosystem accounting provides information on the status of and trends in ecosystem capital, i.e. all assets involving ecosystems (i.e. excluding sub-soil assets such as oil or ores). Once fully developed, ecosystem accounts can serve as a satellite to the system of national accounts (SNA) in order to provide information required for decision making on environmental and natural resource related issues. The SNA (UN et al 2009) is an international statistical standard for the compilation of national accounts, providing a comprehensive description of economic activity. The SNA accomplishes this by describing the transactions (e.g. buying a product; or paying a tax) between institutional units such as households or enterprises (Edens and Hein, 2013).

Ecosystem Accounting aims to includes a comprehensive set of ecosystem services (including provisioning, regulating and cultural services), and to explicitly account for changes in the stock of ecosystem capital (ecosystem assets). The stock of ecosystem capital is related to the capacity of the ecosystem to generate ecosystem services at present and in the future, as further elaborated below. The latter aspect also allows a systematic treatment and accounting for the degradation and rehabilitation of ecosystems: these two aspects are reflected in the capacity of the ecosystem to provide services. In this way, ecosystem accounting provides a comprehensive tool to analyze the sustainability of natural resource use. Characteristic for Ecosystem Accounting is that a spatial approach is followed, in recognition of the large spatial diversity of ecosystems and the services that they provide. A spatial approach also facilitates the integration of ecological data (and data on ecosystem use) in the accounts. As with 'standard' statistical approaches, a sampling strategy will often be required to analyze ecosystem use and management. Contrary to most other economic activities, the spatial component of ecosystems is crucial, scaling up of survey data requires consideration of the soils, climate, vegetation etc. properties of the sampled location; scaling up without consideration of spatial ecological variability will lead to substantial errors.

Constructing ecosystem accounts for multiple years allows measuring the degree of environmental sustainability: a decline in ecosystem capital points to a decreasing capacity of ecosystems to sustain human welfare over time. In addition, ecosystem accounting supports a number of additional policy applications. For instance, ecosystem accounting can support land use planning or zoning by identifying areas critical to the supply of specific ecosystem services. This is based on the spatial approach followed in ecosystem accounting: ecosystem services flows, and the capacities of ecosystems to generate services, are generally mapped for the specific areas for which an ecosystem account is developed. Ecosystem accounting can also support the establishment of Payment schemes for Ecosystem Services (PES), by identifying zones where the supply of a specific ecosystem service is concentrated, or by laying out the co-benefits of PES mechanisms. Modelling ecosystem services can takes place both to support data analysis required for ecosystem accounts (given the high spatial variability of ecosystem services supply), and with the aim of supporting additional applications such as Land Use Planning or developing PES schemes.

2.2 Concepts and indicators

2.2.1 Ecosystem

The Convention on Biological Diversity defines an ecosystem as ‘a dynamic complex of plant, animal and microorganism communities and the nonliving environment, interacting as a functional unit’. Ecosystem dynamics and the supply of ecosystem services depend on the functioning of the ecosystem as a whole, rather than on specific ecosystem components in isolation. Ecosystem accounting extends to both natural and modified ecosystems. The distinction between the two systems, in practice, is not always easy to make, usually there is a gradient in terms of intensity of ecosystem management, as in the case of the gradient from fully managed, intensive rubber plantations to jungle rubber systems (where farmers artificially increase *hevea* rubber trees in an otherwise natural forest) to tapping of rubber in natural ecosystems as still practiced – albeit at a small scale - in the Amazon basin. Ecosystem accounting aims to measure the contribution of ecosystems to economic activity, and this contribution, in a relative sense, decreases with increasing intensity of human management. For instance, in highly intensive systems all nutrients, water, seedlings, weed control, etc. are provided by people. Where possible, indicators for ecosystem services need to be found that as much as possible reflect the contribution of the ecosystem, and these indicators may well differ between ecosystems that are defined as ‘natural’ or ‘human managed’ in the SNA. A still remaining question is if, in line with the SNA, the contribution of the ecosystem in human managed systems should be measured in terms of an increase in volume (for instance of standing timber), as in the SNA, or if the ecosystem services should still be related to the harvest of use of the service at the time the service is actually used (e.g. in the case of timber plantations the service only materializes at the moment in time the timber is harvested).

2.2.2 Ecosystem services

Several slightly different definitions of ecosystem services have been provided (MA 2003; Boyd and Banzhaf 2007; TEEB 2010; Bateman et al. 2010). A key issue is if ecosystem services are *the benefits* provided by ecosystems (e.g. MA, 2003), or *contributions* to these *benefits* (e.g. TEEB, 2010). The SEEA EEA guidelines provide the following definition of ecosystem services: ‘ecosystem services are the contributions of ecosystems to benefits used in economic and other human activity’ (EC et al., 2013). “Use” includes both the transformation of materials (e.g. use of timber to build houses or for energy) and the passive receipt of non-material ecosystem services (e.g. amenity from viewing landscapes). In the context of ecosystem accounting, two types of benefits can be distinguished: (i) the products produced by economic units (e.g. food, water, clothing, shelter, recreation, etc.); and (ii) the benefits that accrue to individuals that are not produced by economic units (e.g. clean air) (Edens and Hein, 2013). The first category can be referred to as SNA benefits since the measurement boundary is defined by the production boundary used to measure GDP in the System of National Accounts (SNA). This includes goods produced by households for their own consumption. The second category of benefits can be referred to as non-SNA benefits reflecting that the receipt of these benefits by individuals is not the result of an economic production process defined within the SNA (Edens and Hein, 2013).

For all provisioning services, the contribution of the ecosystem needs to be combined with other inputs in order to produce a tangible benefit. For instance, even though forests supply wood, labor and equipment are needed in order to produce timber out of standing wood. Or, landed fish require both the presence of fish in the sea (the ecosystem service) and the activities of people in order to harvest these fish. The costs of these activities need to be deducted in the monetary valuation of the ecosystem service, following the appropriate methods. For other services, the distinction between service and benefit may be less pronounced. For instance, carbon sequestration also occurs in natural forests regardless of any human intervention. In this case, the service equals the benefit. In the case of a carbon sequestration through reforestation project, however, the generation of the service may require human activities such as planting seedlings, irrigation of immature trees, soil management, etc. In this case there is a clear distinction between the service and the benefit. Even though the service and the benefit are, as in the case of some provisioning services such as crop production, difficult to disentangle, in monetary terms the distinction is clear: in case of reforestation projects for carbon sequestration the costs of planting and tending the trees need to be deducted in order to obtain the monetary value of the service.

Likewise, the cultural service related to ecotourism may occur in areas that are strongly shaped by people, e.g. to construct walking paths, visitors facilities, and involving guides, or it may take place in fully natural areas. The contribution of the ecosystem is, essentially, providing opportunities for recreation and tourism, which in the first example involved human activities in order to generate or enhance those opportunities. Monetary valuation of the two services would need to consider the costs of preparing and maintaining hiking paths and visitor facilities.

In Ecosystem Accounting, the principle should be that the ecosystem service is the flow/output most directly connected to the ecosystem (e.g. the standing stock of timber that is harvested or the grass that is extracted from the pasture), while recognizing that this flow is, in the case of many ecosystems, the consequence of a combination of natural/ecological processes and man-made inputs (Edens and Hein, 2013). For crop production, the ecosystem service has been defined as the contribution of the ecosystem to crop production in the form of nutrient retention and supply, water retention and supply, and providing a substrate for cultivation (EC et al., 2013). Since these different aspects are difficult to quantify and express in one or a small set of indicators, the current working hypothesis established in discussions that took place in the context of (EC et al., 2013) is that the service crop production can be approximated in physical terms in terms of the amounts of crops produced, and that valuation needs to account for the whole set of human inputs into crop production, following a resource rent approach.

2.2.3 Ecosystems' capacity to supply ecosystem services

Provisioning services. In general terms, the capacity of an ecosystem to provide ecosystem services depends on the area covered by an ecosystem (its extent), and the condition of the ecosystem (its quality) (SEEA EEA – 1.53). The capacity of the ecosystem asset to continue to generate ecosystem services into the future will change as a function of changes in the condition and extent of the ecosystem asset and in response to changes in the expected flows of ecosystem services (EC et al., 2013). While ecosystem condition may be assessed without considering measures of ecosystem services, the measurement of ecosystem assets in terms of their capacity to generate ecosystem services must involve assessment of ecosystem condition, for instance soil fertility and rainfall influence regrowth of standing stock of timber following timber harvest. Note that capacity can be defined per accounting unit (e.g. per Land Cover Ecosystem Unit) or per EAU (Ecosystem Accounting

Unit) and in terms of capacity of each Basic Spatial Unit to generate an ecosystem services (e.g. the capacity of a pixel in a GIS model). Aggregating capacities of individual pixels (/BSUs) over an LCEU gives the capacity per LCEU, and aggregation over an EAU provides the capacity of the EAU to supply a specific service.

Capacity may be aligned with the concept of sustainable yield, in the case of a single resource (e.g. a fish stock) (SEEA EEA 2.32). The sustainable yield, in turn, is determined by the opening stock of the resource (e.g. the fish stock), the growth rate of the resource (e.g. the increase in fish stock due to replenishment) and the loss of fish due to natural processes (e.g. climate variability). However, in reality, single resource use in ecosystems is very rare, many ecosystems provide a basket of goods and services. Hence, in general the capacity to generate provisioning services can be defined on the basis of the long-term capacity of the ecosystem to supply services based on current land use, management and climate (EC et al., 2013). A comprehensive approach is required to establish the capacity. For instance, in the case of timber production (an activity), using timber stands naturally grown in the forest ecosystem (the service), the capacity of the forest at a given time to sustain timber harvesting in the future is a function of the standing stock of timber and the regenerative capacity of the forest (i.e. the mean annual increment, which is in turn determined by among others the age of the trees, soil fertility, water availability, temperature, fire incidence, and potentially management of the forest).

The supply of individual services is often related. For instance, timber extraction at a maximum sustainable rate (a rate that would not jeopardize future timber harvest) may lead to negative effects on biodiversity conservation or carbon sequestration. This indicates that the extraction rate used as a benchmark for sustainable extraction varies for different types of services and land use, and needs to be defined based on locally relevant conditions. The basic principle should be to analyze capacities for all ecosystem services individually based on current management practices. An important implication is that the value of an asset as included in the Ecosystem Accounts is by no means necessarily equal to the maximum value that can be generated by an ecosystem.

Regulating services. Regulating service can be interpreted as involving the generation of a positive externality. The capacity becomes a flow if there are people benefiting from this capacity (aligned with the modelling of ecosystem services in for instance within the ARIES[2] modeling framework (Villa et al. 2014). For instance, in this interpretation, erosion control is a capacity wherever it occurs, and this environmental process becomes an ecosystem service flow if there are people living in the area that experiences a reduction in erosion risk (e.g. who live in the area downslope where mudflows do not, or less occur because of vegetation upslope). Carbon sequestration is a peculiar service, because people always benefit from this service, and for this service capacity equals flow (in line with Schröter et al., 2014).

A particular issue with regulating services is that there can also be a disservice, i.e. services with a negative value, e.g. involving carbon emissions form a degraded peatland, or pest and diseases from ecosystems. Services with a negative value are difficult to accommodate in an accounting context (although there is a potential opening to include negative services in an account when these regulating services are considered to be generated by the sector ecosystems rather than through the activity of a specific sector that uses ecosystems as an asset (see Edens and Hein 2013 for details)). The disservices can be the opposite (in terms of direction) flow of the service, as in the case of carbon emissions from drained peatlands. The flux of carbon from drained peat is from the ecosystem to the atmosphere, the

[2] Artificial Intelligence for Ecosystem Services (http://www.ARIESonline.org/)

sequestration of carbon by forests on mineral soil involves a flux from the atmosphere to the ecosystem. Considering these disservices is important in view of their relative economic importance, their importance for policy making (e.g. REDD+) and the potential occurrence of services and related disservices within the same institutional unit (World Bank, 2014). In the paper 'Linking asset and flow accounts' it is analyzed how services and selected disservices can be included in the accounts.

Cultural services. Cultural services range from tourism and recreation to spiritual aspects and biodiversity conservation. The capacity of the service needs to be defined and determined for each specific service individually. For recreation and tourism, it may relate to the amount of tourists that can potentially be accommodated in a specific area as a function of the level of interest in the type of ecosystem involved, the level of access / remoteness, etc. In case there are grounds to assume that the number of tourists may increase in the future the capacity could be assumed to increase accordingly (World Bank, 2014). For biodiversity conservation, capacity may be related to the species numbers that an area can sustainably harbor under current land use and land cover. The capacity may be higher than the actual occurrence of the species (e.g. because of high hunting pressure) or lower (e.g. because the area is a refuge and current population numbers are above the number that can be sustained in the long-term).

3. Modelling ecosystem services in an accounting context

3.1 Spatial modelling techniques

Spatial modelling is required to produce wall-to-wall maps of ecosystem services for the overall Ecosystem Accounting Unit, covering the different aspects of ecosystem condition, capacity and ecosystem service flows. Often, data is lacking for some areas, for some specific indicators. In this case, spatial interpolation and/or modelling techniques can be used to produce comprehensive maps. This would normally require the combination of a range of datasets including remote sensing images, thematic maps, surveys for specific administrative or ecological units, and point data from specific studies. The different datasets used need to be spatially defined, i.e. they need to be attributed to a spatially defined reference location using a relevant coordinate system – either in case of point data or in case a map is used. Sometimes countries have a specific coordinating system applied in their statistical agencies in which case it is beneficial to use the same coordinate system.

There are a range of spatial modeling tools available for the modelling of ecosystem services. The simplest is called the 'Look-up Tables' approach. More sophisticated methods allow for extrapolation of data to missing points, as well as more elaborate statistical or process based modeling of services supply. In the lookup tables approach, specific values for an ecosystem service or other variable are attributed to every pixel in a certain class, usually a land cover or land use class. These values need to be derived from the scientific literature, for ecosystems that are comparable in terms of vegetation, soil, climate, etc. For instance, every pixel in the land cover class 'deciduous forest' could be given a specific value for its carbon stock, say 250 ton C/ha, based on studies that analyzed the carbon contents of this forest type in a specific agro-ecological zone. In general, the more homogeneous the class is, the more accurate a LUT approach will be.

In addition, there are several statistical approaches for spatial modelling of ecosystem services, capacity and condition, with Maxent being relatively user friendly in the context of ecosystem accounting. Maxent (Phillips et al., 2006) stands for Maximum Entropy, and has traditionally been used to map habitat for different species. The model predicts the potential of a species or ecosystem attribute occurrence by "finding the distribution of maximum entropy (i.e. closest to uniform) subject to the constraint that the expected value of each environmental variable under this estimated distribution matches its empirical average" (Philips et al., 2006). Maxent requires only presence points, and the accuracy levels can also be calculated (using the area under receiver operating characteristic (ROC) curve (AUC), whose value ranges from 0 to 1; an AUC of 1 indicates a perfect accuracy).

Geostatistical interpolation techniques such as kriging rely on statistical algorithms to predict the value of un-sampled pixels on the basis of nearby pixels in combination with other characteristics of the pixel. The basic interpolation methods use simple interpolation algorithms, for instance nearest-neighbor interpolation, but there are more sophisticated geostatistic tools that also considers sets of correlated variables. For instance, timber productivity may be related to productivity in nearby pixels, but in a more comprehensive approach it may also be related to factors such as soil fertility or water availability for which spatial maps are available. Critical in applying geostatistics is that a sufficiently large sample size is available, and that samples are representative of the overall spatial variability found.

3.2 Temporal modelling techniques

In SEEA EEA, temporal modelling is required to forecast the capacity of the ecosystem to generate ecosystem services over time. In particular, the ecosystem asset depends upon the capacity to generate ecosystem services over time. This capacity is a function of the standing stock (e.g. of a timber stand), the regrowth due to natural processes (e.g. growth in timber volume due to regrowth of the forest following harvesting), losses due to natural processes (e.g. storm damage) and ecosystem management (e.g. fire control, pruning, etc.). If the asset is valued in monetary terms, the asset value reflects the Net Present Value (NPV) of the expected flow of ecosystem services (e.g. the discounted net value of the flow of timber during the discounting period). Hence, the flow of timber (and other ecosystem services) needs to be modelled, for every accounting unit.

The modelling approach most consistent with coming to an understanding of flows of ecosystem services is a dynamic systems approach. This approach is based upon the modelling of a set of state (level) and flow (rate) variables in order to capture the state of the ecosystem, including relevant inputs, throughputs and outputs, over time. Dynamic systems models use a set of equations linking ecosystem state, management and flows of services. A dynamic systems model contains state and flow indicators and variables that capture, for instance, the amount of standing biomass (state), the harvest of wood (flow), and the price of wood (time dependent variable). The models runs on the basis of predefined time-increments and requires fully defined initial conditions. The systems approach can contain non-linear dynamic processes, feedback mechanisms and control strategies, and can therefore deal with complex ecosystem dynamics, which are discussed below. However, it is often a challenge to understand these complex dynamics, and their spatial variability, and data shortages may be a concern in the context of ecosystem accounting that requires large scale analysis of ecosystem dynamics and forecasted flows of ecosystem services.

Complex ecosystem dynamics include irreversible and/or non-linear changes in the ecosystem as a response to ecological or human drivers. Irreversible changes in ecosystems occur when the ecosystem is not, by itself, able to recover to its original state following a certain disturbance. Multiple states are relatively stable configurations of the ecosystem, caused by the existence of feedback mechanisms that reinforce the system to be in a particular state. In addition, the ecosystem may also develop as a consequence of stochastic natural conditions, for instance when ecosystem change is driven by fires or high rainfall events. These complex dynamics occur in a wide range of ecosystems, and have a major impact on the future flows of ecosystem services. Where possible (pending data and understanding of the ecological processes involved), these aspects should be considered in the Ecosystem Asset Account.

In some cases, spatial and temporal modelling approaches need to be combined. For instance, process based models are generally required to model regulating services such as erosion control, or ground and surface water flows. Erosion, and erosion control is often modelled with the USLE approach (even though it's reliability outside of the part of the world was developed (i.e. the US) has proven to be variable). Other examples of process based models are the hydrological models such as SWAT and (CSIRO) SedNet. These models are both temporally and spatially explicit, using a dynamic systems modelling approach integrated in a GIS (for instance using the Python modelling language). SWAT is one of the most widely used hydrological models, and uses Hydrological Response Units (HRUs) to model water flows and water stocks, and the processing taking place within these units. The model operates with daily time steps and can therefore be used to model flood regulation throughout the year (through retention of water in upstream HRUs) and maintenance of dry season water flow (through retention and gradual release of water in upstream HRUs). In order to link land use change to hydrology, SWAT needs to be extended with a landscape module, that allows modelling and integration of overland processes such as run-off and run-on and the deposition of soil particles in streams and waterways. SWAT also allows a range of processes affecting water quality such as denitrification.

Note that a critical aspect of modelling hydrological flows is the resolution of the model, both in space and in time. The required resolution depends upon the study area and the geomorphology of the study area, and the selection of the resolution will also be influenced by the availability of data. In general, to have an ecologically robust modelling of water flows, a spatial resolution of at most 30 meters (corresponding to the global ASTER Digital Elevation Model[3]) is recommendable. A temporal resolution of a day would also be recommendable in order to understand and calibrate water flows over time, including the capacity of ecosystems to store water in support of downstream flood control or dry season water supply. Models that use a temporal resolution of months or even years (such as the current InVEST hydrology module) would not generally be adequate to model this service.

3.3 Modelling specific ecosystem services in an Accounting Context

This section presents a very general introduction to the different approaches that can be used to map specific services. The specific modelling approaches applicable to different areas, however, need to be defined as a function of the ecosystem, ecosystem services, ecosystem management, data availability, and the environmental and social context involved (see also World Bank, 2014).

[3] Note that the local accuracy of the global ASTER DEM dataset may vary for different parts of the planet, see also Table 4 of this report.

Table 1. Indicators and mapping methods for selected ecosystem services

Service	Potential indicator	Description
Carbon storage	Ton of carbon (or carbon-dioxide) per hectare or square kilometer.	Carbon storage includes storage in vegetation (above ground, root, dead wood, and litter carbon) and soil carbon. Soil carbon may be low compared to vegetation carbon, as in some types of poor fertility tropical forest soils, or it may be by far the largest component of total carbon storage, as in peatland soils in deep peat (World Bank, 2014). Above ground carbon can be measured with radar remote sensing, but the measurement of below-ground carbon with optical techniques is generally not possible. Instead, for this part of the carbon stock, soil sampling and interpolation of data points is required. Carbon maps are increasingly available for different parts of the world (see also Chapter 4), and the capacity to map above ground carbon stock globally will also increase with the launch of the Sentinel radar satellite in 2014.
Carbon sequestration	Ton of carbon (or carbon-dioxide) sequestered per year, per hectare or per square kilometer.	Carbon sequestration can be related to net ecosystem productivity (NEP), i.e. the difference between net primary productivity (NPP) and soil respiration. NPP can be derived from the Normalized Difference Vegetation Index (NDVI) that can be measured with remote sensing images. However care needs to be taken that the relation between NDVI and NPP is well established for the ecosystems involved, and that accuracy levels are calculated based on sample points. It is often difficult to find credible values for the spatially very variable soil respiration rate, which depends on bacterial and fungi activity which are in turn guided by the local availability of organic matter (e.g. fallen leaves), temperature, moisture, etc.
Maintaining rainfall patterns	mm water evapotranspiration per hectare per year, mm rainfall generated per hectare per year.	Rainfall patterns depend on vegetation patterns at large scales. For instance, it has been estimated that maintaining rainfall patterns in the Amazon at current levels requires maintaining at least some 30% of the forest cover in the basin. Reductions in rainfall in the Western Sahel and the Murray Basin in Australia have also been correlated to past losses of forest cover. This is a significant ecosystem service, however the value of individual pixels is difficult to establish since it requires understanding large scale, complex climatological patterns, large scale analyses of potential damage costs, and interpolations of values generated at large scales to individual pixels with detailed climate-biosphere models.
Water regulation	- water storage capacity in the ecosystem in m3 per hectare (or in mm); - difference	Water regulation includes several different aspects, including (i) flood control; (ii) maintaining dry season flows; and (iii) water quality control – e.g. by trapping sediments and reducing siltation rates). Temporal, i.e. inter-annual and intra-annual, variation is particularly important for this service. Modelling this service is often data-intensive and also analytically

	between rainfall and evapo-transpiration in m3/ha/year;	complex. SWAT is a model often used to model this kind of flows, however extensions of the SWAT model are needed to link land use to water flows, see also Chapter 4.
Surface water modelling; Flood protection	Surface water modelling can be deployed to analyze reductions in flood risk, expressed either as reduction in probability of occurrence, reduction in average duration of the flood, or reduction in water level depending on context	Flood protection depends on linear elements in the landscape that act as a buffer against high water levels (e.g. a mangrove, dune or riparian system). Modelling this service requires modelling flood patterns and the influence of the vegetation. It may not always be needed to model flood protection in physical terms in order to understand the monetary value of the service - in particular in those areas where it is certain that natural systems, if lost, would be replaced by artificial ones (e.g. a dyke), as would be the case in most of the Netherlands, for instance. In this case, valuation may be done on the basis of a replacement cost approach that does not require understanding the physical service in full.
Erosion and sedimentation control	- difference between sediment run-off and sediment deposition in ton/ha/year	There is relatively much experience with modelling this service. Erosion models can be integrated in a catchment hydrological models (such as SWAT or CSIRO SedNet, both freeware) to predict sediment rates. In SWAT, a watershed is divided into Hydrological Response Units (HRUs), representing homogeneous land use, management, and soil characteristics. Erosion rates need to be estimated for each HRU, for instance on the basis of the MUSLE or RUSLE erosion models or alternatively SWAT landscape can be used which includes grid based land cover units.

4. Global Datasets and remote sensing

4.1 Global datasets on ecosystem services analysis

There are several databases providing information on ecosystem services and their values, both spatial and non-spatial (Table 2 below) as well as a number of global tools that provide information on the methods that can be used to map, model or value ecosystem services (presented in Table 3 below).

Table 2. Global ecosystem services databases

Dataset	Author	Description	Scale	Link
Pilot Analysis of Global Ecosystems (PAGE): Agro-ecosystems	World Resources Institute (WRI), IFPRI	The study identifies linkages between crop production systems and environmental services such as food, soil resources, water, biodiversity, and carbon cycling	9 geospatial datasets providing a detailed spatial perspective on agroecosystems and agroecosystem services, see Annex 1.	http://www.ifpri.org/ dataset/pilot-analysis-global-ecosystems- page (187 Mb)
Ecosystem Services Values Database	FSD, Wageningen	Database containing information on valuation studies carried out across the planet (value estimates, authors of studies, general description of methodology used).	Non-spatial.	http://www.fsd.nl/esp/80763/5/0/50

Table 3. Databases with methods for ecosystem service assessment

Dataset	Author	Description	Link
Values Database	Deutsche Gesellschaft für internationale Zusammenarbeit (GIZ) GmbH; Helmholtz-Zentrum für Umweltforschung (UFZ) GmbH	Database with detailed description of modelling methods and valuation approaches	http://www.aboutvalues.net/ method_database/
Ecosystemvaluation.org	University of Maryland	Database with information on and examples of valuation methods	www.ecosystemvaluation.org

4.2 Global datasets on ecosystem components

Table 4 below describes some of the key datasets with a global cover that are relevant for ecosystem accounting, subdivided into datasets covering remote sensing data, land cover and vegetation, soils and water. Note that these datasets are usually derived from remote sensing data in combination with other datasets. The table only lists datasets that can be downloaded free of charge, with commercial datasets usually available at higher resolution, but requiring payment for specific geographical areas. Note that the data from the new European Space Agency Sentinel satellites is not yet available. Their resolution is finer than the Landsat images, and an additional advantage is that the satellites provide both radar and optical images. Note that a total of 6 Sentinel satellites are planned to be launched, with Sentinel 1 (Radar) and Sentinel 2 (Optical) most relevant for Ecosystem Accounting. Note also that remote sensing data provides information on the observable properties of ecosystems. Some of this information can be linked to ecosystem uses (i.e. ecosystem service flows), such as information on deforestation patens or land use change. Other observable information can be linked to Ecosystem assets (such as standing biomass or Net Primary Production). The specific linkage of remote sensing data to ecosystem service flow or asset modelling always needs to be determined for the specific ecology and uses of the area involved. state of This would lead to a large increase in possibilities to model land cover and model ecosystem services such as crop production, carbon sequestration (through fine resolution NPP mapping) and erosion control (e.g. by modelling vegetation cover of the soil). Given that data volumes are large this means that larger data storage and processing facilities will be needed to deal with the information generated. Specific information on potential applications of Sentinel imagery can only be provided when the images become available (currently estimated to be early 2015 for the radar images).

Table 4. Global datasets

Dataset	Author	Description	Scale	Link
Remote sensing data				
MODIS imagery dataset	NASA Earth Observation System (EOS)	Views the entire surface of the Earth every one to two days, imagery can be downloaded from website.	Its detectors measure 36 spectral bands between 0.405 and 14.385 µm, and it acquires data at three spatial resolutions -- 250m, 500m, and 1,000m.	https://lpdaac.usgs.gov/products
Landsat dataset	NASA	Multispectral data of the Earth's surface on a global basis, from several operational Landsat satellites (plus historical images form earlier Landsat satellites).	Depending on satellite and band, for Landsat 8 has 11 bands with a resolution of 30 by 30 meter for 8 out of these 11 bands.	http://landsat.gsfc.nasa.gov/
Sentinel	European Space Agency	■Sentinel-1 is a polar-orbiting, all-weather, day-and-night radar imaging mission for land and ocean services. The first Sentinel-1 satellite was launched on 3 April 2014. ■Sentinel-2 is a polar-orbiting, multispectral high-resolution imaging mission for land monitoring to provide, for example,	Wide-swath mode at 250 km and 5×20 m resolution Wave-mode images of 20×20 km and 5×5 m resolution (at 100 km intervals) Strip map mode at 80 km swath and 5×5 m resolution Extra wide-swath mode of 400 km and 20×40 m resolution	At the time of preparation of this document, the Sentinel data were not yet available. More information can be found at: http://www.esa.int/Our_Activities/Observing_the_Earth

		imagery of vegetation, soil and water cover, inland waterways and coastal areas.		
Land cover and vegetation				
Global Index of Vegetation-Plot Databases (GIVD)		Metadatabase providing an overview of existing vegetation data worldwide, the metadatabase facilitates the use of these data by other scientists.		www.givd.info
The Global Land Cover 2000 Map	EU Joint Research Centre	The map illustrates the distribution of surface materials or "land cover" over the entire globe. This map helps to show the major ecological systems that exist such as forests, grasslands, and cultivated areas.	Published in geographic projection at 30 arc-seconds resolution.	http://geoserver.isciences.com:8080 /geonetwork/srv/en/metadata.show?id=55
MODIS NPP dataset	NASA Earth Observation System (EOS)	Continuous estimates of Gross/Net Primary Production (GPP/NPP) across Earth's entire vegetated land surface. Useful for natural resource and land management, global carbon cycle analysis, ecosystem status assessment, and environmental change monitoring.	1 km resolution	http://www.ntsg.umt.edu/project/mod17
Global Forest Change 2000–2012	University of Maryland	Results from time-series analysis of 654,178 Landsat 7 ETM+ images in characterizing global forest extent and change from 2000 through 2012. For additional information about these results, please see the associated journal article (Hansen et al., Science 2013).	1 km resolution (note that the maps sometimes classifies plantations such as palm oil plantations as forests)	http://www.earthenginepartners.appspot.com/science-2013-global-forest/download.html
Global Forest Resources Assessment 2010 (also available for 1990, 2000, 2005)	FAO	Comprehensive assessment of forests and forestry examining the current status and recent trends for about 90 variables covering the extent, condition, uses and values of forests and other wooded land,	Not spatial, information is presented in tables per country. The reliability and accuracy of the tables varies per country.	http://www.fao.org/forestry/fra/fra2010/en/
Soils and terrain				
SoilGrid	ISRIC Wageningen	Dominant soil types according to FAO/ISRIC soil classification	1 km grid, global.	http://www.isric.org/content/soilgrids

ASTER Global Digital Elevation Map	NASA, METI Japan	DEM and water body coverage and detection in GeoTIFF format	30-meter postings and 1 x 1 degree tiles	http://asterweb.jpl.nasa.gov/gdem.asp
Water				
Tropical Rainfall Measuring Mission (TRMM)	NASA and JAXA	Precipitation over tropical and subtropical regions	From around 35° north latitude (e.g., the Mediterranean Sea) to 35° south latitude (e.g., the southern tip of South Africa), since 1997	http://trmm.gsfc.nasa.gov/overview_dir/background.html
Global Precipitation measurement	NASA	Observations of rain and snow worldwide every three hours	Global, from 65° north latitude (e.g., the Arctic Circle) to 65° south latitude. This is a new satellite, and information is now becoming available.	http://www.nasa.gov/mission_pages/GPM/main/
WaterWorld	King's College London (models), Ambio-TEK (software)	Rainfall and potential evapotranspiration rates, global dataset	1 km grid	http://www.policysupport.org/waterworld

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