WORKING PAPER

Designing Pilots for Ecosystem Accounting

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WAVES

WORLD BANK GROUP

Global Partnership for Wealth Accounting and Valuation of Ecosystem Services (WAVES)

Wealth Accounting and Valuation of Ecosystem Services (WAVES) is a global partnership led by the World Bank that aims to promote sustainable development by mainstreaming natural capital in development planning and national economic accounting systems, based on the System of Environmental-Economic Accounting (SEEA). The WAVES global partnership (www.wavespartnership.org) brings together a broad coalition of governments, UN agencies, nongovernment organizations and academics for this purpose.

WAVES core implementing countries include developing countries—Botswana, Colombia, Costa Rica, Guatemala, Indonesia, Madagascar, the Philippines and Rwanda—all working to establish natural capital accounts. WAVES also partners with UN agencies—UNEP, UNDP, and the UN Statistical Commission—that are helping to implement natural capital accounting. WAVES is funded by a multi-donor trust fund and is overseen by a steering committee. WAVES donors include—Denmark, the European Commission, France, Germany, Japan, The Netherlands, Norway, Switzerland, and the United Kingdom.

One of the key objectives of WAVES is to help develop internationally agreed guidelines for ecosystem accounting. The work on this front is led by the Policy and Technical Experts Committee (PTEC), a multidisciplinary body consisting of experts in economics, environmental accounting, natural sciences, and policy from the World Bank, UNEP, academic institutions, and governments. In addition to methodology development, PTEC also leads work to compile evidence on policy applications of natural capital accounts and to develop training materials.

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Chapter 1: Designing Pilots for Ecosystem Accounting: An Overview

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1.0 Introduction

Interest is still growing in better understanding the economic implications of the ongoing changes to the world's ecosystems (MA 2005, TEEB 2010, EC 2011, and UK NEA 2011). Among other goals, there has been a strong increase in interest in developing ecosystem accounts, building on the experiences gained with environmental economic accounting since the mid-1970s. Ecosystem accounting aims to integrate ecosystem services and ecosystem capital with national accounts. There is an increasing international interest in ecosystem accounting, as expressed at the Rio+20 United Nations Conference on Sustainable Development 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 publication of "System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting" (European Commission, et al. 2013). These guidelines lay out the basic concepts; the relation between ecosystem accounting, environmental economic accounting, and national accounting; as well as remaining challenges in the development of ecosystem accounts.

The Wealth Accounting and Valuation of Ecosystem Services (WAVES) global partnership was launched in October 2010, with the aim of developing new methods for natural capital accounting to be applied and tested in a range of different countries. The overall objective of WAVES is to improve information available to decision makers so that development can continue in the most sustainable way possible. Another key objective is to help develop internationally-agreed guidelines for ecosystem accounting. This task is led by the Policy and Technical Experts Committee (PTEC), a multidisciplinary body consisting of experts in environmental accounting, economics, and natural science and policy experts from the World Bank, United Nations Environment Programme (UNEP) and other UN agencies, academic institutions, and government. PTEC has been established to, among other goals, (1) identify opportunities to mainstream natural capital accounting and better link this to policymaking; (2) contribute to the development of scientifically credible methodologies for ecosystem accounting; and (3) ensure cohesion, consistency, and scalability among WAVES country studies.

This note is intended to give guidance to practitioners and researchers on how to design pilot studies for ecosystem accounting. It makes use of discussions and inputs from PTEC members during a workshop on designing pilot studies for ecosystem accounting in May 2013, as well as discussions during the PTEC annual meeting in November 2013. The purpose of this note is to outline the components that a pilot study on ecosystem accounting should include, give advice on how to design the study, and describe the research issues that the study should address. The focus of the note is on regulating services, since these generally are the most complex to analyze.

1.1 Characteristics of Ecosystem Accounting

Measuring and valuing ecosystem services can be done for different purposes, such as monitoring the changes in the services or doing cost-benefit analysis of a project. Ecosystem accounts use an accounting framework that is consistent with the UN's System of National Accounts (SNA) and System of Environmental-Economic Accounting (SEEA). An important feature of the pilot studies is thus to link the ecosystem services to economic sectors and actors using concepts, definitions, and methodology that is consistent with the SNA.

Box 1. Definitions

An *ecosystem* is "a dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit." Convention on Biological Diversity (2003), Article 2, Use of Terms

Ecosystem services are the contributions of ecosystems to benefits used in economic and other human activity. They are usually divided into the categories *provisioning, regulating,* and *cultural* services. In the SEEA Experimental Ecosystem Accounting, the categories are described as follows:

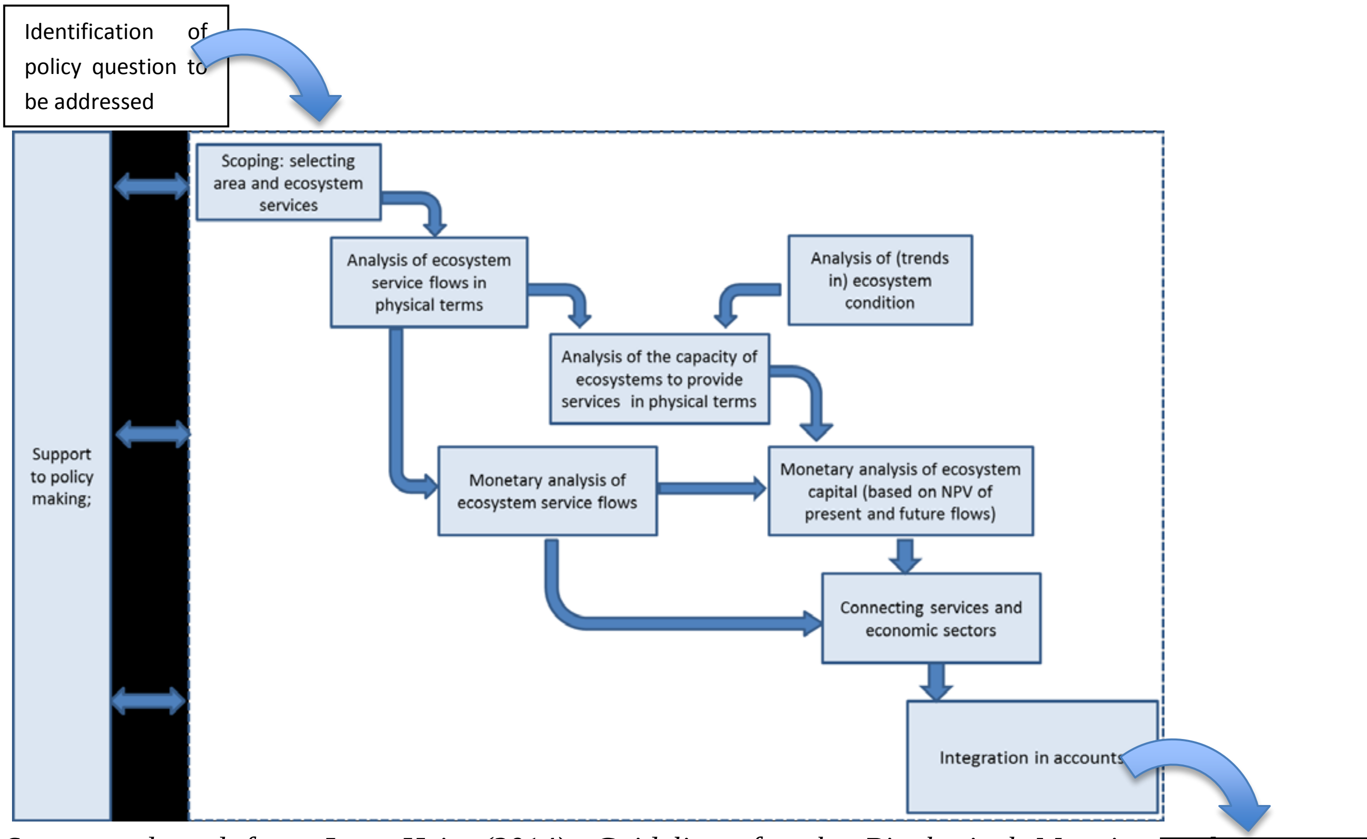
1) *Provisioning services* reflect material and energy contributions generated by or in an ecosystem, for example a fish or a plant with pharmaceutical properties.
2) *Regulating services* result from the capacity of ecosystems to regulate climate, hydrological and bio-chemical cycles, earth surface processes, and a variety of biological processes. These services often have an important spatial aspect. For instance, the flood control service of an upper watershed forest is only relevant in the flood zone downstream of the forest.
3) *Cultural services* are generated from the physical settings, locations, or situations which give rise to intellectual and symbolic benefits that people obtain from ecosystems through recreation, knowledge development, relaxation, and spiritual reflection. This may involve actual visits to an area, indirectly enjoying the ecosystem (e.g., through nature movies), or gaining satisfaction from the knowledge that an ecosystem containing important biodiversity or cultural monuments will be preserved. (SEEA Experimental Ecosystem Accounting, para.3.4)

Ecosystem accounting is "a coherent and integrated approach to the assessment of the environment through the measurement of ecosystems and measurement of the flows of services from ecosystems into economic and other human activity.
Ecosystem accounting goes beyond other approaches to ecosystem analysis and assessment through the explicit linking of ecosystems to economic and other human activity. The links are seen both in terms of the services provided by ecosystems and also in the impacts that economic and other human activity may have on ecosystems and their future capacity. … The use of an accounting framework enables the stock of ecosystems—*ecosystem assets*—and

flows from ecosystems—*ecosystem services*—to be defined in relation to each other" (SEEA Experimental Ecosystem Accounting, para.1.1-1.2).

The key steps in building an ecosystem account are shown in Figure 1 below. It is important that the policy question to be answered is clearly defined at the outset, for the analysis to be useful for policymakers, and to make sure that the subsequent data gathering and analysis is what is needed for the policy analysis in the last step. The policy analysis can include an examination of different scenarios and the costs and benefits of a certain policy, and may involve using tools like economic models and input-output analysis. However, the policy analysis step is not expanded upon in this note.

Figure 1: Key Steps in Building Ecosystem Accounts



Source: adapted from Lars Hein (2014), Guidelines for the Biophysical Mapping Analysis of Ecosystem Services in an Ecosystem Accounting Context

1.2 When is Ecosystem Accounting a Suitable Tool?

Ecosystem accounting involves bringing different databases under one common structure, which helps to handle cross-sectoral, economy-wide issues as well as linkages between ecosystems and the economy, such as when an economic activity is dependent on non-provisioning services. Measuring and valuing ecosystem services can be done for different purposes, such as monitoring changes in the services or doing a cost-benefit analysis of a project. Since ecosystem accounts use the same classification system as national accounts, they can be integrated into analytical tools that use national accounts for economic policy analysis, e.g., to develop or adjust policy instruments to handle the problem at hand.

When you have a policy question that involves trade-offs between different ecosystem services or between ecosystems and economic activities, the accounts can help to

- structure data on the basis of relationships;
- understand the economic implications of changes in ecosystems; and
- ensure that data collected in different areas, sectors, and countries are consistent and comparable.

Examples of situations when ecosystem accounting is appropriate to help determine policy are

- designing a Payment for Ecosystem Services (PES) plan;
- determining land-use trade-offs, e.g., deciding whether to protect nature areas or whether mining or agricultural activities can coexist sustainably with other land uses and how this can be accomplished; and
- estimating the economy-wide impacts of changes in an ecosystem, such as building a dam or instituting other major land-use changes.

Ecosystem accounts may be a less suitable tool when the issue at hand involves a very small spatial or administrative unit or where the comprehensiveness of the accounts is not needed. Similarly, when it is necessary to understand the welfare impacts of a project, the ecosystem accounts must be complemented by measures of welfare impacts.

1.3 Features of Pilot Ecosystem Accounts

1.3.1 Scaling up

An ecosystem account includes spatially disaggregated assessments of biophysical flows in a specified area that can be defined both by administrative borders and by natural borders, such as a watershed. The site-specific values should be possible to scale up to a sub-regional/regional/national scale. Accounting is ultimately done for the country as a whole. However, there are no agreed methods for scaling up in ecosystem accounting, making it an important research issue to be addressed in pilot studies. In so doing, a first step could be to aggregate to a suitable subnational level. To be able to scale up results, it is important to analyze differences in values for different sites, or across a site that is large enough to display varying characteristics.

1.3.2 Valuation methods

An important issue is to choose valuation methods that are consistent with valuation methods used in national accounts. The main valuation method in accounts is using marginal values, which do not include consumer surplus. However, in some non-market sectors, such as government and non-profit sectors, the cost of inputs are used to value the goods and services. More on valuation is included below. An equally important factor to consider is the allocation of property rights, which will have a large influence on the value of the resource or ecosystem service. The value will vary depending on the associated structure of property rights. In the case of open access, it is important to include calculations for different institutional settings, to understand the potential value of the service.

1.3.3 Linking ecosystem services to economic sectors and actors

This is an integral part of ecosystem accounts that is instrumental in assessing the contribution of the ecosystem services to the economy. The purpose is to analyze the distribution of benefits from the services and of costs due to changes in the flows of services; e.g., between regions, households, businesses, income groups, and domestic and foreign actors. This will be a basis for looking at promoting sustainable growth, reducing poverty, and reducing inequality.

1.3.4 Comprehensiveness with regard to ecosystem services

To make a full ecosystem account for a study site, all ecosystem services generated should be identified. However, this may be difficult to achieve within the time frame of the study and may not be relevant for the policy question at hand. If this is the case, it is sufficient to list all the services while setting priorities to measure a few of them that are most relevant for the policy question at hand. What is crucial is to choose classifications and measurement methods (e.g., choice of indicators) so that they can be integrated into a full account at a later stage.

1.4 Issues to be Tested in Pilot Studies

Relevant research issues that pilots can focus on include the following:

1. What are the spatial scale and temporal scales required for regular development of ecosystem accounts, e.g., for scaling up to national ecosystem accounts?
2. What biophysical services can be modeled reliably enough for decision making, in terms of both capacity and service flow? What models are appropriate for different ecosystem services and different levels of data availability?
3. What guidance can be provided for valuation methods for different ecosystem services in terms of complexity, data availability, and relevance for answering the policy issue at hand?
4. How do different valuation methods compare for the same ecosystem? This can include comparisons of shortcut formulas for valuing natural stocks to stock values, based on explicit projections of future service values, as well as comparisons of welfare-based valuation methods to methods based on SNA principles. In addition,

this could include comparisons of methods that are known to generate biased estimates (e.g., replacement costs) to less-biased methods, in order to understand the practical significance of the bias.

1.5 Designing a Pilot Study

1.5.1 Defining the Scope of the Project

The following steps can be followed to define the scope of the project:

1. **Define the policy question that the pilot is being designed to answer**
   Criteria for choosing the policy question include
   - the policy's relevance and the likelihood that it will influence decision making: governmental interest as expressed e.g. in plans and policies and active government support, expedient institutional setting
   - stakeholder involvement
   - technical criteria (e.g., data availability)

2. **Identify the relevant ecosystems and ecosystem services**
   It is not always possible to include all services of the flow from the ecosystem under consideration, due to time and resource constraints. However, it is preferable that all services are included in the conceptual framework, even if they are not included in the subsequent analysis. There may be trade-offs among ecosystem services or unanticipated consequences that cannot be reliably measured at the time of the study, but at least such possibilities can be flagged by including all the ecosystem services in the framework.

   The listing of ecosystem services is not always straightforward. It is necessary to distinguish between "intermediate" ecosystem services, i.e., services that support other ecosystem services, and "final" ecosystem services that directly deliver welfare gains and/or losses to people. This distinction is important to avoid double counting in the valuation of ecosystem services (Fisher and Turner 2008).The ecosystem services that are relevant for ecosystem accounts are thus the contributions of ecosystems to benefits used in economic and other human activity.

   There are multiple classifications of ecosystem services and one purpose of the pilot may be to test out the usefulness of these alternatives. It should be noted that the Common International Classification of Ecosystem Services (CICES) provides a list of ecosystem services; similar to the NACE classification in standard national accounts, it does not in itself provide guidance to avoid double counting.

3. **Determine the relevant scale**
   Issues at the national or regional scale should be considered to identify the priority one and then a suitable pilot area (which can be on a smaller scale) should be selected. One or multiple areas could be chosen. An important issue that might influence the choice of scale is whether there may be confidentiality issues, such as when only one or a few companies are involved.

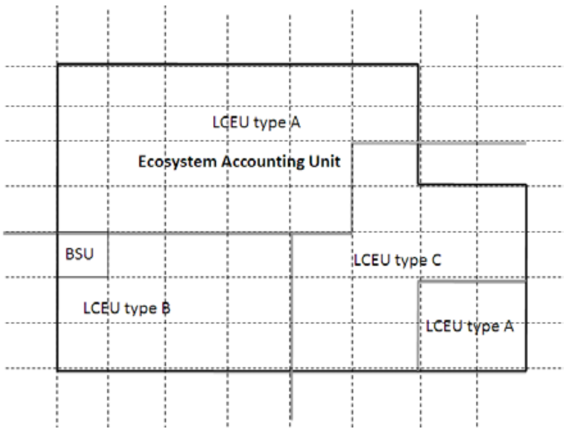
   Sites should be selected to be statistically representative, so that it is possible to scale up the results to a national, regional and/or subregional scale. To be able to scale up results, it is important to analyze differences in values for different sites, or across a site that is large enough to display varying characteristics.

1.5.2 Collecting and Systematizing Data

A pilot study for ecosystem accounting will typically include land cover data, following land cover classifications of the SEEA Central Framework, which can be tailored to the specific characteristics of the country. This basic part will then be complemented by physical measures of quantity and quality of relevant natural assets, including flows of services and capacities of ecosystems to generate services. The steps to follow are outlined in Box 2.

Box 2: Data Collection

1) Compile national/regional data where available. Select appropriate Ecosystem Accounting Unit (EAU) (e.g., administrative area, drainage area, management area).
2) Create a register at the basic spatial unit (BSU) level (e.g., pixel, cadastre, and grid). Aerial data are finer than remote sensing data, but are harder to interpret. These can be used to ground truth remote sensing data.
3) Make sure that data are consistent over time.
4) Identify users/beneficiaries of the ecosystem services.
5) Collect available data on population, income, economic activity, taxes/fees/subsidies, employment, industry of employment (including location), and adapt to your chosen area. For provisioning and cultural services, data for the valuation step also would be collected from official statistics and surveys.
6) Aggregate data from BSU to land cover/ecosystem functional units (LCEU). For each type of LCEU, compile measures of condition (e.g., leaf area index, biomass index, species diversity, soil fertility, water quality, net carbon balance).
7) Choose condition indicators relevant to services. Each may have its own rules for aggregation and scaling. In the case of dissimilar measures, index to reference condition to assign a common currency.



Stylized depiction of relationships between BSU, LCEU, and EAU. The outer border represents the EAU.

Source: System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting, p.31

1.5.3 Selecting the Biophysical Models to Model the Physical and Spatial Flow of Regulating Ecosystem Services

Biophysical models are often needed to estimate the flow of regulating ecosystem services and the impact on them from changes in, for example, use and management of the ecosystem and surrounding areas. Depending on data availability, the first step is often to scale up your data and fill in data gaps. The following gives an idea of methods to use. For more detailed guidance on mapping, see Hein (2014). Comparisons of different biophysical models can be found, for example, in Vigerstol and Aukema (2011). They compare ecosystem services tools (InVEST, ARIES, SWAT and VIC) to each other and across categories. Assessment criteria include data requirements, ease of use, policy question at hand, and interpretability of results by non-experts. Comparisons of tools and models, as well as empirical testing, can be found in Bagstad et al. (2012) and Bagstad et al. (2013).

Mapping and scaling up physical data

1. Interpolation methods can be used for filling in gaps in the data set and scaling up the data to cover a larger area.

2. Kriging is a group of geostatistical techniques (geostatistics is a branch of statistics related to spatial datasets and in closely associated with interpolation methods). Kriging interpolates the value of a random field (e.g., the elevation of the landscape as a function of the geographic location) at an unobserved location from observations of its value at nearby locations.

3. Maxent refers to a maximum-entropy approach for species habitat modeling. It takes as input a set of layers or environmental variables (such as elevation, and precipitation), as well as a set of georeferenced occurrence locations, and produces a model of the range of the given species.

Modeling ecosystem service flows

There are a number of models available, each with their pros and cons. They are roughly divided into process-based and empirical models. Table 1 gives a sample of these models.

Box 3. Empirical vs. Process-Based Models

Empirical models are based on statistically significant relationships between or among variables for which a reasonable database exists. The Universal Soil Loss Equation—on which many erosion models are based—is an example of an empirical model, with a database amounting to more than 10,000 plot years of soil erosion data. The simplicity of empirical models, in terms of data requirements and modeling power, make them useful for a preliminary measure of ecosystem services (Merritt et al. 2003). The simplicity of empirical models also is their downfall, as they ignore the heterogeneity of ecosystem processes and characteristics (ibid.). Empirical models are also limited in their transferability, as relationships between variables have been developed based on data collected at a particular site and under particular conditions (Nearing et al. 1994).

Process-based models are based on the solutions of physical equations, such as conservation of mass and momentum. They can potentially provide a more accurate and precise simulation of ecosystem processes than empirical or conceptual models because they incorporate a greater number of physical equations that describe natural processes. For example process-based erosion and sediment transport models often incorporate physical equations that describe streamflow and sediment and associated nutrient generation in a catchment (Merritt et al., 2003). However, these models are characterized by large numbers of parameters, many of which are difficult to measure and so must be calibrated against observed data. These characteristics also introduce problems such as parameter identifiability, errors in the measurement of important ecosystem characteristics, and errors introduced in the scaling-up of model parameters from the plot to the catchment scale (Wheater et al. 1993).

Table 1: Examples of Biophysical Models

Model	Ecosystem Service	Type of Model
WEPP	Soil erosion	Process based
USLE	Soil erosion	Empirical
ARIES	Carbon sequestration and storage Open space proximity Aesthetic view sheds Flood regulation Sediment regulation Water supply Coastal flood regulation Subsistence fisheries Recreation Nutrient regulation	A modeling platform that incorporates several models. It can use process-based models, and where they are not available, uses agent-based models (probabilistic Bayesian models)
InVEST	Aesthetic quality Habitat quality and rarity Carbon storage and sequestration Coastal protection (avoided erosion and flood protection)	A modeling platform that uses several process-based models

	Pollination Timber production Fisheries (provisioning) Water yield Sediment retention (avoided sediment) Water purification	
SWAT	Soil erosion Water purification	Process based
VIC	Water yield Stream flow	Process based

1.5.4 Estimating the Value of the Ecosystem Service

The next step is to assess the monetary values of the ecosystem flows and ecosystem capital. For provisioning and cultural services, valuation can be done, to a large extent, using data on market prices from official statistics and survey data (see Table 2). To value regulating services and certain cultural services, the services need to be linked to economic assets and economic beneficiaries. Questions that help in this linking process include:

- What economic activities are being supported?
- Who are the users/beneficiaries and where are they located?
- What is the distribution of value added by factors of production and by income categories?

It is vital to apply valuation principles that are consistent with an accounting framework. This means not to include consumer surplus in the valuation of ecosystem services. However, it is appropriate to use the change in consumer surplus (=price) times quantity, since this will provide a marginal price. The production function approach or damage costs avoided approach are suitable methods to use.

A related and equally important principle is that the value of the service should be estimated as the willingness to pay for a marginal unit of the service. For instance, replacement costs or restoration costs may not reflect what consumers are willing to pay for goods that don’t have competitive markets. On the other hand, there are times when the replacement/restoration cost is less than willingness to pay, and then this would be the right value to use.

An important part of the valuation step is to assess the impact of institutional context on service values. The supply of ecosystem services is contingent on the institutional context. For instance, an open-access fishery generates no resource rent: labor and capital earn returns equal to their opportunity costs, but the fish stock itself earns no return. In contrast, a fishery that is better managed and addresses the stock externality that causes rent dissipation can generate a positive resource rent. Thus, good governance will increase the value of the resource. This information is vital for planning and policy decisions.

To advance knowledge on the empirical performance of different methods, it is valuable to use and compare multiple valuation methods.

Table 2: Examples of Valuation Methods Compatible with National Accounts

Type of Ecosystem Service	Valuation Method	Short Description
Provisioning services	Unit resource rent	Producer's surplus is calculated net of labor and man-made capital inputs and adjusted for taxes and subsidies. The value will vary depending on the associated structure of property rights. In the case of open access, it is important to include calculations for different institutional settings, to understand the potential value of the service.
Regulating services	Production function method	The contribution of ecosystem services to production processes are valued by estimating their contribution to the value of the final product when sold on the market (i.e., net of labor and capital costs).
	Damage costs	The value of production losses or damages due to degradation or loss of ecosystem services can be used as estimates of the value of these services.
Cultural services	Travel cost method	The amount that consumers are willing to pay for goods and services related to visits to recreational sites can be used as a proxy for the value of the ecosystem and its attributes.
	Hedonic pricing	This involves disentangling the part of the price that people pay for marketed products or assets that can be attributed to the local ecosystem services.
	Production function	Similar to regulating services, the value of cultural services can be disentangled from the value of marketed products. An example is to estimate the part of the value added of the tourism sector that can be attributed to the ecosystem.

1.5.5 Scaling Up and Integrating with SEEA/SNA

As noted above, it is vital to pick sites to be statistically representative, so that they are suitable for scaling up, whether to the national, regional, or sub-regional scale. The value of ecosystem services is typically location specific, for ecological and social reasons in addition to institutional reasons. To be able to scale up the results, it is thus important to study several sites or ecosystems and analyze possible differences in values. The mapping of services to beneficiaries and assets done in the valuation step also is vital for integrating into the accounts system.

The physical measures and values of the ecosystem services then should be integrated into national or regional accounts. There are currently several suggestions on how to do this. Edens and Hein (2013) suggest recording ecosystem services with a public goods character as generated by an ecosystem sector, and ecosystem services with a private goods character as contributions of the economic sector that reaps the benefits. However, this issue has yet to be agreed upon, and it is valuable to investigate the pros and cons of different approaches.

1.5.6 Policy Analysis

The final step is to use the developed ecosystem account for policy analysis. Here, the impact of various future scenarios and policy decisions on the ecosystem can be estimated, as well as impacts on economic actors from changes in the management of ecosystems. The analysis also can involve changes in the price of the benefits generated by the ecosystem, due to changes in the supply and demand of the ecosystem services and ensuing changes in the benefits.

1.5.7 Reporting

In the pilot study report, it is recommended to include the cost of the valuation method chosen. The cost of applying different valuation methods varies, as does the accuracy and precision of the estimates they generate. These factors, along with the availability and quality of existing data, influence their relative suitability for different countries. Increased knowledge about this is therefore an important part of the research.

It is also useful for other researchers/practitioners to get information about communication issues, stakeholder involvement, and particular difficulties that arise during the project. Communication with policy makers and capacity building in the country are important factors that also are interesting information. Furthermore, while pilots may not be testing out classifications as such, it is very useful to get information on how the classification used worked in this particular project/site.

Chapter 2: Scoping of Experimental Ecosystem Accounting

Hedley Grantham, Lars Hein, Miroslav Honzák, Daniel Juhn, Rosimeiry Portela, and Ana Maria Rodriguez

2.0 Introduction

Background on WAVES

To inform decision making, WAVES uses the System of Environmental and Economics Accounts (SEEA). National accounts are important because they constitute the primary source of information about the economy and are widely used for assessment of economic performance and policy analysis in all countries.

Traditional economic indicators used in national accounts, such as gross domestic product, have important limitations, in particular in the way they record changes in natural and environmental resources. GDP indicates whether an economy is growing, but gives no information on whether the growth is sustainable. GDP does not account for depletion or degradation of natural capital (for instance, through mining or over-harvesting of forests). It also fails to explicitly identify and record changes in the supply of critical ecosystem services, such as regulating water cycles, preventing erosion and flooding, and sequestering carbon from the atmosphere.

To support more informed decision making on economic development and natural resource use, WAVES will help develop and implement expanded measures of natural wealth. In particular, WAVES will provide countries with the tools they need to integrate the economic benefits of ecosystems like forests and wetlands into their national accounting systems and to improve decision making. WAVES comprises a number of components aimed at further developing and implementing different methodologies for natural capital accounting. This report focuses on ecosystem accounting, following the recently published white paper, “System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting” (European Commission et al. 2013).

The report has been prepared for the Policy and Technical Experts Committee (PTEC) to support the work in WAVES partner countries. PTEC has been established to guide development and implementation of scientifically credible methodologies for ecosystem accounting; identify opportunities to contribute to policy and mainstreaming; and ensure cohesion, consistency, and scalability among country studies. Supporting national partners with the testing and implementation of different approaches for natural capital accounting is an important component of the PTEC work program.

Background on EVA

Conservation International’s Ecosystem Values Assessment and Accounting (EVA) project is a pilot initiative to design and field test a replicable and scalable framework for incorporating nature’s value into decision making and informing more sustainable policies and practices. A Conservation International team will implement EVA in Peru, in collaboration with the

Ministry of Environment (Directorate of Ecosystem Evaluation, Valuation, and Financing), Conservation International Peru, and several other partners (see Chapter 2).

Three key objectives of the EVA project are to (1) develop and test methods for providing information on the state of relevant ecosystems, on biophysical and economic values of stocks and flows of ecosystem services, and on trends and thresholds in their provision; (2) translate these values into information that can be used to inform policy and decisions, such as natural capital accounts; and (3) identify key opportunities for supporting policies that incorporate this ecosystem services information into more effective decision making and management.

Ecosystem capital accounting is a central element of the EVA project, and this part of EVA will be implemented in alignment with the methodologies that have been developed in the context of the guidelines on experimental ecosystem accounting (European Commission et al. 2013) coordinated by the UN Committee of Experts on Environmental-Economic Accounting, and the methodological approaches being developed and tested in the context of the WAVES project.

It's necessary to ensure that recent insights in scoping, mapping, modeling, and valuing ecosystem services described in the SEEA experimental ecosystem accounting guidelines and being discussed in the context of WAVES are incorporated in the methodological design of the EVA project. At the same time, experiences from the EVA project should be used to develop overall guidelines on ecosystem accounting, which is one of the components of the WAVES project. A main asset of the EVA project is that it is well embedded in a range of programs carried out by Conservation International in Peru, and that data availability is relatively high. Moreover, there is strong interest from the Peruvian government in natural capital and ecosystem accounting.

Objectives and Approach

The general aim of this report is to contribute to the building of knowledge within WAVES on how ecosystem accounting can be realized, focusing on the establishment of pilot projects for ecosystem accounting. The selection of a pilot area is important because its degree of success will influence the national debate on ecosystem accounting, including the decision to invest long term in developing and maintaining ecosystem accounts. In addition to selecting a pilot site, there is a need to select ecosystem services to be included in the pilot project, since it may be too ambitious to analyze all ecosystem services provided in the pilot area. Given that pilot projects will generally aim to contribute to the development of methods for national-level ecosystem accounts, there is a rationale for testing the approach on a relatively large scale, for instance, a state, province, or large watershed.

The general assumption underlying this report is that, at this point in time, there is a need to further test the recently published experimental ecosystem accounting guidelines and other relevant approaches and insights at a sub-national level, to better understand data collection needs, analytical approaches, feasibility of establishing ecosystem accounts, and the accuracy of such accounts once created. It is therefore important to have a solid understanding of the criteria that can be used to identify pilot project areas, and ecosystem services to be included in the pilot. In particular, case study selection requires a number of choices: selecting the physical area, delineating the area (physical or administrative boundaries) and selecting the ecosystem services to be included in the assessment. This report demonstrates how the site selection process was conducted for Peru (Chapter 2) and provides a number of general lessons for case study selection based on the experiences gained in Peru (Chapter 3).

The report draws mainly on the experiences gained during a July 7–19, 2013, mission to Peru by the Conservation International team working with PTEC. Based on preparatory work by Conservation International, the case study site for the EVA project was selected during this mission. The report also builds upon the scientific literature in the field of ecosystem services and ecosystem accounting, and on earlier discussions on the selection of ecosystem services held in the context of WAVES, including a short survey that was conducted among a small number of experts in 2011. This survey elicited experts' assessment of the possibility for biophysical and monetary analysis of different types of ecosystem services at a large scale. The report is intended to provide support to subsequent scoping studies for ecosystem accounting.

2.1 Scoping of the EVA Project, Peru

2.1.1 Background on Peru

Peru, which extends across 1.3 million square kilometers, has a population of about 30 million people, of which 76 percent live in urban areas. The country is very diverse culturally, as well as in terms of landscape and biodiversity. For instance, the country includes no less than 72 ethnic groups. Lima's urban population is more than 7 million people, whereas on the other side of the spectrum, Peru houses several tribes that have not come into contact with modern society. The ecological diversity of Peru is reflected in the range of ecosystems present in the country, including dry coastal deserts, high-altitude plains and peaks in the Andes, and wet lowland forest in the Amazonian part.

Peru has enjoyed a period of strong economic growth for the past 10 years. The country has been promoting a free-trade policy since 2006 and its poverty rate has decreased by 23 percent since 2002. The country imports a considerable amount of food and depends highly on the export of minerals and metals, which account for more than 60 percent of total exports. Key crops are rice, potatoes, plantain, coffee, and vegetables. Peru's waters are among the most productive in the eastern Pacific, and its fishing sector is one of the strongest in the region.

The Peruvian government is well aware of the importance of natural resources to the country's economy and has developed institutions to promote better management of these resources at the four administrative levels: national, regional, provincial, and municipal. The regional level plays a key role in terms of regulating resource use and environmental management, including planning of resource use. The diversity of Peru is also reflected in its administrative system, where capacities and priorities regarding environmental and resource management vary considerably between regions.

The national mandate for national capital accounting lies with the Directorate for Ecosystem Evaluation, Valuation, and Financing,[1] which is hosted by the environment ministry. Other institutes that are involved in monitoring and regulating resource and environmental use include several other directorates of the environment ministry (climate change, forestry, water resources, and soils), the National Institute of Statistics and Informatics, and the Ministry of Agriculture. At the level of San Martin's regional government, the main focal point for national accounts lies with the Department of Environment and the Department of Economics and Production, which is responsible for regional-level statistics.

2.1.2 Approach Followed in the Scoping Mission

The two key objectives of the mission were to support the government of Peru, as well as Conservation International and Conservation International Peru, in the site selection and scoping process, and to provide initial technical support and guidance to the biophysical analysis and mapping of ecosystem services in an accounting context. Support for site selection involved an analysis—conducted jointly with Conservation International and the government of Peru—of the potential suitability of different sites according to a set of specific criteria. These included data availability and the potential of different sites to support relevant policies at both the national and the regional levels. In addition, the Conservation International team working with PTEC has identified ecosystem services potentially to be included in the case study. Throughout the mission, Conservation International Peru coordinated all activities with the director of the Directorate for Ecosystem Evaluation, Valuation, and Financing.

In an initial workshop at the environment ministry, the Conservation International team working with PTEC held several presentations to further explain the concept of ecosystem accounting, and the site selection process was discussed. The ministry clearly communicated that it was crucial to have a transparent and objective site-selection process based on a set of predefined criteria. Then, jointly with the ministry and Conservation International Peru, the

[1] La Dirección General de Evaluación, Valoración, y Finaciamiento del Patrimonio Natural.

team developed a set of criteria and evaluated four sites in particular—Loreto, Selva Central, Piura, and San Martin—according to these criteria.

A comparison of the scores of the different sites (see Annex 1) indicated to the participants at the meeting that San Martin ranked most favorably according to these criteria. The meeting participants agreed that the director of the Directorate for Ecosystem Evaluation, Valuation, and Financing would further discuss the selection of the case study site within the ministry based on the outcome of the ranking process. Based on the ranking conducted during the stakeholder workshop and further internal discussions, the environment ministry selected San Martin as the case study for EVA.

Subsequently, the team from Conservation International and PTEC (henceforth called the project team) visited San Martin July 10–16, 2013, to verify a number of the scores given to the region. The field visit and discussions with the regional government confirmed the suitability of San Martin as case study site, and the selection of San Martin was formally endorsed by a broad set of stakeholders during a closing meeting at the Directorate for Ecosystem Evaluation, Valuation, and Financing on July 17. In addition, various technical aspects related to ecosystem accounting and next steps were discussed at this meeting, based on presentations by Conservation International and the government of San Martin. All participants signed a memorandum of understanding indicating their willingness to collaborate on the project. A full list of stakeholders involved in the scoping process is included in Annex 2.

In San Martin, the team visited the Department of Environment for a detailed briefing on policies and experiences with ecosystem services analysis in the region. On subsequent field days, the team visited a range of stakeholders (farmers associations, indigenous communities, projects, consultants who had worked for Conservation International, and technical staff for the government of San Martin) and ecosystem types (cloud forest, mid-altitude forest, and agricultural zones including fish farms, wetlands, and dry forests).

A critical aspect of ecosystem accounting is the identification of how these accounts can support existing and/or new economic and environmental policies. Potential policy applications of ecosystem accounting in general, and the case study to be implemented as part of EVA in particular, were discussed with both the regional government of San Martin and the environment ministry, which houses the Directorate of Ecosystem Evaluation, Valuation, and Financing. Both regional and national policies to which ecosystem accounting is highly relevant have been identified, as described in the next section.

2.1.3 Contribution of Ecosystem Accounting to Policymaking in Peru

National level. Stakeholder discussions showed that ecosystem accounting is highly relevant for a number of policies in Peru. In particular, it may support the following:

1. **Land Use Planning.** Land use planning is undertaken at the national, regional, provincial (meso) and district (micro) levels. With the ongoing decentralization of environmental and resource management in Peru, the regional level is becoming increasingly important for land use planning. The capacity at this level varies between the different regions. In all cases, ecosystem accounting, and in particular the mapping of ecosystems, can assist land use planning by indicating both trade-offs involved in changing land use, and zones of particular relevance to the supply of specific ecosystem services. Ecosystem accounting also can provide a tool to monitor changes in land use and subsequent economic impacts on different economic sectors.

2. **Addressing perverse incentives in fiscal policies.** A number of policies are in place that provide fiscal incentives for resource degradation, including subsidized loans for small-scale land owners who want to develop new plots in forest areas. This is of particular concern if these developments do not lead to productive agriculture, for instance, when small-scale farmers move from the Andes to the Amazon area and have limited capacities and experiences in lowland agriculture. Stakeholders identified a need to evaluate some of these policies. The Initiative for Conservation in the Andean Amazon is doing just that. Analyzing and monetary valuation of ecosystem services can provide an additional input into the identification of perverse fiscal incentives.

3. **National planning and development**. Peru's National Center of Strategic Planning is responsible for preparing guidelines for development planning as applied by the various regions. A better understanding of the benefits provided by ecosystems and the values of these benefits can support better integration of sustainability issues into the activities of this center.

4. **Private sector engagement**. In addition, there may be scope to examine if and how EVA can reach out to the private sector, for instance, by inviting selected companies to workshops where results of EVA will be presented. A particular issue is that several companies have expressed an interest in biodiversity offsets. With the rapidly developing mining and oil and gas sectors in Peru, ecosystem accounting can identify zones that are critical for biodiversity conservation and/or provide important co-benefits. It is important for this particular aspect that biodiversity values, expressed in suitable physical indicators, are appropriately mapped as part of the EVA project.

Conclusions on relevance for national policymaking. It became clear during the mission that ecosystem accounting is highly relevant to a number of policy issues in Peru. At the national level, the main government partner for the EVA project is the Directorate of

Ecosystem Evaluation, Valuation, and Financing, which has a particular interest in developing accounts for Peru as mandated by the environment ministry (and the statistics institute). One of the directorate's broad aims is to develop environmental economic accounts, with a view of better understanding changes over time in the natural capital base of Peru. The directorate showed high interest in ecosystem accounting as a tool with a substantial potential to monitor changes in ecosystem capital (a subset of natural capital, i.e., excluding subsoil assets such as oil and gas and mineral ores). The directorate envisaged a comprehensive approach to analyzing and valuing ecosystem services, i.e., including a comprehensive set of different ecosystem services in different categories: provisioning, regulating, and cultural services. However, the directorate requested further information, including a hands-on training in ecosystem accounting, to further assess how ecosystem accounting can support this aim, and in particular to be better informed on the added value of ecosystem accounting versus the SEEA Central Framework. The project team agreed that there would be further discussions with the directorate and other relevant stakeholders in coming months to ground the EVA project in the Peruvian policy context.

Conclusions on relevance for regional policymaking. In San Martin, there is a general awareness of and great interest in the concept of ecosystem services. A case study by The Economics of Ecosystems and Biodiversity (TEEB) initiative involving the mapping of several ecosystem services in the region was undertaken in 2009 and 2010. However, these maps were still relatively qualitative and there was no explicit link to economic sectors in the case study. The government of San Martin is finalizing its environmental-economic zoning of the complete region to identify priority areas for conservation, including enforcement of conservation policies. A second policy priority is San Martin is the ongoing deterioration of water quality in water inlet stations (for the preparation of drinking water). Land use change, and in particular the conversion of forests to agricultural land, including cattle ranging land, is leading to increasing bacterial contamination of water inlets for villages and towns in San Martin. A third priority in San Martin is the promotion of aquaculture fisheries using native species (such as paiche, or *Arapaima gigas*), and a fourth priority is dealing with the influx of migrants from other parts of Peru who engage in forest conversion in specific parts of the region. These challenges takes place in the context of the San Martin government's ambition to promote green economic growth, i.e., ensuring a combination of economic growth, poverty alleviation, and environmental sustainability.

Contribution of ecosystem accounting to policy formulation at the regional level. Ecosystem accounting is no panacea for all the different policy issues faced by San Martin's regional government. Nevertheless, it can substantially support policymaking in a number of ways. First, it can support more robust land use zoning (environmental economic zoning), by making the economic benefits provided by different land cover units clear in a quantitative rather than a qualitative way. This would provide additional arguments in trade-off analyses, for instance, in selecting forest areas that provide important ecosystem services and should be strictly maintained as forest. It should be noted that a comprehensive approach to analyzing ecosystem services is necessary to support environmental economic zoning, since a comprehensive approach requires an overview of all key ecosystem services provided per spatial unit. Second, ecosystem accounting can support efforts to deal with the drinking water intake issue. In particular, by mapping the hydrological services provided by forests and other land uses, the routes through which water reaches the drinking water inlets can be analyzed to establish protection zones, and/or alternative locations for inlets can be searched. The support to paiche farming is less concrete, but ecosystem accounting can be helpful in monitoring the impacts on water quality of future, potentially rapid increases in aquaculture. Finally, ecosystem accounting maps can be used to identify areas where conversion to agricultural land would do the least damage to ecosystem services (which also would require a biodiversity account to consider the aspect of biodiversity). In further discussions with the regional government in the coming period, these various opportunities to support policymaking should be further examined and made more concrete through the gradual implementation of the ecosystem accounts.

2.1.4 Relevant Ecosystem Services and Data Availability

Land cover and ecosystem services. It is essential in ecosystem accounting to have an up-to-date land cover map of adequate resolution (for instance, 100 meter grain). There is no recent and complete land cover map of San Martin, however, there are a number of maps that can be combined to produce a land cover map (including the forest maps available at Conservation International and the coarse land cover map of the San Martin TEEB case study). Potential classes for such a land cover map, which can correspond to the ecosystem accounting units in the ecosystem accounts to be developed, have been identified, in line with the global land cover classes described in the experimental ecosystem accounting guidelines (see Table 3). It is important, however, to also consider the classes of the Peru eco-zoning, which provides a high-level classification of land cover in Peru. Ideally, the land cover classes to be distinguished would be aligned with both the GlobCover units identified in the SEEA experimental ecosystem accounting guidelines and the Peru eco-zoning. The project team discussed with Conservation International Peru that it would be helpful if such a map could be generated in the course of the coming weeks.

A complicating factor in mapping land use in San Martin (as in many tropical zones, including other parts of Peru) is that permanent cropland and agricultural mosaic may be hard to distinguish. This is particularly the case where plot sizes are small and when different crops are grown every year, in one or two cropping cycles—as happens in most of San Martin. This aspect needs to be further analyzed based on available data, especially remote sensing imagery; in case these classes cannot be identified with sufficient accuracy, they should be merged. If they are merged on the map, however, it is still necessary to understand the ratio between the two to be able to analyze crop production.

Table 3 presents a preliminary classification for land cover and land use classes that could be considered as a first basis. The table also presents a first identification of ecosystem services supplied by each land cover unit. The field survey showed that the ecosystem services to be considered for San Martin are (1) the production of major crops such as rice, maize, beans, vegetables, palm oil, cacao, coffee, and coconut; (2) grazing; (3) fish production; (4) timber; (5) production of non-timber forest products; (6) water regulation and supply; (7) flood control; (8) tourism; (9) carbon sequestration; (10) carbon storage; and (11) biodiversity conservation. Biodiversity would not be expressed in monetary terms but be part of a specific biodiversity account to be developed in the context of EVA. Based on feedback from policymakers, the project team decided that initially, a broad set of ecosystem services would be considered for EVA, and that they would be analyzed at the scale of San Martin as a whole. Given the need to pilot ecosystem accounts at a large scale and the policy priorities of the regional government, there is a need to compare hotspots of ecosystem services supply as they occur across the biomes of San Martin. The team also agreed that water and hydrological services are crucially important for the government of San Martin and that this service would be included in EVA, as would carbon sequestration and storage, which also ranked high in terms of importance and for which data are already available. Selection should take place in terms of the specific provisioning services to be included, with the proposal at this point to include the most economically important ones. However, the precise ecosystem services would need to be selected jointly with key stakeholders during subsequent phases of the project.

Table 3: Potential Land Cover Classes and Ecosystem Services in San Martin

Unit	Description	Potential Ecosystem Services
Urban (industrial land, houses, roads)	Habited areas including urban zones as well as peri-urban zones and villages	Small scale agriculture in peri-urban zones and villages
Open water	Rivers and lakes, aquaculture	Fishing, tourism, aquaculture production
Wetlands	Wetlands occurring in flood plains as well as in areas with limited drainage due to geomorphology	Biodiversity conservation, tourism, carbon sequestration, water regulation, and production of reed, wood, and non-timber forest products
Forest (cloud, moist, dry, degraded/regenerating)	Different forest types, distinguished based on available forest maps (different zones supply different sets	Wood, non-timber forest products, hunting, tourism, carbon sequestration, biodiversity conservation, and—in riparian zones and upper watersheds—water regulation and supply

	of ecosystem services)	
Agriculture		
- Plantations	Perennial crops	Crops (coffee, cacao, coconut, palm oil), carbon sequestration
- Permanent cropland	Annual crops on land under permanent cultivation	Crops, in particular rice
- Agricultural mosaic	Vegetable gardens, mixed plantations with fruit trees and plantains, areas used mainly for maize and beans. Also, shifting cultivation areas, including patches of recovering forest, which produce different crops but will be hard to distinguish in terms of land cover unit.	Various crops, carbon sequestration, biodiversity conservation
Grassland (riparian, degraded land, pasture)	Low and mid-altitude grasslands	Grazing, some biodiversity, some water regulation
Paramo	High-altitude grasslands	Grazing, water regulation, biodiversity conservation
Bare land (rock outcrops, landslides, river beds)	Recent landslides, heavily degraded land, and rock outcrops	Few services provided

Source: Developed jointly by the consultant and the staff of Conservation International during the field trip to San Martin

First assessment of data availability. Data availability is key to establishing ecosystem accounts. Data are required to support the spatial quantification of a range of ecosystem services, each requiring a specific dataset. In general, the amount of data available in San Martin is very large, in particular when compared to a non-Organization for Economic Co-operation and Development context. Among others, there is a basic analysis that includes valuation of ecosystem services in San Martin (the TEEB case study in Martin) and that can be built upon, there is data on agricultural production at the level of the district, and there are maps of different forest ecosystem types. Conservation International has already produced a carbon stock map for the region. There is also specific data on biodiversity—in particular on endemic species occurring in San Martin—however, we did not receive these data and it is as yet unclear if these data are geo-referenced. One of the subsequent steps of the EVA project is to match existing data with the data required for ecosystem accounting. Where data is missing, the Conservation International team—potentially in collaboration with the consultant—will need to carry out additional analysis and/or modelling, based on either existing proxy data or data to be collected. Given time constraints and the size of San Martin (51,000 square kilometers), primary data collection must be kept to a minimum.

Conclusions on the scoping mission. The team's mission achieved a solid grounding of ecosystem accounting in the policy context of Peru and San Martin. All key stakeholders agreed to the selection of San Martin as the case study site, and to collaborating on testing the experimental ecosystem accounting approach through the EVA project. To get stakeholder buy-in is a major step in site selection. These achievements were possible in particular because of elaborate preparatory work by Conservation International's Peru and international teams. The overall next steps, as discussed during the workshop on July 17, include (1) starting data collection for San Martin; (2) setting up a work group to support implementation of the EVA project at both the national and the regional levels; (3) planning a training activity to further familiarize key stakeholders with ecosystem services and ecosystem accounting; and (4) conducting modeling and analysis to construct the actual accounts. To ensure successful data collection and the broad application of EVA results in San Martin, the team must reach out to one additional stakeholder: the national land use planning directorate in the environment ministry. In addition, the team discussed that it would be useful to conduct a training on ecosystem services mapping, analysis, valuation, and accounting to teach regional stakeholders in San Martin about quantitative approaches to ecosystem services analysis. The training also should introduce ecosystem accounting to the participants. At the national level, there is already a broader understanding of ecosystem services, and the environment ministry requested a training activity specifically focused on ecosystem accounting. Such a training module does not exist, and once developed, also may be relevant in the wider context of WAVES. The training should cover the principles and basics of ecosystem accounting; methods for identifying, analyzing, mapping, and valuing ecosystem services; and the positioning of ecosystem accounts versus national accounts.

2.2 Selection Criteria

2.2.1 Criteria for Selecting a Case Study Site

The selection of a pilot study site requires the consideration of a range of criteria, as further discussed below. In addition, it is crucial to follow a selection process that is agreed with key stakeholders, and where the selection itself is a joint decision between the scientific team, the users of the accounts, and the policymakers involved. The general steps to be followed in the pilot site selection process are the following:

1. Informing stakeholders and discussing the general properties of ecosystem accounting and how it can support national and local policy and decision making;
2. Agreement on the process to be followed to develop ecosystem accounts, including the selection of a pilot site;
3. Identification of nationally and locally relevant criteria for selecting the pilot site (a list of potential criteria is included below, in Table 4). Note that these criteria preferably should be identified jointly with stakeholders;
4. Selection of potential pilot study sites, based on proposals from different stakeholders;
5. Joint ranking of potential pilot sites based on the different criteria;
6. Comparing the scores of the different criteria. It is clear that different stakeholders may put extra weight on specific criteria (e.g., scientists may place a higher value on data availability; politicians may prefer the relevance for policies) and a participatory discussion will be required to come up with a selection of a pilot study site and potentially also a backup site; and
7. Conducting a field visit and confirming that there is local support for the pilot site.

A number of fundamental choices are involved in the selection of potential sites for the pilot ecosystem accounting project. The first is if an administrative or a biophysical boundary (e.g., a watershed) should be followed. Key considerations are that much of the statistical data (agricultural production, fisheries production) will be available for administrative boundaries (e.g., a municipality or a province). On the other hand, models required to analyze regulating services typically operate for biophysical units, which for water services normally is the watershed or a part thereof (TEEB 2010). The selection needs to be based on locally relevant criteria. One factor is the specific services to be analyzed: Is there a focus on hydrological services or are these prominent for ecosystem accounting in the local context? Another factor is the size of the area, since many administrative units will cover a range of sub-watersheds, each with its specific hydrology; hence in this case, most watersheds may fall within the administrative boundary. Finally, it’s necessary to consider the availability of data and models. Perhaps specific hydrological models have been developed already for a large basin and production data is available at a fine resolution and can be linked easily to the basin. In the case of San Martin, the area is large (around 51,000 square kilometers) and contains a large number of small watersheds, none of which have been modeled in detail before. Statistical data is available at the level of the municipality or province. To link to policymaking, it's preferable to develop the accounts for the region following administrative boundaries. It must be noted also that the eventual purpose of ecosystem accounting is developing national-level accounts, which in any case requires following an administrative rather than a biophysical boundary.

A second consideration concerns the size of the pilot area. Administrative units exist at multiple scales (from municipal to national) and the question is which unit is most appropriate for a pilot project, considering that the areas of individual administrative units vary widely between and sometimes also within countries. Clearly, the ambition level of the ecosystem accounting pilot project needs to be commensurate with data availability, available resources, and local technical capacities. Further testing of the ecosystem accounting approach is required to obtain a better understanding of the resources required to develop an ecosystem account as a function of the size of the area and other factors (e.g., ecosystem types, ecosystem services, data availability, and capacities).

Table 4: Potential Criteria for Site Selection

Potential Criteria /1	Considered in EVA (Yes/No)/2	Comments
Policy Relevance and Support		
- Potential for ecosystem accounting to support national development objectives	Y	
- Potential for ecosystem accounting to support specific sector policies	Y	Relevant policies may be related to a specific sector that may or may not be present in the pilot site
- Potential to support policies aimed at watershed regulation	Y	
- Potential for ecosystem accounting to support policies with a specific geographical focus	Y	Relevant policies may be related to an ecosystem type or geographical area that may or may not be present in the pilot site
- Potential for ecosystem accounting to support local level policies	Y	Potentially relevant local policies include land use zoning and planning, biodiversity and protected area management and/or expansion, and hydrological policies

- Degree of support from the national government	Y	
- Degree of support from the local government	Y	
- Potential for the local government to make resources available in support of ecosystem accounting	Y	
- Capacity of the local government	Y	
- Degree of political conflict over environmental management and/or ecosystem accounting between different actors at the local level	N	
- Degree and pace of environmental and resource degradation in the pilot site	Y	San Martin has one of the highest rates of land use change in Peru
- Poverty in the pilot site	Y	
- Presence of specific industries or (agricultural) activities that lead to (potential/future) large-scale environmental degradation	N	
- Competing uses of natural resources	Y	
Representativeness		
- Presence of protected areas	Y	
- Presence of areas with high biodiversity	Y	
- Presence of upper watersheds important for downstream water supply	Y	
- Representativeness in terms of ecosystem types	Y	
- Presence of indigenous communities	Y	

- Presence of a wide variety of agricultural crops	Y	
- Geomorphological representativeness (altitude, landscape types)	Y	
Data Availability		
- Land use data (land cover and/or use maps)	Y	The availability of all data was considered; however, not all data were available for San Martin (but more data were available for this region than for other regions)
- Remote sensing data (including visible and radar images/satellite and fly-over)	Y	
- Biodiversity surveys	Y	
- Soil data (type, pH, infiltration rates, texture, depth, carbon and organic matter content, etc.)	Y	
- Hydrological data (river courses, flow measurements, extraction and use of surface water, groundwater tables, groundwater extraction)	Y	
- Topography (Digital Elevation Model)	Y	
- Precipitation (and evapotranspiration) data	Y	
- Forestry data (species, harvest rates, Mean Annual Increment, management regimes)	Y	
- Reliable statistical data on agricultural and fisheries production ()	Y	
- Statistical data on industrial activities, including in particular mining and food processing (and reliability of	Y	

data)		
- Statistical data on government expenses for environmental and resource management, including agricultural support (and reliability of data)	Y	
- Data on eco-tourism and recreation (number of visitors, length of stays, expenditures, activities undertaken, etc.)	Y	
- Data on other ecosystem services, if relevant (air pollution levels, pollinators, etc.)	Y	
Practicality		
- Infrastructure/ease of access	Y	
- Safety	Y	

1 Note: The list of criteria is not exhaustive; local conditions may make it important to consider additional, locally relevant criteria. Also, the list of data requirements is not exhaustive and needs to be fine-tuned based on local characteristics.
2 The specific criteria considered in EVA (as indicated in the table) were merged into broader criteria to facilitate their interpretation and decision making (see Annex 1).

2.2.2 Criteria for Selecting Ecosystem Services

The selection of ecosystem services to be analyzed in the pilot ecosystem account requires a participatory process, where local users in particular and also national users of ecosystem accounts and policymakers are involved. A prerequisite is that there has been sufficient prior information on the concept of ecosystem services and how ecosystem services are included in ecosystem accounts. An important difference with the pilot site selection process is that there is more flexibility. If it is unclear at the start of the development process which ecosystem services can be meaningfully included, there is the option of starting with a comprehensive list of services. Then, if in a later phase, required data for specific services do not appear to be available and cannot be collected, these services can be omitted from the accounts—provided that this would not compromise the policy application of the accounts.

To identify and select ecosystem services, it may be helpful to start with analyzing the different land cover units in the pilot area. Each land cover unit will have a typical set of ecosystem services, for instance, involving wood harvest, recreation, and watershed regulation in forest lands, and crop production in combination with specific regulating and/or cultural services in agricultural lands. Some ecosystem services, of course, depend on a range of ecosystem types. For instance, ecotourism may benefit from a diversity of landscapes and ecosystems, and for other ecosystem services, the spatial structure of the landscape is important, as it is for hydrological services (e.g., European Environment Agency 2011). Hence, ecosystem services should be identified for specific land use units, but also across larges scales.

One of the challenges in the selection process is that there have been a number of different terms and even concepts used in defining ecosystem services, both in the ecosystem services literature at large and in the context of ecosystem accounting. For instance, the ecosystem service related to agricultural production has been framed in terms of the amount of crops produced (TEEB 2010) or in terms of the contribution of natural processes in agricultural land that support production (e.g., water and nutrient retention, providing substrate for agricultural activities) (e.g., Boyd and Banzhaf 2007). These natural processes, however, are in practice very difficult to measure individually and to relate to crop production. In addition, the processes themselves are heavily influenced by human management (e.g., the use of fertilizers and manure, drainage of fields, and ploughing). One analogy is the timber harvesting service, where the standing stock of timber just before harvest is defined as the ecosystem service, and the harvested timber is defined as the ecosystem benefit (aligned with European Commission et al. 2013). In the case of agricultural production, the service could be interpreted as the crop just before harvest, and the benefit as the harvested crop. There often will be little difference between these two, and this approach does require accepting the fundamental notion that ecosystems are not purely natural systems but also can be strongly modified by people (as in Edens and Hein 2013). There is no consensus yet on this particular aspect, and a pragmatic choice needs to be made at the level of individual pilot projects. Further experience with the WAVES pilot projects and other ongoing research activities will assist in reaching this consensus in the coming years. It must be noted that for regulating services as well, it's necessary to be very specific when defining what the service comprises. For instance, flood control can be expressed in terms of a reduction in flood risk, in terms of a reduction in average flood levels, or as hectares of land not flooded. Again, a pragmatic choice is required, based on the relevant policy issues and the local conditions and land uses.

In addition, biodiversity remains a cumbersome service for inclusion in accounts. A consensus is starting to emerge that biodiversity is both an ecosystem service (since people appreciate biodiversity itself, for instance, the presence of iconic or threatened species) and an essential component required for maintaining ecosystem functioning (Mace et al. 2012). Hence, the biodiversity service should be measured in the context of ecosystem accounting. However, there are no reliable methods to quantify biodiversity in monetary terms, and this service may need to be restricted to a satellite account in physical terms only. Also, in the latter case, it's a challenge to find appropriate indicators to quantify biodiversity, based on ecological criteria, but also on local, national, and perhaps global perceptions of the relative importance of specific species and other aspects of biodiversity (Millennium Ecosystem Assessment 2003).

In case of resource constraints, a selection of ecosystem services to be included in ecosystem accounts should be made. A range of selection criteria can be applied as shown in Table 5 below. Further information is provided in Annex 4. Importantly, the importance of each criterion will depend on the relevant policy issues and the local context, and it's necessary to fine-tune the locally relevant selection criteria with local and national stakeholders. Table 5 and Annex 4 are based on a survey of 10 ecosystem services experts in the autumn of 2011, conducted in the context of WAVES. These criteria may not be equally important, however, the respondents were not uniform in endorsing or rejecting specific criteria, so no ranking of importance can be given. In particular, the criterion "possibility to influence environmental and/or economic decision making" was evaluated differently by the respondents, with some arguing that this should be a prime driver for selecting ecosystem services and others indicating that the impact on decision making will be through the overall SEEA and therefore, this should not be a criterion for including ecosystem services in accounts.

Table 5: Criteria for Including Ecosystem Services in Pilot Ecosystem Accounts

	Criteria	Brief explanation
Data Availability and Modeling		
1	Availability of broadly accepted methods for analyzing ecosystem services supply in physical terms at a high aggregation level	Priority may initially be given to services for which broadly accepted modeling/quantification techniques are available
2	Availability of broadly accepted methods for analyzing ecosystem services supply in monetary terms at a high aggregation level	Priority may initially be given to services for which broadly accepted valuation approaches are available
3	Availability of data for measuring ecosystem services in physical terms	Point-based data, data collected for administrative units, and spatially explicit data (e.g., on land cover, soils, water levels, and ecosystem productivity) all may be required
4	Availability of data for measuring ecosystem services in monetary terms	
5	Possibility of generating new data on ecosystem services supply	
Other Criteria		
6	Economic importance of the ecosystem service	Priority may be given to those services that generate substantial economic benefits
7	Possibility of influencing environmental and/or economic policy and decision making	Priority may be given to services that can relatively easily be influenced by decision making to have maximum relevance for policymaking
8	Sensitivity of the service to changes in the environment, including from anthropogenic stressors	Priority may be given to services that are sensitive to environmental change and/or under particular threat from human activities, to enhance the interest of policymakers
9	Whether the service is a final or intermediate ecosystem service	Final ecosystem services may be prioritized

2.3 Summing Up

This report presents a range of criteria for the selection of pilot sites for developing an ecosystem account, and it demonstrates how the site selection process was successfully implemented in Peru. The process was dependent on the excellent contacts between Conservation International Peru and the responsible authorities, which facilitated rapid progress during the scoping mission. Prior information and political interest in the countries, as well as a certain level of trust between the government and the organizations to be involved in developing the ecosystem accounting pilot, seem to be important elements during the scoping phase. In addition, it is important that the process is implemented in a transparent and inclusive manner, on the basis of specific criteria. Table 4 of this report presents a comprehensive list of potential criteria, which needs to be adjusted (through selecting, fine-tuning, and/or merging specific criteria) to the national and local context. Preferably, the selection of criteria is done jointly with the government agency in charge of national accounting.

The mission confirmed the importance of very thoroughly grounding SEEA-related activities in the context of WAVES—including ecosystem accounting—in the national and sub-national policy setting. In the case of San Martin, a set of policy priorities were identified at both the regional and the national levels. These resulted in a comprehensive approach to analyzing ecosystem services in EVA, and an initial focus on water-related services. Taking a comprehensive approach still requires focusing on the key ecosystem services, given the broad range of ecosystem services relevant in San Martin and the limited availability of data for many services. The scoping report presents a first set of ecosystem services from which a further selection can be made, jointly with the national and regional stakeholders.

Annex 1. Screening of Four Potential Sites for the EVA Ecosystem Accounting Case Study

The four potential sites were selected by the Ministry of Environment. Criteria for analyzing their potential to serve as the case study site were developed jointly by the ministry and Conservation International, and scores were given jointly by the ministry and Conservation International, in a workshop on July 8, 2013, at the ministry. The selection of San Martin as the case study site was confirmed in a broad stakeholder workshop on July 17.

	Data Availability	**Government Support for Ecosystem Accounting**	**Representativeness of Ecosystem Types for Peru at Large**	**Diversity of Ecosystem Services**	**Importance of Ecosystem Capital in the Local Economy**	**Presence of Communities of Native People**	**Presence of Protected Areas**	**Other Comments**
Loreto	++	+	++ (no mountain ecosystem types)	+++	+++	+++	+++	Institutional arrangements are complicated
Selva Central	+++	+	++	+++	+++	+++	+++	The site covers three regions; reaching consensus between the regions may be difficult
Piura	++	+++	+ (dominated by dry forests)	++	+	++	++	Piura has a higher GDP than Loreto and San Martin, mainly due to petroleum, fisheries, agriculture, and mining; the

								contribution of ecosystems to regional GDP is relatively smaller
San Martín	+++	+++	+++	+++	+++	+++	+++	There are strong institutional arrangements and capacity

+ = low, ++ = intermediate, +++ = high

Annex 2. List of Stakeholders Met during the Mission to Peru

Organization	Contact Persons
National	
Conservation International Peru	Claudio Schneider, Percy Summers, Eddy Morales
Ministry of Environment - Directorate of Ecosystem Evaluation, Valuation, and Financing - Directorate of Climate Change - Directorate of Water Resources and Soil - Directorate of Forestry	Roger Loyola, plus other staff
Ministry of Agriculture	
GIZ	William Postigo
Iniciativa para la Conservación en la Amazonia Andina	Fernando Léon
San Martin	
Regional government - Department of Environment - Department of Economics and Production	 - Silvia Reategui - Vanessa Sanchez
Conservation International San Martin (among others, Biocuenca Project)	Ulla Hélimo
Conservation International-supported protected forest management unit Alto Mayo	
Conservation International project river bank reforestation	
Stevia One, Stevia farm (large scale)	
Pucacaca Farmers Association	
Tingana eco-resort and farmers association	
Marona fish research center	
Tarapoto fishery research station	
Community Solutions	Rodrigo Ponce
Pronam project	Daniel Vecco

Annex 3. Simplified List of Ecosystem Services for Ecosystem Accounting

Categorized per ecosystem service types, and based on the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin 2010, Haines-Young and Potschin 2013). Note that the CICES classification is still under discussion and updates are to be expected in coming years.

Provisioning Services	Commercial cropping Subsistence cropping Commercial animal production Subsistence animal production Harvesting wild plants and animals for food Commercial fishing (wild populations) Subsistence fishing Aquaculture Harvesting fresh water plants for food Commercial fishing (wild populations) Subsistence fishing Aquaculture Harvesting marine plants for food Water storage Water purification Non-food plant fibers Non-food animal fibers Ornamental resources Genetic resources Medicinal resources Plant-based energy resources Animal-based energy resources
Regulating Services	Remediation using plants Remediation using microorganisms Dilution Filtration Sequestration of nutrients in organic sediments, removal of odors Air flow regulation by windbreaks, shelter belts (e.g., by process) Air flow regulation by ventilation Attenuation of runoff and discharge rates Water storage Sedimentation Attenuation of wave energy

	Erosion protection Avalanche protection Global climate regulation (including carbon sequestration) Local and regional climate Water purification and oxygenation Cooling water Maintenance of soil fertility Maintenance of soil structure Pollination Seed dispersal Biological pest and disease control mechanisms Maintaining nursery populations
Cultural Services	Cultural landscapes Wilderness, naturalness Sacred places Charismatic wildlife or habitat Prey for hunting or collection Scientific services Educational services

Annex 4. Potential Feasibility of Including Ecosystem Services in Ecosystem Accounts

Based on expert opinion, as elicited with a 2011 survey of 10 international experts in ecosystem services, a preliminary and general indication of the potential feasibility of including ecosystem services in accounts has been obtained. However, it is critical to bear in mind that the specific possibility to model and analyze ecosystem services always depends on the local and national context (data availability, ecosystems, geomorphology, ecosystem management, etc.). Hence, the tables below should be seen as indicative only.

Table A presents the perceived feasibility of *biophysical* quantification of ecosystem services supply at national scales, and Table B presents the same for quantification in *monetary* terms. In general, there is consistency between the two tables, which partly may stem from the notion that economic quantification is only possible if biophysical quantification is feasible as well. However, as was to be expected, the scores in Table B are lower than those in Table A for a number of ecosystem services.

Table A. Perceived Feasibility of Quantifying Ecosystem Services in Different Biomes in Biophysical Terms

Regulating Services	**Feasibility (from 0 to +++)**							
	Coastal	**Wetlands**	**Lakes and Rivers**	**Forests**	**Woodland and Shrubland**	**Grass and Rangeland**	**Tundra**	**Cultivated Areas**
Regulation of air quality through filtration of air pollutants, including particulate matter	0	0	0	++	+	+	0	+
Carbon sequestration	0	+	0	+++	+++	+++	++	+++

Regulation of hydrological flows through buffer function of forest ecosystems	0	+	+	++	++	+	+	+
Protection of coastal zones from floods by coastal ecosystems, for instance, mangroves	+	+	0	++	+	0	0	0
Control of erosion and sedimentation	+	+	0	++	++	+	0	++
Maintenance of soil fertility	0	0	0	+	+	+	0	++
Pollination	0	0	0	+	+	+	0	++
Control of pests and diseases	0	0	0	+	0	0	0	+
Nursery service that regulates species populations	+	+	+	+	+	+	0	0
Cultural services								
Recreation and tourism	+++	++	+++	+++	++	++	+	+
Inspiration (spiritual, cognitive)	+	0	+	+	0	0	0	0
An attractive living environment	++	++	+++	++	++	+	0	0

Table B. Perceived Feasibility of Quantifying Ecosystem Services in Different Biomes in Monetary Terms

Regulating Services	**Feasibility (from 0 to +++)**							
	Coastal	**Wetlands**	**Lakes and Rivers**	**Forests**	**Woodland and Shrubland**	**Grass and Rangeland**	**Tundra**	**Cultivated Areas**
Regulation of air quality through filtration of air pollutants, including particulate matter	0	0	0	+	+	0	0	0
Carbon sequestration	0	+	0	+++	+++	++	+	++
Regulation of hydrological flows through buffer function of forest ecosystems	0	0	+	++	++	+	+	+
Protection of coastal zones from floods by coastal ecosystems, for instance, mangroves	+	+	0	++	+	0	0	0
Control of erosion and sedimentation	+	+	+	+	++	+	0	+
Maintenance of soil fertility	0	0	0	+	+	0	0	++
Pollination	0	0	0	+	+	0	0	+

Control of pests and diseases	0	0	0	0	0	0	0	+
Nursery service that regulates species populations	+	+	+	+	+	+	0	0
Cultural services								
Recreation and tourism	++	++	++	++	++	++	+	+
Inspiration (spiritual, cognitive)	0	0	0	0	0	0	0	0
An attractive living environment	++	+	++	+	+	+	+	+

Chapter 3: Biophysical Mapping and Analysis of Ecosystem Services

Lars Hein,
with inputs from Miroslav Honzák and Hedley Grantham

3.0 Introduction

Background

Ecosystem accounting is being tested in three projects connected to the WAVES Policy and Technical Experts Committee (PTEC): in India, Peru, and the Netherlands, Norway and Indonesia. This report is prepared specifically to support the ecosystem accounting work in Peru.

Objectives and Setup of the Report

The general aim of this report is to contribute to knowledge within WAVES about how ecosystem accounting can be realized, with a focus on the biophysical elements of ecosystem accounts. Ecosystem accounts need to record ecosystem services flows, and the capacity of ecosystems to provide services, in both biophysical and monetary units. Monetary valuation of ecosystem services and these capacities can only take place once the biophysical accounts have been established. Based on experiences with ecosystem services analysis and mapping worldwide (e.g., MA 2003, 2005; TEEB 2010; Daily et al. 2009), it is clear that a range of different spatial and analytical techniques generally will need to be applied to map a comprehensive set of ecosystem services, depending on the services involved, the environmental and economic setting, and data availability.

The specific aim of this report is to provide a general approach for the mapping and biophysical analysis of ecosystem services in an accounting context, and to provide initial guidance on how this general approach can be applied in the case of the Conservation International case study area—the San Martin region in Peru. The report builds on insights in ecosystem services analysis and mapping as described in the general literature and in the various discussions by the editorial boards of PTEC and of the System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA-EEA). This report is a follow up to the scoping report prepared for PTEC, which describes a general approach to the scoping of ecosystem accounting studies. This report is prepared on the basis of a range of inputs, including the scientific literature and various discussions on ecosystem accounting that took place in the WAVES PTEC meetings, with Conservation International's international and Peru teams, the editorial board of the EEA guidelines, and further discussions with experts in the field (see also the Acknowledgements section).

Chapter 2 of the report first describes the general concepts underlying biophysical analysis of ecosystem services in an accounting context. Second, it describes potential approaches to map ecosystem services. Chapter 3 focuses on San Martin. The third chapter briefly describes the biophysical characteristics of San Martin and subsequently presents a number of recommendations for the mapping of ecosystem services in that region.

3.1 Biophysical Accounting for Ecosystem Services

3.1.1 General Approach

Ecosystem accounting generates information for policymakers on the status of ecosystem capital, i.e., all capital dependent on ecosystems (hence excluding subsoil assets such as oil or ores). Ecosystem accounts— once fully developed—can serve as a satellite to the UN's System of National Accounts (SNA) and provide additional information for environmental decision making. The SNA (UN et al. 2009) is an international statistical standard for the compilation of national accounts, with the aim of providing a comprehensive description of economic activity (Edens and Hein 2013). 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. These units can be classified either into institutional sectors such as the central government or households, or into economic sectors such as agriculture or mining (Edens and Hein 2013).

The SEEA has been developed in the context of the SNA to provide a more comprehensive understanding of the interrelationship between economy and environment (Edens and Hein 2013). The SEEA integrates environmental statistics with economic statistics using the organizing principles, classifications, and definitions of the SNA. At the same time, it takes a much broader perspective on the environment by expanding the SNA asset boundary. While the SNA defines assets in terms of two necessary conditions of benefits and ownership, the SEEA defines environmental assets more broadly as the naturally occurring living and non-living components of the earth, together comprising the biophysical environment, which may provide benefits to humanity (SEEA Central Framework). Another important aspect is that the SEEA complements the monetary scope of the SNA with physical descriptions of stocks and flows, for instance of stocks and changes over time of standing timber, quantities of water abstractions, and land cover accounts. In the SEEA, there is an explicit distinction between cultivated assets (e.g., a plantation) and natural assets (e.g., a natural forest) (Edens and Hein 2013). While the SEEA Central Framework provides a much broader perspective on the environment than the SNA, it does not provide an analysis of ecosystem services or ecosystem capital. Consequently, both the SNA and SEEA exclude from the production account various types of ecosystem services, such as regulating services, as well as the natural growth of biological assets. In addition, while the SEEA Central Framework provides recommendations on the treatment of depletion, it does not contain a discussion of the treatment of environmental degradation or rehabilitation (Edens and Hein 2013).

Hence, ecosystem accounting goes beyond the SEEA Central Framework in terms of how it records ecosystem capital. In particular, ecosystem accounting includes a more comprehensive set of ecosystem services (in particular, regulating and cultural services), and it explicitly accounts for changes in the stock of ecosystem capital. 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. This also allows a more systematic treatment of 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. A characteristic of ecosystem accounting is that a spatial approach is followed, in recognition of the large spatial diversity of ecosystems and the services they provide.

Constructing ecosystem accounts for multiple years makes it possible to measure 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, whose relevance depends on the specific environmental and socioeconomic conditions of the countries and areas involved. 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 also can support the establishment of payment for ecosystem services plans, by identifying zones where the supply of a specific ecosystem service is concentrated, or by laying out the co-benefits of these payment mechanisms. Mapping ecosystem services can take 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.

The basic approach to ecosystem accounting is illustrated in Figure 2 below, which shows that ecosystem accounting is driven by, and needs to be embedded in, the specific policy context of the country where it is being implemented. In addition to being a valuable contribution to national accounts, ecosystem accounting can be useful for land use planning or dealing with increasing scarcity of one of a selected number of key ecosystem services, for instance by identifying priority intervention areas or supporting monitoring. Based on the policy assessment, scoping of the account can take place. This involves selecting the area (on a country or sub-national scale) and the ecosystem services involved. A key issue is if administrative or physical boundaries are to be followed (e.g., a watershed).[2] Subsequent to the scoping, ecosystem services flows (as well as capacity and condition of ecosystems providing the services) need to be analyzed, usually requiring a variety of data sources, as elaborated in the next section.

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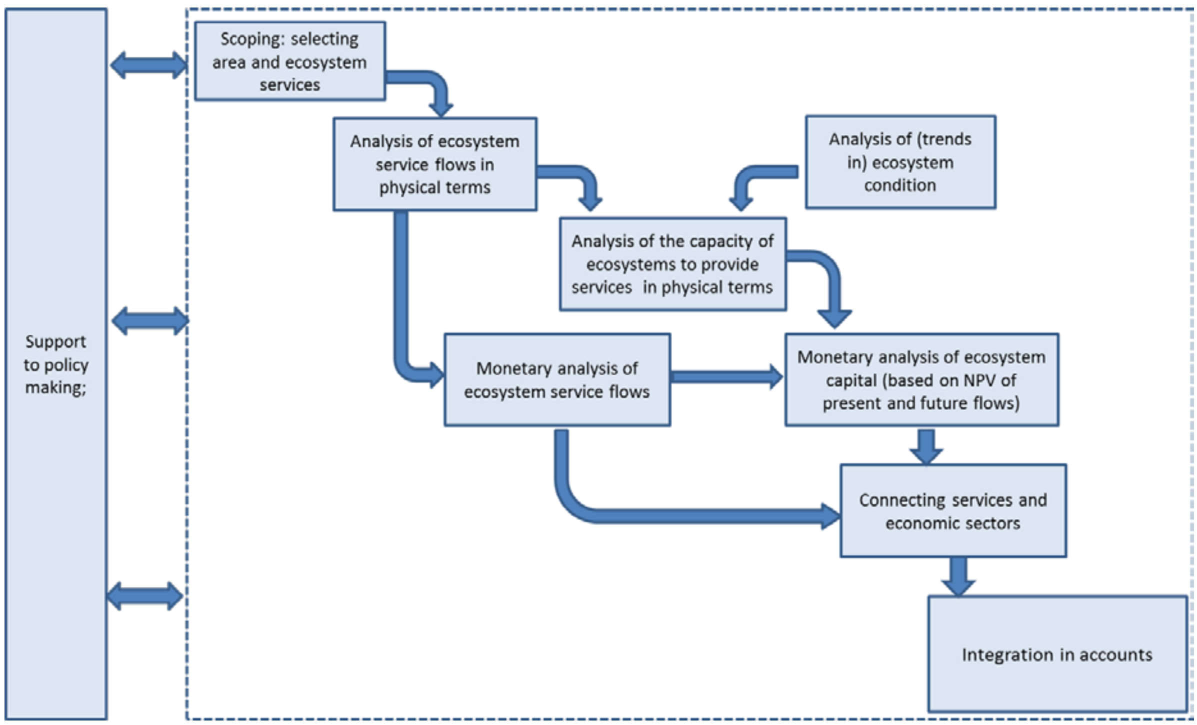
[2] See the WAVES PTEC Report, "Scoping Guidance Document for the EVA Peru Project."

Ecosystem services need to be analyzed both in terms of flow and in terms of capacity, i.e., the capacity of the ecosystem to supply services, under current land cover/use and climate. The aggregated capacity of ecosystems to supply ecosystem services constitutes the ecosystem capital of an area. A reduction of this capacity implies development that is unsustainable from an environmental perspective. The capacity is influenced by the condition of ecosystems; for instance, soil degradation may lead to a reduced capacity of forests to support timber production. Trends in ecosystem condition—for instance, due to overharvesting of resources or external pressures such as climate change—can reduce ecosystem capital over time. Both service flows and capacity need to be expressed in physical as well as monetary terms. The value of ecosystem services requires evaluating the contribution to production that the ecosystem service makes, following the valuation principles of the SNA (which is not further elaborated on in this document). The capacity of ecosystems to generate services needs to be valued based on the flow of present and discounted future benefits provided by the ecosystem, using an appropriate discount rate aligned with the SNA. Subsequently, ecosystem accounting requires connecting ecosystem services to economic sectors, both in terms of the ecosystem owners generating the benefits and the users benefiting from the services, as well as integration in the accounts. These two aspects also are not covered in this guideline, but see, for instance, Edens and Hein (2013) for details.

Figure 2: Framework for Ecosystem Accounting



Source: this report.

Note that this report focuses on the biophysical elements of ecosystem accounting, in particular: (1) analysis of ecosystem services in physical terms, (2) analysis of the capacity of ecosystems to provide services in physical terms, and (3) analysis of (trends in) ecosystem condition.

3.1.2 Concepts and Indicators

There are a range of concepts that are fundamental to ecosystem accounting. These are discussed in, among others, the SEEA-EEA guidelines. Based on these guidelines, Edens and Hein (2013), and several other sources mentioned in the text, the following clarification of the basic concepts underlying ecosystem accounting is provided.

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." Importantly, 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 (e.g., Potter et al. 1993, Arshad and Martin 2002, Van Oudenhoven et al. 2012). One of the challenges of ecosystem accounting is to integrate the complex concept of the ecosystem with the compartmental approach of the SNA accounting structure. Furthermore, in an ecosystem approach, the distinction between cultivated and natural assets is difficult to make. There are few, if any, ecosystems left on the planet that are not strongly modified by people, and even in cultivated assets, ecosystem dynamics and natural processes remain important. Therefore, it is important to include both natural and modified ecosystems in the ecosystem account.

Ecosystem Services

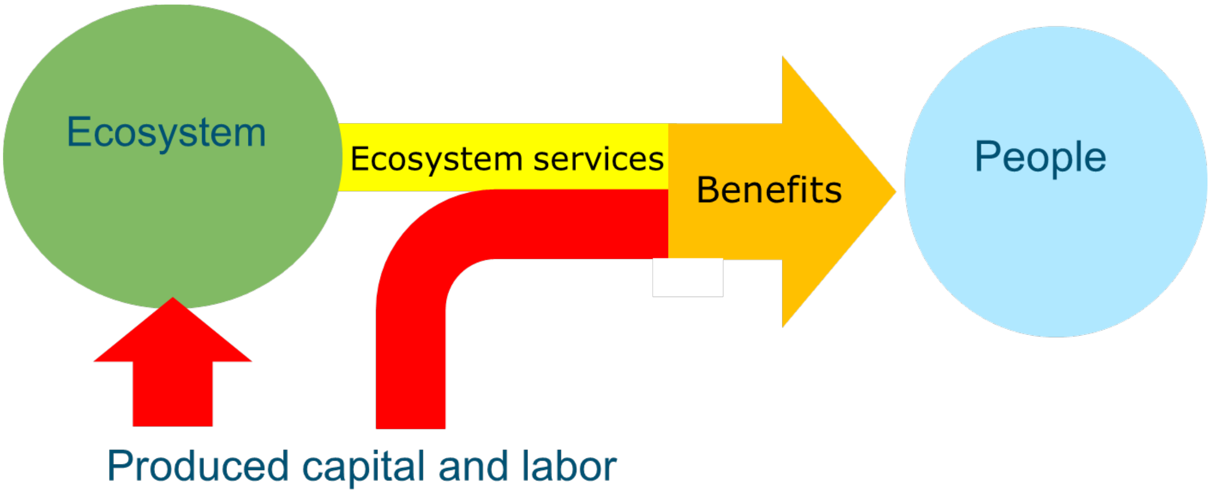
Various definitions of ecosystem services have been provided (MA 2003; Boyd and Banzhaf 2007; TEEB 2010; Bateman et al. 2010). A key issue is if ecosystem services are the *benefits* provided by ecosystems (e.g., MA 2003), or *contributions to these benefits* (e.g., TEEB 2010). In the case of accounting, there is a need to very specifically define what an ecosystem service is and how this service is generated as a function of ecosystem activity and other inputs (e.g., labor and capital goods). Also, it must be recognized that the large majority of ecosystems have been modified by people, often with the specific aim of increasing the supply of specific outputs, as in the case of the conversion of forests to crop land. For instance, even in natural parks, hiking trails may have been constructed to display scenery to visitors, and firebreaks may have been constructed in a forest to control fire risks. In reality, very few—if any—truly untouched ecosystems still exist (potentially with the exception of the deep oceans) and the large majority of ecosystems on the planet are to a higher or lower degree modified by people (MA 2005). In an accounting context, the costs incurred in the past to modify the ecosystem, or the benefits obtained from these modifications, can be seen as "sunk costs" (Edens and Hein 2013). They are reflected in the current state and value of the ecosystem and thereby in the current capacity of the ecosystem to provide services (both the type of services and the productivity).

The SEEA EEA guidelines provide the following definition: "ecosystem services are the contributions of ecosystems to benefits used in economic and other human activity" (European Commission 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., the pleasure from viewing landscapes). This definition is in line with Edens and Hein (2013), who state that ecosystem services can—in the context of ecosystem accounting—be defined as "the contributions of ecosystems to productive activities (such as timber harvest) or to consumptive activities (such as enjoying the recreational opportunities offered by an ecosystem)."

A crucial distinction needs to be made between ecosystem "service" and "benefit." In particular, outputs from the ecosystem often need to be combined with other inputs to produce a tangible benefit. For instance, even though forests supply wood, labor and equipment are needed to produce timber from standing wood. Or, landed fish require both the presence of fish in the sea (the ecosystem service) and the activities of people 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. The distinction between service and benefit also is shown in Figure 3. The human input into the ecosystem, and its costs, also need to be considered in ecosystem accounting. Whereas past costs can be seen as "sunk costs" (Edens and Hein 2013), annual costs for using or harvesting ecosystem services need to be considered in monetary valuation. For instance, in a forest ecosystem, there may be costs related to both the harvest of timber (the generation of the benefit) and maintaining the ecosystem (e.g., maintaining a firebreak in a forest). A basic principle for valuing provisioning services is that the resource rent can be used as an indicator of their monetary value (European Commission et al. 2013), and the resource rent is adjusted for costs related to intermediate inputs, labor, and consumption of fixed capital (depreciation).

Hence, in the context of ecosystem accounting, benefits comprise the products produced by economic units (e.g., food, water, clothing, shelter, and recreation) and 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 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. One way of distinguishing between these two types of benefits is that, in general, SNA benefits can be bought and sold on markets, whereas non-SNA benefits cannot (European Commission et al. 2013, Edens and Hein 2013).

Figure 3: Ecosystem Services versus Benefits



In the case of provisioning services, the contribution of the ecosystem (for instance, a standing stock of timber) is used as an input into a production process (e.g., logging, which also requires the use of labor and produced capital). Provisioning services represent the final output from the ecosystem (a physical flow), as used in a productive activity (e.g., Ansink et al. 2008). In the overall chain of economic activities in which ecosystem outputs are used, it is not always easy to pinpoint the ecosystem service. For instance, in the case of dairy production, cattle may feed on grass from a nearby pasture, but typically also benefit from additional feed, veterinary care, and shelter provided by the farmer, and milking. In this case, the physical output (flow) that is most closely associated with the ecosystem is not the produced milk (since it depends on a whole range of other inputs as well), but the amount of grass eaten by the cattle. In the case of an improved pasture, grass production may in turn depend on human activities such as the sowing of highly productive grass species, irrigation or drainage, weeding, and fertilizer application. Hence, even in the ecosystem, natural (e.g., photosynthesis) and man-made inputs (e.g., seeds of highly productive grass species) are combined.

However, it is not possible to meaningfully disentangle the contributions of these separate elements to the production of grass, and many of these different elements do not comprise a flow (e.g., nutrient retention in the soils of the pasture). 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). A particular issue pertains to crop production, where 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 (European Commission et al. 2013). These different aspects are difficult to quantify, express in one or a small set of indicators, and difficult to disentangle. Therefore, the current working hypothesis—established in discussions that took place in the context of producing the SEEA-EEA guidelines—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. It must be noted that crop production, as any activity carried out in an ecosystem, may create negative (or positive) externalities. For instance, crop production can lead to the runoff of fertilizers or pesticides in nearby waterways, affecting the condition of these waterways. The SNA (2008) specifies (page 241) that degradation of land, water resources, and other natural assets caused by economic activity is recorded in the other changes in the volume of assets account. In an ecosystem account, where relevant, those impacts also can be connected to changes in ecosystem condition.

In the case of regulating services, there is no extraction, but the service has a beneficial, external impact on economic activities or on people. For instance, flood regulation by coastal or riparian ecosystems reduces flood risk, thereby facilitating productive activities (e.g., the operations of a factory) and allowing people to live safely. Regulating services can only be understood by analyzing the scale at which they operate and the specific mechanisms through which they generate benefits. For instance, pollinators support agricultural production through local-scale activities (foraging and exchange of pollen). Economic valuation of a specific forest patch requires monetary analysis of the specific contribution of pollinators residing in this forest patch to crop production in nearby fields (e.g., Rickets et al. 2004). However, at an aggregated level, as for instance in national accounting, crop production is already accounted for. In this case, pollination supported by forest ecosystems in nearby agricultural fields may be considered by attributing part of the benefits of the ecosystem service “crops” generated in agricultural land to the ecosystem service “pollination” generated in nearby forest ecosystems, to avoid double counting (e.g., Hein et al. 2006). In practice, however, the level of refinement required for including pollination effects in ecosystem accounting for large areas will be difficult to achieve. Therefore, the focus in ecosystem accounts should be—at least initially—on regulating services that affect economic activities at a relatively large scale (such as a hydrological or flood-control service or carbon sequestration).

It must be noted that many ecosystem services are already included in economic accounts, following the SNA (European Commission et al. 2013; Edens and Hein 2013. For instance, harvested crops and the turnover of recreation companies are already in the production boundary of the SNA. In this case, ecosystem accounting makes it explicit that these benefits are generated using services from ecosystems, and ecosystem accounting provides better insight into the total benefits generated by ecosystems and how these change over time. Even the contributions of regulating services are, to a degree, already reflected in the national accounts. For instance, in the case of flood protection or air filtration, the current economic activities and their recording reflect that these regulating processes are taking place. Without regulating services—for instance, due to future ecosystem degradation—the level of economic activity may be lower (e.g., due to floods) or additional mitigation measures may need to be taken (e.g., dyke construction). However, not all regulating services are included in the SNA outputs; for instance, carbon sequestration is not included.

For cultural services, the picture is mixed. Recreation and tourism-related economic activities are already included in the SNA, although no part of the value they generate is attributed to the ecosystems that are required for providing this service (in addition to the tourism infrastructure required, such as hotels, roads, restaurants, and canoe rentals). However, the enjoyment of people is not included in the SNA boundary, in particular because this reflects a consumer surplus generated by tourism and recreation. There are potentially ways to define an exchange value for the recreational experience obtained by people through ecotourism or nature recreation—for instance, using a quasi-market approach (Campos et al. 2007)—but it must be further examined if and how these could be applied in ecosystem accounting.

3.1.3 Ecosystems' Capacity to Supply Ecosystem Services

Provisioning Services. 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 and management and on climate. In principle, the capacity needs to reflect the flow of services that can be sustained in the coming decades without degrading the ecosystem, in the absence of climate change. This capacity is determined by the "stock of ecosystem capital"; however, 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 other factors—the age of the trees, soil fertility, water availability, temperature, fire incidence, and potentially the management of the forest).

It cannot be assumed that the present management equals sustainable management. In case present extraction rates are lower than sustainable rates, the value of the stock may be higher than suggested by current extraction rates. In case the current extraction rate is higher, there is a need to correct and the capacity will be lower than a simple aggregation of present extraction rates over time. In short, the capacity equals the maximum sustainable harvest rate (i.e., the harvest rate that would not lead to a decline in the capacity of the ecosystem to sustain a specific flow of benefits over time). An interesting question arises in case the sustainable harvest rate is higher than the present rate, and in case extracting at that rate would lead to a decline of other services. 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 define the sustainable extraction rate as a rate that would lead to maintaining the long-term supply of all relevant ecosystem services supplied by an ecosystem in a mix that is comparable to the present mix.

Regulating Services. The capacity to generate a regulating service can be defined as the generation of a positive or negative externality (e.g., carbon emissions due to peat degradation) that may or may not benefit people. The capacity becomes a flow if there are people benefiting from this capacity, aligned with the modeling of ecosystem services, in for instance within the ARIES[3] modeling framework (Villa et al. 2014). For instance, 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 who experiences a reduction in erosion risk (e.g., who live in a downslope area where mudflows do not occur, or occur less often, because of vegetation upslope). Carbon sequestration is a peculiar service, because people always benefit; in this case, capacity equals flow (in line with Schröter et al. 2014), even though some people may be more affected than others by climate change.

A particular issue with regulating services is that there also can be a disservice, i.e., services with a negative value. These 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 flow of the service in terms of direction, 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 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 policymaking (e.g., reducing emissions from deforestation and forest degradation, or REDD+), and the potential occurrence of services and related disservices within the same institutional unit. Hence, these guidelines propose to map and include disservices as well as services where relevant, realizing that the discussion of if and how disservices can or should be included in ecosystem accounts requires further work.

Cultural Services. Cultural services are strongly varied, ranging from tourism and recreation to spiritual aspects and biodiversity conservation. The capacity needs to be individually defined and determined for each specific service. For recreation and tourism, this may pertain to the number of tourists that potentially can be accommodated in a specific area, as a function

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

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. For biodiversity conservation, capacity may be related to the number of species that an area can sustainably harbor, under current land use and land cover. This may be higher (e.g., because of high hunting pressure) or lower (e.g., because the area is a refuge and current population numbers are higher than the number that can be sustained in the long term).

The difference between flows of ecosystem services and capacity is summarized in Table 6 below.

Table 6: Flow versus Capacity of Ecosystem Services

	Ecosystem Service Capacity	**Ecosystem Services Flows**
Provisioning services	Capacity to provide the products (overharvesting may occur)	Amount of products extracted/harvested
Regulating services	Regulating the impact of ecosystems on physical environment	Regulating impact on people
Cultural services	Depends on service	Depends on service

3.1.4 Ecosystem Condition

Ecosystem condition indicators need to reflect the main factors influencing the ecosystem's capacity to supply ecosystem services, including such abiotic and biotic factors as soil type, rainfall, elevation, Net Primary Productivity (NPP), biomass, and species composition. There also may be specific indicators in the ecosystem account that reflect the degree of degradation in an ecosystem, as in the case of Rain Use Efficiency, an often-applied indicator for the status of semiarid rangelands that can be analyzed on the basis of data that can be collected with remote sensing. The relevant indicators will always depend strongly on the ecosystem types and ecosystem services included in the account, as well on the relevant policy questions in the area covered by the account.

Often, one condition indicator will be relevant for multiple ecosystem services, and the capacity to supply a specific service will depend on multiple condition indicators. Clearly, these condition indicators are variable in space, and therefore they need to be mapped in the context of ecosystem accounting. Since many of the condition indicators are observable ecosystem properties, remote sensing analyses are of particular relevance for the analysis of ecosystem condition. It should be noted that, whereas in principle, flows and capacities of an ecosystem can be valued in monetary terms, this does not apply to ecosystem condition accounts that require only a physical analysis.

Ecosystem condition indicators also need to include what has been labeled enabling factors in the EEA guidelines (European Commission et al. 2013). These are the environmental factors that make regulating services relevant, i.e., the pressures that are mitigated by regulating services, such as air pollution levels being mitigated by deposition of particulate matter air pollution in vegetation, and increasing global atmospheric CO2 concentrations being mitigated by the sequestration of carbon. In general, it can be stated that without these enabling factors, there would be no need for the regulating service. The set of regulating services relevant for the ecosystem account under development determines the enabling factors to be included. With the exception of atmospheric carbon levels (which are spatially variable but not at a level relevant for ecosystem accounting), the enabling factors are spatially variable.

One question is whether ecosystem condition should be measured in comparison to a reference condition. It has been proposed, for instance, to use the state of an ecosystem before settlers' modification of the landscape as the reference ecosystem condition, and the SEEA EEA guideline provides an elaboration of how this can be done. However, such a "natural" or semi-natural condition is hard to establish in some and perhaps many parts of the world, and therefore this method is not universally applicable. Given that a reference condition may be difficult to establish, reach consensus on, and measure, in many parts of the world, it may be more practical to measure ecosystem condition using indicators measurable on a ratio scale rather than indices. Where indices need to be used because there are no clear alternatives, a reference condition can be selected on the basis of either a reference condition or a specific year (see also Edens and Hein 2013). There are several criteria for the selection of indictors for ecosystem condition, including (1) the sensitivity of ecosystem services supply to the indicator, (2) the degree to which the indicator reflects the overall health of or key processes in the ecosystem, (3) the availability of data, and (4) the possibility of cost-effectively generating new data.

3.2 Mapping Ecosystem Services in an Accounting Context

3.2.1 Basic Approaches

Mapping ecosystem services can be pursued with several basic approaches: (1) a dedicated ecosystem services mapping tool such as InVEST, (2) a modeling framework such as ARIES that can design specific algorithms for individual ecosystem services in a dedicated GIS environment, or (3) ArcGIS or a freeware GIS program.

InVEST stands for Integrated Tool to Value Ecosystem Services and their Trade-offs and is an open-access GIS tool collection. It includes separate models to map different ecosystem services and track changes caused by land cover change. InVEST includes models of varying complexity, including proxy-based mapping (tier 1) and basic biophysical production equations (tier 2).The models included in InVEST address ecosystem services including

Carbon Storage and Sequestration: Climate Regulation, Coastal Erosion Protection Model, Coastal Vulnerability Model, Marine Fish Aquaculture, Aesthetic Quality, Pollinator Abundance: Crop Pollination, Habitat Quality: Biodiversity, Managed Timber Production, Recreation Model, and Water Yield: Reservoir Hydropower Production. New models are still being developed.

ARIES stands for ARtificial Intelligence for Ecosystem Services and is a modeling framework that contains a range of general modules (deterministic and/or probabilistic), enabling spatial modeling of ecological processes, ecosystems' capacity to supply services, as well as flows of services. ARIES contains a range of user interfaces that facilitate the use of these modules. Several other modeling tools (SolVES, MIMES) have been published and are available as freeware software, but InVEST and ARIES are the most widely used.

An alternative to these mapping tools is directly modeling ecosystem services in a GIS environment. ArcGIS is the most widely used in planning (and sometimes statistical) agencies as well as research centers around the world. In a GIS environment, specific analytical approaches can be developed and modeled to analyze ecosystem condition, capacity, and services flow, building on the scientific literature available in this field, which comprises about 100 published studies that involved the mapping of ecosystem services (Martínez-Harms and Balvanera 2012, Egoh et al. 2012).

Both approaches have advantages and disadvantages. An advantage of using a mapping tool such as InVEST is that it offers a relatively straightforward way of generating maps of ecosystem services, guided by predefined algorithms. An advantage of using ARIES or a basic GIS environment is that it offers greater flexibility to adjust mapping approaches to data availability and the specific economic and environmental context. It also does not depend on the developers of mapping tools for updates and for ensuring Internet security, in case the mapping tool software is connected online. The following section describes a number of general approaches that can be used to spatially model ecosystem services, and as input into the design of ArcGIS models as well as in ARIES user-defined modules.

Analyzing and mapping ecosystem condition, capacity, and service flows requires the integration of spatial and non-spatial data. Non-spatial data may be linked to specific coordinates (point data), or to specific units (for instance, administrative units in a map). In case additional non-spatial data need to be collected, a range of sampling strategies can be pursued. In particular, stratified sampling can be considered in this context. In stratified sampling, data collection can explicitly include all relevant classes for the ecosystem accounting unit under examination. For instance, depending on the amount of data that are already available, and the resources available for collecting additional data, stratified sampling can be used to ensure that all land cover/ecosystem units and/or all areas generating specific ecosystem services are covered. Having comprehensive data covering all land cover/ecosystem units and ecosystem services is important to allow scaling up and extrapolation of data in support of ecosystem accounting.

3.2.2 Mapping Techniques

There are several approaches available to map ecosystem services. In ecosystem accounting, usually a combination of different data sets is required to map specific ecosystem services, as well as the prediction of the capacity of ecosystems to supply services. These data sets needs to be spatially defined, i.e., they need to be attributed to a spatially defined reference location using a relevant coordinate system. However, often, not all data sets are in the form of maps; specific data points also may apply to a specific location (point based), or an administrative unit (say, the amount of crops produced in a district, or wood produced annually in a forest concession). There are several ways in which these data sets can be combined, integrated, extrapolated, or interpolated. Some of the most common mapping methods are briefly described below, and in the next section, more specific guidance is provided on how they can be applied to model specific regulating services. In line with the focus of WAVES, only the spatial modeling of regulating services is discussed in this paper.

There are a range of spatial modeling tools available for the biophysical mapping of ecosystem services. The most basic of these is look-up tables, whereas more sophisticated methods allow for extrapolation of data to missing points, as well as more elaborate statistical or process-based modeling of services supply. This report can only provide a brief description of each of these approaches. The selection of mapping techniques always needs to be done on the basis of the specific characteristics of the area involved, based on—among other factors—point and non-point data availability, the ecosystem services involved, the physical and ecological properties of the area under investigation, the use of ecosystem services and the overall socioeconomic setting, and the resources available for the assessment.

Look-up Tables. Using look-up tables is the simplest way of creating a map to indicate ecosystem services supply (InVEST tier 1). A specific value for an ecosystem service or other variable is attributed to every pixel in a certain class, usually a land cover or land use class. For instance, every pixel in the land cover class “moist evergreen forest” could be given a specific value for its carbon stock, say 200 ton C/ha. The accuracy of this model depends on the number of land use (or other) classes, and the accuracy and representativeness of the data within each class. Clearly, it may be that there is substantial variation within classes, for instance the moist evergreen forest could include pristine as well as strongly degraded forest patches with a very different carbon stock. If specific data are available on ecosystem services not used for establishing the relation between land cover and ecosystem service, the standard deviation of this method can be assessed.

Geostatistical Interpolation. Geostatistical interpolation techniques rely on statistical algorithms to predict the value of unsampled pixels on the basis of nearby pixels, in combination with other characteristics of the pixel. The most basic interpolation methods use simple interpolation algorithms, for instance, nearest-neighbor interpolation, but there are more sophisticated geostatistic tools that also consider sets of correlated variables. For instance, timber productivity may be related to productivity in nearby pixels, with consideration of the land cover (forest cover) and potentially other indicators, such as soil fertility. Kriging is an example of an often-applied geostatistical interpolation tool. Geostatistics also allows calculating the error levels made in the analysis.

Statistical Approaches. There are several statistical approaches to map ecosystem services, capacity, and condition. Maxent is 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. It also is increasingly used to map the suitability of ecosystems for other services, such as recreation. 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). In other words, Maxent analyzes the likelihood of occurrence of a species (or other services) as a function of predictor variables, based on an analysis of the occurrence of that species in those data points where the species occurrence has been recorded. Maxent requires only presence points, and the accuracy levels also can be calculated using the area under receiver operating characteristic (ROC) curve (AUC), whose value ranges from 0 to 1 (an AUC of 1 indicates perfect accuracy).

Process-Based Modeling. This method involves predicting ecosystem services flows or other variables based on a set of environmental properties, management variables, and/or other spatial data sources. It also can be used, as geostatistics, to model ecosystem services flow if data are only available for a specific sample rather than the whole area under examination. The methods can be used to model provisioning, regulating, and selected cultural services. For provisioning services, however, a key input that is required is the land use/management, since this kind of services always represents a physical flow from the ecosystem to society, and this flow is determined both by the capacity of the ecosystem to sustain the flow and by the actual management and extraction patterns. A challenge to process-based models is that this management variable may not be known with sufficient (spatial) accuracy. For instance, in a case study in Kalimantan, Indonesia, it was found that wood production cannot be reliably modeled with process-based models, since the spatial pattern of extraction was not available (there were only estimates for administrative units, as well as relatively few point estimates of extraction rates). Crop forecast models, on the other hand, have a long history as a process-based approach to forecast crop yields as a function of environmental properties (e.g., soils), weather patterns, and management (e.g., cropping systems). The potential applicability of process-based models to analyze provisioning services therefore needs to be assessed based on local ecosystem services, ecosystem management, and data availability.

Process-based models are key for the modeling of many regulating services. For instance, erosion and erosion control are often modeled with the Universal Soil Loss Equation (USLE) approach, even though its reliability has proven to be variable outside the United States, where it was developed. Process-based models are sometimes more easily applied to model regulating services than to provisioning services, since regulating services are less directly dependent on human management (of course, the ecosystem in which they are generated is often dependent on management, but this is revealed through the observable condition of the ecosystem itself).

The mapping techniques as applied in the different approaches are further explained in Table 7 below.

Table 7: Mapping Approaches and Techniques

Mapping Approach	**Basic Characteristic**	**Mapping Techniques Applied**
Dedicated ecosystem services mapping tool such as InVEST	Use predefined modules for mapping ecosystem services	Are mostly based on look-up tables; use predefined techniques for specific services
Modeling framework such as ARIES	Enable designing specific algorithms for individual ecosystem services in a dedicated GIS environment, using predefined modules where appropriate	Flexible; different mapping techniques are supported in ARIES
ArcGIS or freeware GIS programs	Require that all services be modeled individually	Flexible; allow use of all mapping techniques

3.2.3 Mapping Ecosystem Services

This section presents some insight into approaches that can be applied to map selected regulating services. However, only a very general introduction can be provided below, and the mapping approaches and methods also must be specified for each ecosystem account to be developed as per the ecosystem, ecosystem service, management models applied, data availability, and environmental and social context involved.

1. **Carbon Storage**. Carbon storage includes storage in vegetation carbon (above ground, root, dead wood, and litter carbon) and soil carbon. The 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 peat land soils in peat of several meters deep. Above-ground carbon can be measured reliably with

remote sensing (in particular Radar) imagery, but for peat soils, the measurement of carbon stored with optical techniques is more difficult, and this is often dependent on soil sampling of peat depth and extrapolation of values between sampling points. Another approach is to use look-up tables that specify the average (above and below ground) amount of carbon per ecosystem type, including carbon in different stages of degradation. Note that there is an increasing number of carbon maps available for different parts of the world, and the capacity to map carbon stock globally also will increase strongly with the launch of the Sentinel satellites in 2014.

2. **Carbon Sequestration**. Carbon sequestration can be analyzed with a process model based on net ecosystem productivity (NEP), i.e., the difference between net primary productivity (NPP) and soil respiration. NPP can be related to the Normalized Difference Vegetation Index (NDVI), which can be measured with remote sensing images. However, care needs to be taken that the relation between NDVI and NPP is well established, and that accuracy levels are calculated based on sample points. In addition, it is often difficult to find credible values for the 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, and other factors. There are often substantial local variations in the soil respiration rates, yet these rates are usually only estimated for specific ecosystem types, leading to a difficult-to-quantify source of uncertainty in ecosystem services mapping. Various measurement techniques for carbon fluxes have been developed that can provide data to correlate and verify estimates based on NEP, or—at some time in the future when the number and density of accurate carbon flux measurements has increased—allow interpolation of carbon flux rates.

3. **Water Regulation**. Water regulation comprises a whole range of different services, including flood control, maintaining dry season flows, and 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. For instance, depending on rainfall, the importance of the flood control service may vary strongly between years. Also, flood control typically occurs only during selected months of the year. It must be noted also that forests may have a range of related effects: some forests reduce water availability throughout the year (because of high evaporation rates compared to other ecosystems), but increase water availability during the dry season (by acting as a buffer). In addition, this service has a high spatial variability and interdependency. For instance, forests close to waterways may be relatively much more important for the hydrological services compared to forests farther away from water courses. In addition, cutting some of the forest in a watershed is likely to change the hydrological service of other forested parts of the catchment (for instance, by changing the water flows through these other forest patches). Hence, modeling this service is often data intensive and also analytically complex. Ideally, a runoff model is

constructed that defines per pixel the contribution of the vegetation in that pixel to maintaining downstream water flows. Importantly, such a model needs to account for all relevant water flows: rainfall, interception, evapotranspiration, overland flow, flow in the unsaturated zone, flow in the saturated zone, and stream and rover flows. 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. The WaterWorld Initiative[4] also is worth mentioning. WaterWorld makes spatial hydrological data sets for the entire world available at 1-square km and 1 hectare resolution, including spatial models for biophysical and socioeconomic processes. WaterWorld can be used to understand the hydrology and water resources baseline and water risk factors associated with specific activities.

4. **Erosion and Sedimentation Control**. The most widely used model for modeling erosion rates is the USLE and the extensions of the original model, such as the Revised USLE (RUSLE) and Modified USLE (MUSLE). USLE contains several key aspects, including soil erodibility (as a function of soil type, slope, slope length, etc.), rainfall erosivity (as a function of rainfall intensity, among other factors), and vegetation cover. The effect of vegetation on erosion can be analyzed by varying the parameter describing the effect of vegetation on erosion rates. In spite of its wide uses, there are several issues with USLE. One issue is the degree to which the model represents the various slope types (e.g., concave or convex, steepness), climate conditions, and rainfall intensities found in different parts of the world. Also, the model does not cover well downslope deposition of sediments, and therefore may overestimate the overall erosion occurring on large areas. Third, the USLE ignores gully and bank erosion and does not specify deposition of sediments in river streams and during floods of rivers, which is often an important sink for sediments and leads to enhanced soil fertility in deposition areas. A range of more specific models have been developed that are often better adjusted to local conditions—therefore limiting their applicability in other parts of the world. Erosion models can be integrated in a catchment hydrological model, such as SWAT, 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 model. In addition, there are several new models that provide a more sophisticated modeling tool for the erosion control service. For instance, the CSIRO SedNet model allows modeling of erosion, sedimentation rates, and nutrient budgets of water courses.[5]

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[4] http://www.policysupport.org/waterworld
[5] http://www.toolkit.net.au/sednet

5. **Flood Protection**. Modeling flood protection through linear elements in the landscape that act as a buffer against high water levels (e.g., a mangrove, dune, or riparian system) requires modeling flood risks as well as potential impacts in absence of, or with reduced, flood protection. It must be noted that this service is somewhat different from hydrological service, which also contains an element of flood control. Hydrological service provides a buffer that can store water during high rainfall events; flood control service mitigates the impacts of floods during the actual occurrence of high water level. A key question is whether it is always necessary to model flood protection for the development of monetary accounts, in particular in those areas where there is a certainty that natural systems would be replaced by artificial ones (e.g., a dyke) if the natural systems are lost (as would be the case in the whole 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. In other cases, however, it cannot be assumed that an alternative structure would be built and avoided damage costs could be estimated, which requires an estimate of the flood zone, the likely frequency of floods, and the potential depth of the water level across the flooded zone. There is likely to be a probabilistic element in this kind of modeling, given that extreme floods may do by far the largest damage, yet may occur only few times over decades. ARIES may be particularly useful to model this service, given its capacity to deal with probabilistic events.

6. **Maintaining Rainfall Patterns.** Regulating services typically are generated at different spatial scales. The maintenance of rainfall patterns is dependent on vegetation patterns at large scales. For instance, it has been estimated that maintaining rainfall patterns in the Amazon at current levels—in line with the rainfall required for an area where forest is the dominant ecosystem—requires maintaining at least some 30 percent of the forest cover in the basin. Differences in rainfall patterns in the Murray Basin in Australia also have been correlated to past losses of forest cover. These are very significant ecosystem services, 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. A literature review revealed that to date, there has been no comprehensive physical, let alone monetary, assessment of the local-scale implications of this service.

7. **Waste Treatment.** Water purification occurs in natural ecosystems, both in aquatic systems and in the soil of many ecosystem types. River flows are generally purified through bacterial activities in wetlands or flood plains, or by vegetation growing in the border of the river. Groundwater flows are purified both through microbiological activities and through adsorption of pollutants on soil particles. These processes are usually spatially variable, depending on, for example, vegetation communities in the

river or soil types. Even though there are a range of studies that have analyzed and valued this service, there are much fewer studies that have mapped the spatial diversity in this service. Outside of the ecosystem services literature, however, there is more experience with mapping such services in the field of pollution management.

8. **Pollination**. The effects of pollination have been analyzed at different levels, from a farm up to national and global levels. Mapping the service itself is difficult given the patchiness of this service related to its dependence on small scale landscape elements, and its complex ecology. Therefore, proxy methods using land cover and land use, pollinator habitat, and crop yields are the most common approaches to map pollination services (European Commission 2013), but the number of studies mapping this service is very small. An example of a relatively elaborate study mapping the pollination service is Lonsdorf et al. (2009), who use a set of indicators including crop yields, land use, and pollinator habitats.

3.3 Biophysical Mapping of Ecosystem Services in San Martin, Peru

3.3.1 Background on San Martin

San Martin, located in the northwestern part of Peru, covers about 51,000 square kilometers and has a population of about 1.5 million people. Its elevation ranges from 150 meters in the northeastern part to around 3,500 meters in the western part. The ecosystems include lowland Amazonian forest; wetlands, lakes, and riparian systems; mid-altitude plains used as cropland; sub-humid, moist, and cloud-mountain forests; and a relatively small area of paramo grasslands in the highest part. The main crops include coffee, rice, plantain, banana, cocoa, tobacco, and yucca, and there is extensive grazing, mainly with cattle. The area also is known for being the largest coconut producer in the country, and there is a significant amount of aquaculture, including with native species. The two main urban centers are the capital, Moyobamba, and the largest city, Tarapoto. San Martin, in particular its central part, is prone to rapid deforestation and land-use change, partly as a result of immigration from higher parts of the Andes.

3.3.2 Indicators for Ecosystem Services in San Martin

Ecosystem Services in San Martin
As discussed with policymakers and experts in San Martin, and examined in the field survey, the key ecosystem services relevant to environmental management in the region are (1) production of major crops such as rice, maize, beans, vegetables, palm oil cacao, coffee, and coconut; (2) grazing; (3) production of fish; (4) production of timber; (5) production of non-timber forest products (NTFPs); (6) water regulation and supply; (7) flood control; (8)

tourism; (9) carbon sequestration; (10) carbon storage; and (11) biodiversity conservation. A specific biodiversity account would be developed in the context of EVA, with bird watching (as a form of ecotourism dependent on biodiversity) potentially valued in monetary terms. There are discussions on how to zoom in on a more restricted amount of ecosystem services, for instance by focusing on specific crops. Since the outcome of these discussions is not known at the time of writing of this technical paper, and since the paper is intend to be somewhat broader in terms of providing support to ecosystem services mapping for ecosystem accounting, potential indicators are given for all these ecosystem services, as defined for ecosystem services flow, capacity and condition.

Tables 8, 9, and 10 below provide guidance on indicators that can be used to analyze ecosystem services in an accounting context. It must be noted that it is important that flow and capacity are specified per spatial unit, i.e., as per the resolution of the spatial model used. For illustrative purposes, the unit is assumed to be hectare (ha) in the tables below, but this can be adjusted to fit the resolution of the spatial data set.

Provisioning Services

The key provisioning services in San Martin are crop production, grazing, drinking water production, fish production in lakes, rivers, and aquaculture ponds, timber production, and NTFP production. The latter category includes seedlings of ornamental plants; the area is particularly rich in orchids. Table 8 presents potential indicators for the services. The specific methods to model capacity and flow need to be determined on the basis of data availability.

Table 8: Potential Indicators for Provisioning Services Relevant in San Martin

Ecosystem	**Ecosystem Service**	**Physical Indicator for Ecosystem Service (Flow Indicator)**	**Benefit**	**Capacity**	**Capacity Indicator**
"Cultivated" assets, i.e., ecosystems dominated by human management					
Cropland	Contribution of the ecosystem to crop production: retention and	Kg of crops (kg/ha/year) (proxy)	Harvested Crops	Maximum harvest of crops with current inputs. The capacity may decline	Crop production (kg/ha/year)

	supply of plant nutrients and water, supply of substrate (area plus soil) for growth. Since these various specific contributions cannot be measured individually, the service can be expressed, in physical units, in terms of the standing crop of potatoes produced per ha. Human inputs (e.g., fertilizers, pesticides) need to be recorded and accounted for in the valuation of this service, using a resource rent approach.			due to land degradation.	
Grassland: confined grazing system as well as herding on communal pastures	Contribution of the ecosystem to grazing: providing substrate and grass. Other inputs (fences,	Amount of animal feed provided by the ecosystem (kg grass/ha/year)	Milk, meat, hides, etc.	Maximum sustainable animal feed extraction (i.e., maximum stocking density/grazing capacity that	Maximum amount of animal feed that can sustainably be provided by the ecosystem (kg/ha/year)

	veterinary care, supplementary feed) are provided by people.			does not lead to degradation with current management)	
Aquaculture	Contribution of the ecosystem to aquaculture: providing substrate (water), plus the ecological processes that take place in the water and that facilitate fish production. As in the case of crop production, this contribution is difficult to measure.	Kg of fish produced (kg/ha/year) (proxy)	Fish	Maximum capacity to produce fish under current production systems	Kg fish production (kg/ha/year)
natural "assets, i.e., ecosystems dominated by natural processes					
Timber production (in forests)	Contribution of the ecosystem to timber production: resources that can be harvested.	Standing stock of timber produced (before harvest) (kg/ha/year)	Harvested timber	Maximum extraction rate that can be sustained by the forest without leading to degradation, for instance,	Kg timber/ha/year

				expressed as mean annual increment	
NTFP production (in forests)	Contribution of the ecosystem to NTFP production: resources that can be harvested.	Standing stock of NTFP resources that is extracted (measured before harvest) (kg/ha/year)	Harvested NTFPs	Maximum sustainable extraction rate	Kg NTFPs/ha/year
Fishing (in open water)	Contribution of the ecosystem to fishing: fish are produced in the ecosystem, and the service equals the amount of fish that is extracted from the ecosystem.	Kg of fish that is extracted (kg/ha/year)	Harvested fish	Maximum sustainable fish catch, as determined by annul increment of fish stock	Kg fish/ha/year
Hunting (in forest and other natural vegetation)	Contribution of the ecosystem to hunting: number of animals shot per time unit.	Kg of animal weight (kg/ha/year)	Meat, hides, other products	Maximum amount that can be sustainably hunted, as determined by annual increase in animal populations because of reproduction	Kg animal weight/ha/year

Regulating Services

Regulating services can be defined as the regulation of an environmental process with a potential positive externality. The service materializes if there are people living in the area affected by the process (see above). In the case of carbon sequestration, there are always people benefiting from the service and the service equals the capacity. For all other services, a question is whether the capacity should be mapped and modeled in case there are no people benefiting from it. In this case, the service may not be highly relevant for accounting, but in situations where land use is changing rapidly, as in the case of San Martin, there can be circumstances where analyzing and mapping the capacity is still relevant. For instance, it would be relevant if people could be expected to move to an area affected by this service in the near future (e.g., maintaining an erosion control capacity if people are moving into an area that is affected by erosion). Carbon storage is a peculiar type of regulating service: it represents a potential flow rather than an actual flow. The potential flow may materialize in case of changes in land use (e.g., a conversion of forest land to plantation). It is highly relevant for understanding the effects of land use change, but since it is not an annual flow, it is difficult to include in an account. An alternative is to include carbon storage as an ecosystem condition indicator rather than as an ecosystem service. Table 9 presents potential indicators for San Martin, excluding the service erosion control, which was not identified as a priority ecosystem service for the area.

Table 9: Potential Indicators for Regulating Services Relevant in San Martin

Ecosystem	Ecosystem Service	Physical Indicator for Ecosystem Service (Flow Indicator)	Benefit	Capacity	Capacity Indicator
All ecosystems	Carbon sequestration	Amount of carbon sequestered (or emitted)/ha/time unit	Climate regulation	Equal to service	Equal to service indicator
All ecosystems	Carbon storage	Amount of carbon stored/ha	Climate regulation	Equal to service	Equal to service indicator
Upland forests in particular	Supporting drinking water extraction: amount of water generated per pixel that contributes to the availability of water that can be extracted for	Liter of water/ha/year	Drinking water production	Amount of water generated that could potentially be used for drinking water production	Liter of water/ ha/year

	producing drinking water (				
Upland and riparian forests	Flood control: limiting flood risks for downstream crop cultivation in floodplains and other low areas, as well as limiting damage to people, houses and other infrastructure	Reduction in flood risk in land used by people (e.g. expressed as chance of flood occurrence per year, average of flood height or expected value of the duration of the flood in days per year)	Crop production and other uses of lowlands	Reduction in flood risk; becomes a service if people are benefiting from the reduction in flood risk	Reduction in flood risk on all land (e.g. expressed as chance of flood occurrence per year, average of flood height or expected value of the duration of the flood in days per year ()

Cultural Services

In the case of cultural services, the interaction may involve visiting the ecosystem or enjoying its presence in a more passive manner. Often, specific attributes of the ecosystem are relevant to cultural services, for instance, the presence of attractive views in a landscape, or specific species relevant to cultural or religious activities. Hence, the cultural services may not be strongly dependent on the ecological quality of an area, except in the case of eco-tourism. A specific issue pertains to biodiversity, or nature conservation. This supports the functioning of an ecosystem and also can be seen as an output in itself, since people value species diversity or the conservation of rare or threatened species. Table 10 presents potential indicators for cultural services. When mapping the capacity to support tourism and recreation, there are two options: on the basis of the maximum amount of people that can be accommodated, or on the basis of the properties of the ecosystem that trigger the interests of the tourist to visit the area (in the case of bird watching in San Martin, the presence of rare and endemic birds). There is no ecosystem accounting standard and it would be recommended to further discuss which indicator is most appropriate for San Martin, or perhaps to test both approaches.

Table 10: Potential Indicators for Cultural Services Relevant in San Martin

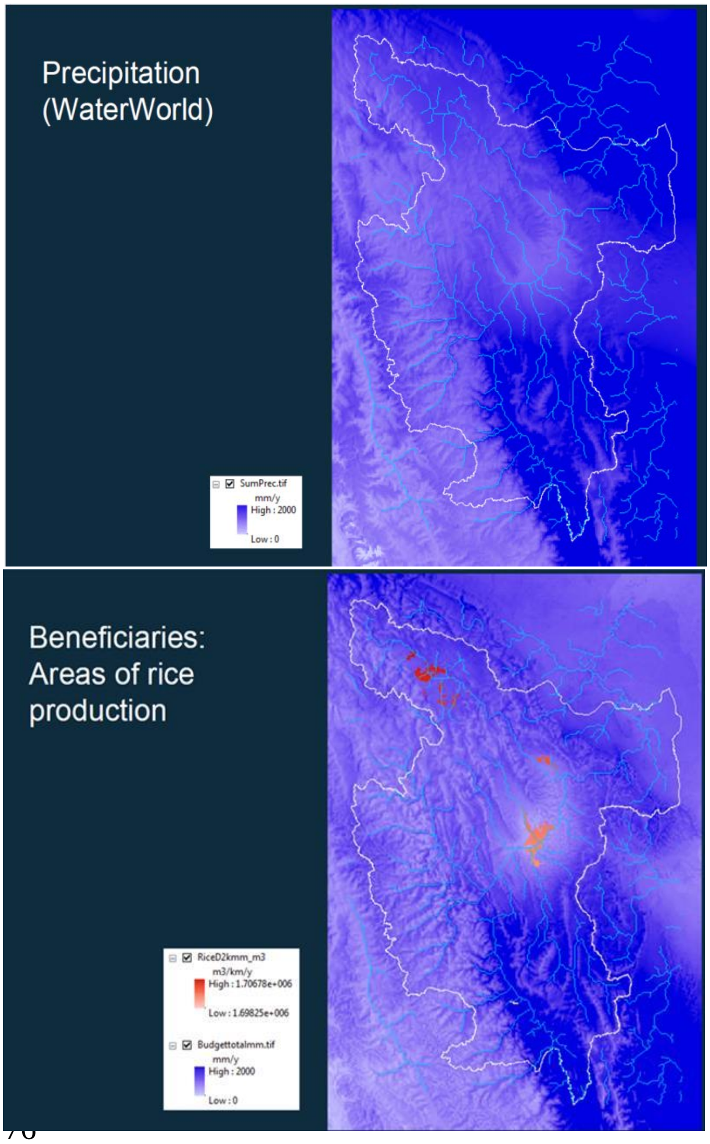
Activity	Ecosystem Service	Benefit	Flow	Capacity
Tourism and recreation	Offering opportunities for recreation and tourism	For consumers: enjoyment of nature through tourism and recreation For producers: recreational facilities (e.g., restaurants, camping sites)	Number of person days spent in an area per time unit Number of meals consumed in a restaurant, number of overnight stays, etc.	For consumers: (1) number of people that can be accommodated, which may be equal to the present number, but which may also in- or decrease over time for instance in case of a change in access to the site (e.g., a new road to a park) For producers: capacity of restaurants (seats), hotels (beds) with present infrastructure
Nature conservation	Harboring threatened, endemic, and/or otherwise appreciated species populations and ecosystem types	Protection of biodiversity	No "flow"; however, in a biodiversity account, the ecosystem service could be quantified based on numbers of particular species present in the area	The capacity of the ecosystem to sustain population numbers, which may be higher if the species is hunted, or lower in case of a refugee function of a habitat

3.3.3 Mapping Ecosystem Services in San Martin

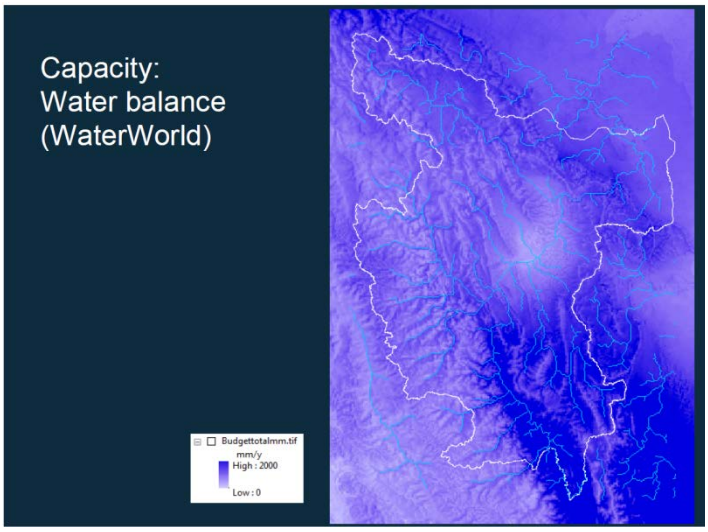
General approaches to mapping the various ecosystem services have been described in Section 2.3, and in addition, specific mapping details have been discussed with Conservation International during a workshop at its offices in Washington, D.C., in November 2013. Limited data availability is a concern, as generally will be the case when developing ecosystem accounts. Conservation International is still collecting data from various sources, but based on a first evaluation of data availability, as also discussed jointly with Miroslav Honzák of Conservation International, some key additional recommendations for mapping ecosystem services in San Martin are provided below. These are divided into specific recommendations for modeling the water supply service (which was identified as a priority regulating service for San Martin), and specific recommendations that can be considered for the overall next steps related to developing and testing mapping approaches in the EVA project.

Modeling the Hydrological (Water Supply) Service

Detailed modeling of the water supply service requires developing a hydrological model that includes such variables as rainfall, interception, evapotranspiration, overland flow, flow in the unsaturated zone, flow in the saturated zone, and stream and river flows. To model the service flows, spatial information about locations of users and their water demand is important. These flows would need to be specified for every pixel in the watershed or administrative unit to be analyzed. For the purpose of San Martin, as a first proxy of this service, a simplified approach based on existing data sets can be pursued. This approach is based on a data set that is global in nature but readily available through running the WaterWorld model. WaterWorld incorporates relevant global spatial data sets, such as rainfall and evaporation, into spatial models of biophysical and hydrological processes to derive water balance (water available for runoff) at 1-kilometer and 1-hectare resolutions. When



connected to a digital elevation model and information on users, which also is available, service flows can be constructed, as described below. For this service, the section below specifies preliminary condition, capacity, and flow indicators. Honzák has provided the preliminary results and figures.



Condition. To map the condition for this service, it would be ideal to have (1) precipitation (pictured to the right); (2) vegetation cover, to determine evapotranspiration and interception rates; (3) elevation; and (4) soils, as the basis element for a hydrological model. WaterWorld-derived water balance and runoff from one pixel to the next was calculated. A ratio between water balance and rainfall was used to assess the condition of ecosystems to provide water.

Capacity. In the case of this service, capacity can be defined as the surplus of water per pixel that is available for extraction, in other words, the maximum amount of water that can be sustainably extracted per pixel (i.e., without depleting ground or surface water reservoirs). Per-pixel values of water balance derived from WaterWorld reflect the capacity (see “Capacity” picture). The water balance is the water available to flow from one pixel to the next in the form of overland flow, as flow in the unsaturated zone, as flow in the saturated zone, or through streams and rivers. It must be noted that the calculation of capacity requires understanding which part of the water surplus needs to be reserved for maintaining water flows in the ecosystems (e.g., maintaining water flows in rivers), and which part is available for extraction.

Service Flow. Modeling the service flow involves linking the capacity of the ecosystem to generate the service to the actual users. In the case of the water provisioning service, these users are normally downstream. With basic hydrological analysis in GIS, the upstream pixels contributing to the availability of water in one pixel can be identified, and potentially their relative contribution can be specified. This means that the contribution of each pixel to making water available to downstream users can, in principle, be quantified. In this way, the hydrological service generated by a pixel, expressed as its contribution to downstream water use (cubic meters of water/spatial unit/year) can be assessed.

As important as quantity is the quality of the water. In a simplified approach, a limited number of classes can be defined, for instance, on the basis of water quality, parameters such as bacterial contents or sediment content. In case such data are not available, a crude, proxy-based approach can be used on the basis of different water quality classes. In the case of San Martin, this would be pixels generating water that is: (1) potentially suitable for drinking water production, (2) potentially suitable as irrigation water, and (3) potentially contaminated. In a proxy-based approach, water can be attributed to these classes as a function of upstream water use, with pixels that have upstream land dominated by forests classified in the first category, and pixels that have upstream areas with significant polluting activities—such as industries discharging into rivers—classified in the third category. In this way, it's possible to analyze the service's contribution to irrigation and to drinking water production, as well as the potential impacts of cutting a forest on the availability of water of sufficient quality for drinking. The figure above (see "Beneficiaries" picture) presents the location of irrigated rice fields (a map pointing out drinking water production inlet points is required to analyze the contribution to drinking water production). With a spatial hydrological model, the pixels contributing to water used for irrigating rice can be identified, and their contribution can, in principle, be estimated. This involves modeling water flows in the catchment, including estimating the loss of water in between the point generating the water surplus and the point where water is extracted (e.g., because of evaporation). This can be done with, for instance, the ARIES modeling platform.

It is recommended to test the approach described above for the hydrological service in San Martin. It also would be highly interesting to compare the accuracy of the overall general model with a more specific model involving more detailed models implemented for part of San Martin, in particular the Alto Mayo Basin where Conservation International has a long-standing involvement and there is higher data availability. An important issue to test, in addition to the above, is the effects of inter-annual (monthly/seasonal) variation. Forests have a complex effect on water supply, and one of the main effects of forests can be a better distribution of water throughout the year. This requires a more complex modeling than currently possible on the basis of timing for this initial analysis, but is planned in the next stage of the project.

Recommendations for Next Steps in EVA Concerning Biophysical Analysis and Mapping

1. Existing ecosystem and land-use maps should be used as a basis for identifying ecosystem accounting units and beneficiaries, respectively. This may require integration of several existing maps prepared for San Martin, including maps used by the government of San Martin, maps prepared for the TEEB study in San Martin, and the Conservation International forest cover map. A particular point of attention is that the various land cover maps are not produced in the same year, and a reference condition needs to be selected (potentially 2007 and 2013), for which land cover data are available and statistical data have already been published by the regional statistical agency.

2. It is clear that the focus of the EVA Project should be to consider the key ecosystem services in San Martin: (1) crop production, (2) water regulation (maintaining water supply), (3) flood control, (4) carbons sequestration, (5) tourism and recreation, (6) biodiversity conservation, (7) timber production, and perhaps also (8) erosion control. Crop cultivation is important because agricultural expansion is the main driver for land-use change in the region. Tourism is a rapidly growing ecosystem sector, with important potential to contribute to greening the economy of San Martin. The two water-related regulating services are key to maintaining other services in the region, and carbon sequestration and biodiversity conservation are two key ecosystem services relevant across scales that are generated in San Martin.
3. Understanding and mapping crop cultivation poses a key challenge. Cropping involves a wide range of different crops and cropping systems, with several broad spatial axes: lowland to upland, floodplain to mountainous, and wet to sub-humid. The cropping systems also are very fragmented, with numerous small-scale plots dominating overall production—even though there is a trend towards the establishment of large-scale (e.g., oil palm) plantations, and large rice-growing areas can be easily distinguished on satellite images. A suggestion is to not map individual crops, but to identify key cropping patterns and map those, considering the three broad spatial patterns described above. The assistance of the European Space Agency in mapping this spatial pattern should be helpful, and it is important to pursue this because complex cropping patterns also are likely to occur in many other WAVES countries.
4. Given Conservation International's experience in using ARIES, it would be advisable to test to what degree ARIES can assist in providing/provide a suitable platform to model flows and capacities of the key ecosystem services identified in San Martin. Comparison and/or integration of the spatial approaches applied in the Ecospace project at Wageningen University with/into ARIES would provide a much better understanding of whether and how the use of modeling and mapping tolls could facilitate the development of ecosystem accounts.
5. A priority would be to map the water regulation (maintaining water supply) service using existing coarse-scale data sets that describe rainfall, evapotranspiration, and runoff for the whole region (available in the WaterWorld model). It would be crucial to collect the water extraction data from the regional drinking water company as soon as feasible, to calibrate the model and understand if this coarse water flow model could be credibly applied in San Martin.
6. Further collection of statistical data (on production of crops, wood, and NTFPs and processing of agricultural products, wood, and NTFPs) for a range of years (tentatively 2010, 2005, and 2000) also would be crucial, to allow further steps in modeling and mapping ecosystem services in San Martin. Specific routines would have to be deployed to allocate these data to spatial units, following the general options presented in Section 2.3.2 of this report.
7. For biodiversity conservation, a specific biodiversity account should be established, as discussed in detail during the workshop at Conservation International offices.

Conservation International's available data set offers great potential to test and publish different approaches to establishing biodiversity accounts in support of ecosystem accounting.

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References

Chapter 1—Designing Pilots for Ecosystem Accounting

Bagstad, K.J., D. Semmens, S. Waage, and R. Winthrop. 2013. "A Comparative Assessment of Tools for Ecosystem Services Quantification and Valuation." *Ecosystem Services* 5: 27-39.

Bagstad, K.J., Darius Semmens, Rob Winthrop, Delilah Jaworski, and Joel Larson. 2012. "Ecosystem Services Valuation to Support Decision Making on Public Lands—A Case Study of the San Pedro River Watershed, Arizona." *U.S. Geological Survey Scientific Investigations Report 2012–5251*. http://pubs.usgs.gov/sir/2012/5251/

European Commission, Organisation for Economic Co-operation and Development, United Nations, and World Bank. 2011. *Our Life Insurance, Our Natural Capital: An EU Biodiversity Strategy to 2020*.

European Commission, FAO, IMF, OECD, United Nations, and World bank, 2013. *System of Environmental-Economic Accounting 2012: Central Framework.*

MA (Millennium Ecosystem Assessment). 2005. *Ecosystems and Human Well-being: Current State and Trends*. Washington, D.C.: Island Press.

European Commission, OECD, United Nations, and World Bank, 2013. *System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting.*

Hein, L. Forthcoming. *Guidelines for the Biophysical Mapping and Analysis of Ecosystem Services in an Ecosystem Accounting Context*. Washington: Policy and Technical Experts Committee.

Merritt, W. S., R. A. Letcher, and A. J. Jakeman. 2003. “A Review of Erosion and Sediment Transport Models.” *Environmental Modelling & Software* 18: 761–99.

Nearing, M. A., L. J. Lane, and V. L. Lopes. 1994. “Modeling soil erosion.” In *Soil Erosion Research Methods*, edited by Rattan Lal, 127–56. 2nd ed. Delray Beach, FL: St. Lucie Press and Soil and Water Conservation Society.

TEEB (The Economics of Ecosystems and Biodiversity). 2010. *Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions, and Recommendations of TEEB.* http://www.teebweb.org/publication/mainstreaming-the-economics-of-nature-a-synthesis-of-the-approach-conclusions-and-recommendations-of-teeb/.

UK National Ecosystem Assessment. 2011. *The UK National Ecosystem Assessment: Synthesis of the Key Findings*. Cambridge, UK: UNEP-WCMC.

United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, and World Bank. 2013. *Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003*.

Vigerstol, K.L., and J.E. Aukema. 2011. “A Comparison of Tools for Modeling Freshwater Ecosystem Services.” *Journal of Environmental Management* 92 (10): 2, 403-9.

Wheater, H.S., A.J. Jakeman, and K.J. Beven. 1993. “Progress and Directions in Rainfall-Runoff Modelling.” In *Modelling Change in Environmental Systems*, edited by A.J. Jakeman, M.B. Beck and M.J. McAleer, 101–32. Chichester, UK: Wiley.

Chapter 2—Experimental Ecosystem Accounting: Scoping Guidance Document

Boyd, J., and S. Banzhaf. 2007. “What are Ecosystem Services? The Need for Standardized Environmental Accounting Units.” *Ecological Economics* 63: 616–626.

European Commission, Organisation for Economic Co-operation and Development, United Nations, and World Bank. 2013. *System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting*.

European Environment Agency. 2011. *An Experimental Framework for Ecosystem Capital accounting in Europe*. Copenhagen: European Environment Agency.

Edens, B., and L. Hein. 2013. “Towards a Consistent Approach for Ecosystem Accounting.” *Ecological Economics* 90: 41–52.

Haines-Young, R., and M. Potschin. 2010. *Proposal for a Common International Classification of Ecosystem Goods and Services (CICES) for Integrated Environmental and Economic Accounting*. United Kingdom: University of Nottingham.

European Environment Agency, 2013. *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August–December 2012*.

Mace, G.M., K. Norris, and A.H. Fitter. 2012. “Biodiversity and Ecosystem Services: A Multilayered Relationship.” *Trends in Ecology & Evolution* 27 (1): 19–26.

Millennium Ecosystem Assessment. 2003. *Ecosystems and Human Well-Being: a Framework for Assessment*. Washington, D.C.: Island Press.

The Economics of Ecosystems and Biodiversity (TEEB). 2010. *Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions, and Recommendations of TEEB*. www.teebweb.org/publication/mainstreaming-the-economics-of-nature-a-synthesis-of-the-approach-conclusions-and-recommendations-of-teeb.

UK National Ecosystem Assessment. 2011. *The UK National Ecosystem Assessment: Synthesis of the Key Findings*. Cambridge, U.K.: UNEP–WCMC.

Chapter 3—Guidance for the Biophysical Mapping and Analysis of Ecosystem Services in an Ecosystem Accounting Context

Ansink, E., L. Hein, and K.P. Hasund. 2008. “To Value Functions or Services? An Analysis of Ecosystem Valuation Approaches.” *Environmental Values* 17: 489–503.

Arshad, M.A., and S. Martin. 2002. “Identifying Critical Limits for Soil Quality Indicators in Agro-ecosystems.” *Agriculture Ecosystems and Environment* 88: 153–160.

Banzhaf, S., and J. Boyd. 2012. “The Architecture and Measurement of an Ecosystem Services Index.” *Sustainability* 2012: 4.

Campos, P., F. Bonnieux, A. Caparros, and J.C. Paoli. 2007. “Measuring Total Sustainable Incomes from Multifunctional Management of Corsican Maritime Pine and Andalusian Cork Oak Mediterranean Forests.” *Journal of Environmental Planning and Management* 50 (1): 65–85.

Daily, G.C., S. Polasky, J. Goldstein, P.M. Kareiva, H.A. Mooney, L. Pejchar, T.H. Ricketts, J. Salzman, and R. Shallenberger. 2009. "Ecosystem Services in Decision Making: Time to Deliver." *Frontiers in Ecology and the Environment* 7: 21–28.

Egoh, B., E.G. Drakou, M.B. Dunbar, J. Maes, and L. Willemen. 2012. *Indicators for Mapping Ecosystem Services: A Review*. Luxembourg: European Union.

European Commission, Organisation for Economic Co-operation and Development, United Nations, and World Bank. 2011. *Our Life Insurance, Our Natural Capital: An EU Biodiversity Strategy to 2020*.

European Commission, 2013a. *Mapping and Assessment of Ecosystems and their Services: An Analytical Framework for Ecosystem Assessments under Action 5 of the EU Biodiversity Strategy to 2020*.

European Commission, OECD, United Nations, and World Bank, 2013b. *System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting*.

Edens, B. and L. Hein. 2013. "Towards a Consistent Approach for Ecosystem Accounting." *Ecological Economics* 90: 41–52.

Lonsdorf, E., C. Kremen, T. Ricketts, R. Winfree, N. Williams, and S. Greenleaf. 2009. "Modeling Pollination Services across Agricultural Landscapes." *Annals of Botany* 103 (9): 1,589–1,600.

MA (Millennium Ecosystem Assessment). 2003. *Ecosystems and Human Well-being: A Framework for Assessment.* Washington, D.C.: Island Press.

Hassan, R., Scholes, R., and Ash, N., 2005. *Ecosystems and Human Well-being: Current State and Trends*. Washington, D.C.: Island Press.

Martinez-Harms, M.J., and P. Balvanera. 2012. "Methods for Mapping Ecosystem Service Supply: A Review." *International Journal of Biodiversity Science, Ecosystems Services, and Management* 8: 17–25.

Phillips, S.J., R.P. Anderson, and R.P. Schapire. 2006. "Maximum Entropy Modeling of Species Geographic Distributions." *Ecological Modeling* 190 (3–4): 231–259.

Potter, C., J. Randerson, C. Field, P. Matson, P. Vitousek, H. Mooney, and S. Klooster. 1993. "Terrestrial Ecosystem Production: A Process Model Based on Global Satellite and Surface Data." *Global Biogeochemical Cycles* 7: 811–841.

Ricketts, T.H., G.C. Daily, P.R. Ehrlich, and C.D. Michener. 2004. “Economic Value of Tropical Forest to Coffee Production.” *PNAS* 101 (34): 12,579–12,582.

Schröter, M., D. Barton, R.P. Remme, and L. Hein. 2014. “Accounting for Capacity and Flow of Ecosystem Services: A Conceptual Model and a Case Study for Telemark, Norway.” *Ecological Indicators* 36: 539–551.

TEEB (The Economics of Ecosystems and Biodiversity). 2010. *Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions, and Recommendations of TEEB*. http://www.teebweb.org/publication/mainstreaming-the-economics-of-nature-a-synthesis-of-the-approach-conclusions-and-recommendations-of-teeb/.

Thrush, S.F., J.E. Hewitt, P.K. Dayton, G. Coco, A.M. Lohrer, A. Norkko. J. Norkko, and M. Chiantore. 2009. *Forecasting the Limits of Resilience: Integrating Empirical Research with Theory*. Proceedings of the Royal Society B.

United Nations. 1992. *Convention on Biological Diversity*.

European Commission, OECD, United Nations, and World Bank, 1993. *Handbook of National Accounting: Integrated Environmental and Economic Accounting*. New York.

United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, and World Bank. 2013. *Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003*.

Van Oudenhoven, A.P.E., K. Petz, R. Alkemade, L. Hein, and R.S. de Groot. 2012. “Framework for Systematic Indicator Selection to Assess Effects of Land Management on Ecosystem Services.” *Ecological Indicators* 21: 110–122.

Villa F., K.J. Bagstad, B. Voigt, G.W. Johnson, R. Portela, M. Honzák, and D. Batker. Forthcoming. *A Methodology for Adaptable and Robust Ecosystem Services Assessment*. PLOS One.

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