European Commission

JRC TECHNICAL REPORTS

Implementing an EU system of accounting for ecosystems and their services

Initial proposals for the implementation of ecosystem services accounts

Report under phase 2 of the knowledge innovation project on an integrated system of natural capital and ecosystem services accounting in the EU

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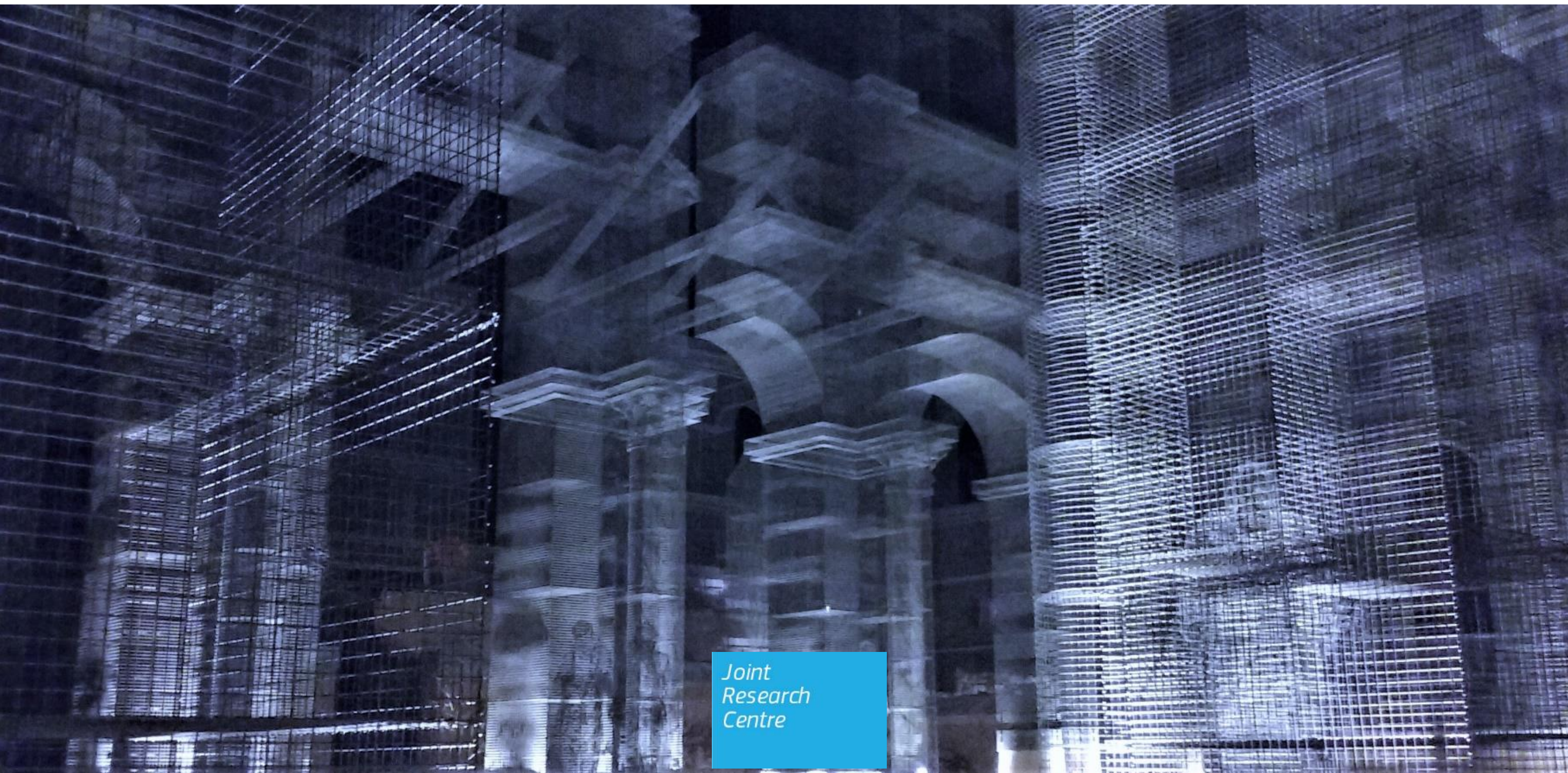
2017

EUR 28681 EN



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This report is a contribution to the **K**nowledge **I**nnovation **P**roject of **I**ntegrated system for **N**atural **C**apital and ecosystem services **A**ccounting (KIP INCA). KIP INCA partners include: DG ENV, ESTAT, EEA, JRC and RTD. The content of this report is only under the responsibility of the JRC.

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JRC107150

EUR 28681 EN

PDF ISBN 978-92-79-70517-5 ISSN 1831-9424 doi:10.2760/214137

Luxembourg: Publications Office of the European Union, 2017

How to cite this report: La Notte A, Vallecillo S, Polce C, Zulian G, Maes J. 2017. *Implementing an EU system of accounting for ecosystems and their services. Initial proposals for the implementation of ecosystem services accounts*, EUR 28681 EN; Publications Office of the European Union, Luxembourg, doi:10.2760/214137, JRC107150

Cover page by Alessandra La Notte, 2016: Art Installation at the Santa Maria di Siponto Archaeological Park (Manfredonia [FG], Italy) called "*Dove l'arte ricostruisce il tempo*" built with funds from the Programma Operativo Interregionale "Attrattori culturali, naturali e turismo" POIn 2007-2013 (Interregional Operational Programme Culture, Nature and Tourism)

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Abstract

The Knowledge Innovation Project on an Integrated system of Natural Capital and ecosystem services Accounting (KIP INCA) aims to work in line with the UN System of Environmental-Economic Accounting- Experimental Ecosystem Accounts (SEEA EEA) and also to propose how the approaches to accounting can be further developed based on experience in the EU. The Technical Recommendations of SEEA EEA make proposals on how to develop accounting tables of ecosystem extent, asset, condition and service supply and use.

This report outlines initial proposal for the service supply and use tables that will be produced by KIP INCA. JRC is the main organization responsible for the development of this set of accounts but it will collaborate closely with the other KIP partners. In particular, accounts will be developed for provisioning ecosystem services (arable cropping, marine fish, outdoor animal husbandry, timber and water), regulating and maintenance services (crop pollination, erosion control, water purification, air purification, global climate regulation and flood control) and cultural services (outdoor recreation). A detailed fact sheet with the description of each ecosystem service is also included in this report.

The SEEA EEA proposes that the stocks in ecosystem accounts are represented by spatial areas, which constitute ecosystem assets. Drivers of change, such as land conversions and land management practises, alter the structure and processes within ecosystems and the functional characteristics of these ecosystem assets. A special section of this report reviews and compares a number of land cover datasets and discuss about the implications of dataset uncertainty on ecosystem service accounts.

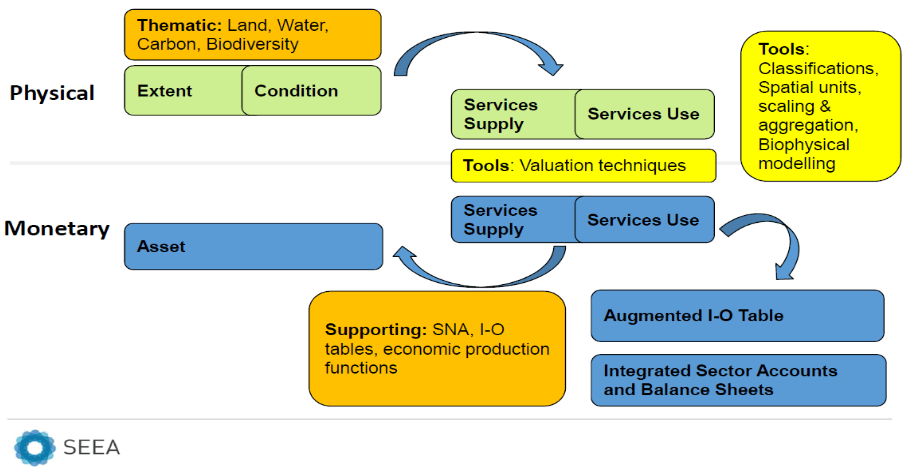
KIP INCA will apply and critically test the SEEA EEA framework. The work and experience of KIP INCA will be an essential contribution to the further development of the SEEA EEA during its current experimental phase.

Executive summary

Ecosystem services are the contributions of ecosystems to human well-being. Ecosystem accounts aim to measure these contributions in a consistent manner at different points in time. Such accounts allow tracking the changes in ecosystems including land, water and biodiversity, ecosystem extend and condition, and ecosystem services. Ecosystem accounts can be used to measure how ecosystems, through the delivery of ecosystem services, contribute to human well-being and the economy and how this evolves over time. The objective is to support decision making in the context of sustainable development.

Consistent and regular updates of ecosystem accounts require the development of guidelines with best practises and testing these guidelines with pilot ecosystem accounts. This is the objective of the Knowledge Innovation Project on an Integrated system for Natural Capital and ecosystem services Accounting (KIP INCA). All Knowledge Innovation Projects were initiated under the European Knowledge Community umbrella to create the knowledge base for achieving the objectives of the 7th Environment Action Programme. KIP INCA was set up by the European Commission (including the Joint Research Centre (JRC), the Directorate-General for Environment, the Directorate-General for Research and Innovation, and Eurostat) and the European Environment Agency. KIP INCA builds on the first phase of the EU initiative on Mapping and Assessment of Ecosystems and Services (MAES), which aims to map and assess ecosystems and their services in the EU, and supports the second phase of MAES, which aims to value ecosystem services and integrate them into accounting and reporting systems by 2020.

KIP INCA aims to work in line with the UN System of Environmental-Economic Accounting-Experimental Ecosystem Accounts (SEEA EEA) and also to propose how the approaches to accounting can be developed based on experience in the EU. The Technical Recommendations of SEEA EEA make proposals on how to develop accounting tables of ecosystem extent, asset, condition and service supply and use. Associated to these accounts are thematic accounts of land, water, carbon and biodiversity.



Legend: Green: physical accounts; Blue: monetary accounts; Yellow: Tools; Orange: thematic and supporting accounts

This report outlines initial proposal for the service supply and use tables that will be produced by KIP INCA. JRC is the main organization responsible for the development of this set of accounts but it will collaborate closely with the other KIP partners. In particular, accounts will be developed for provisioning ecosystem services (arable cropping, marine fish, outdoor animal husbandry, timber and water), regulating and maintenance services (crop pollination, erosion control, water purification, air purification, global climate regulation and flood control) and cultural services (outdoor recreation). KIP INCA will apply and critically test the SEEA EEA framework. The work and experience of KIP INCA will be an essential contribution to the further development of the SEEA EEA during its current experimental phase.

Developing large scale ecosystem service accounts involves making certain choices with respect to indicators, methods, models or valuation techniques to quantify accounts. This report does not contain an exhaustive overview of available indicators, methods, models and valuation techniques, which are available and appropriate for making ecosystem services accounts. Instead, the information provided in this report provides initial experimental proposals on how one could develop ecosystem service accounts at EU level, with the aim of supporting decisions to guide development that is sustainable. These proposals will be developed further and expanded with time.

Different classification systems exist to identify and define ecosystem services but KIP INCA follows the Common International Classification of Ecosystem Services (CICES) version 5.0. This classification links ecosystem functions to benefits through the flow of ecosystem services. Ecosystem functions are the combination of ecosystem properties and characteristics that gives rise to the service. The functional characteristics determine the potential to supply ecosystem services in a certain region given current land use and ecosystem properties and conditions. This differs from the actual use or actual flow of the service by people which is the quantity accounted for in the supply-use tables proposed by the SEEA EEA. The actual use is largely driven by the demand for an ecosystem service. The use of the service finally results in a benefit and benefits contribute to human well-being.

The proper definition of these terms is of crucial importance in accounting. In this report we sometimes go beyond some terms and definitions proposed by the SEEA EEA Technical Recommendations. Standard economic accounting tables equate supply to use. What is supplied by one economic sector is used by another sector or by households. In the ecological literature, not only the service flow that is used by the economic sectors is considered important, but also the ecosystem service potential, which is the amount of the ecosystem service that can be provided or used in a sustainable way. This means that ecosystem services should not be used at rates which exceed the natural capacity of ecosystems to generate them or that emissions of pollutants should not exceed the capacity of ecosystems to assimilate or remove them. Overusing ecosystems can result in stock declines or ecosystem degradation. This is not measured by standard supply and use tables. Therefore, we argue in this report that it is important to keep track of both potential and actual use of ecosystem services in order to provide information on the sustainable use of natural resources.

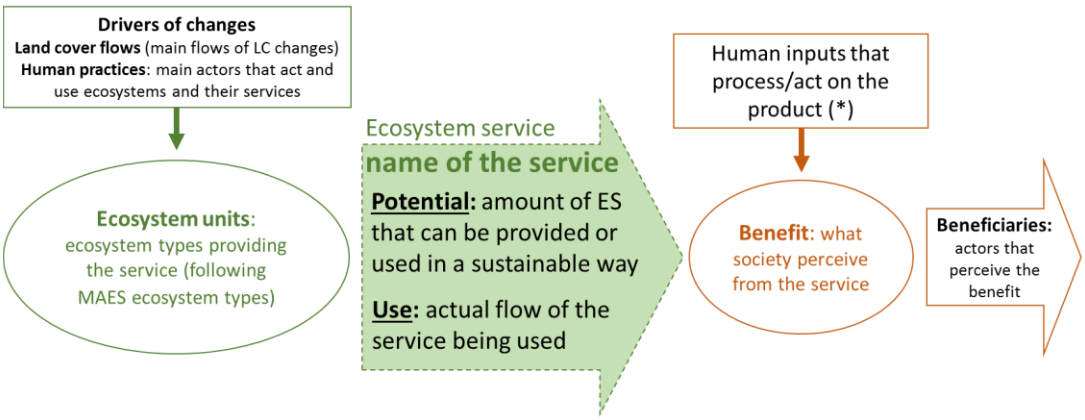
Reconciling the different perceptions that ecologists and accountants have of supply and use might be difficult; it requires properly defining the quantities that are measured and subsequently recording them in different ecosystem accounting tables. Defining the boundaries between sustainable and unsustainable use of different bundles of ecosystem services, however, remains a challenging task for ecologists, but will be essential in order to ensure the use of ecosystem service concepts to support sustainable development.

KIP INCA will apply and critically test the SEEA EEA conceptual framework and the supply and use tables.

The SEEA EEA proposes that the stocks in ecosystem accounts are represented by spatial areas, which constitute ecosystem assets. Drivers of change alter the structure and processes within ecosystems and the functional characteristics of these ecosystem assets. In particular, land conversions and land management practises are considered as the most important drivers of change and warrant separate accounting tables (extent and condition accounts). A special section of this report reviews and compares a number of land cover datasets and discuss about the implications of dataset uncertainty on ecosystem service accounts. Temporal resolution of land cover and land use datasets including the possibility to compare changes over time in a consistent way is key to develop ecosystem service accounts and to determine the levels of uncertainty of the values that will be reported in the tables.

Ecosystem services provide the link between ecosystem assets and the benefits derived and enjoyed by people. For many ecosystem services, human inputs are needed to harvest ecosystem services or to turn services into benefits. The SEEA EEA specifically identifies benefits as SNA products (products which are accounted for in the system of national accounts) as well as non-SNA benefits (which are not considered in the national accounts but which are captured in satellite accounts).

The general approach of the KIP INCA ecosystem service accounts is to quantify supply and use tables for ecosystem services and link these to the different tables for the benefits. This approach differs to some extent with the SEEA EEA but the resulting accounting tables are fully compliant with the technical recommendations.



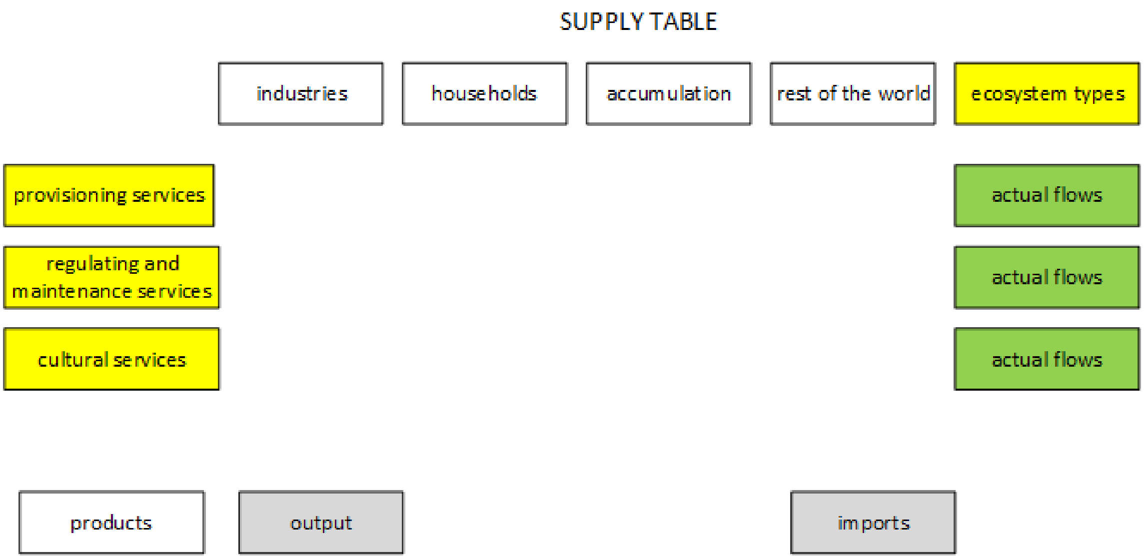
Based on this scheme this report presents a series of fact sheets have been prepared which include the following information for every ecosystem service:

- The **definition of the ecosystem service** composed of an ecological clause (i.e. ecosystem-related) and a use clause (i.e. service-related) following the structure of the Common International Classification of Ecosystem Services (CICES version 5.0). Ecosystem services as defined as the direct contributions of ecosystems to human wellbeing.
- The **ecosystem service-providing unit** (i.e., spatially referenced **ecosystem type**) based on the MAES ecosystem types However, until there are annual or regular updates of the ecosystem map, land cover types will be used as proxies of the ecosystems. The ecosystem units will be integrated in the supply table to quantify the amount of the service that is provided by each ecosystem type.
- **Ecosystem services** are quantified as potential and actual flows (using metric units **per unit time**). **The potential flow** measures the amount of ecosystem service that can be provided or used in a sustainable way in a certain region given current land use and ecosystem properties and conditions. **The actual flow** is the actual use of the ecosystem service by the different economic units. The actual flow may be higher (overuse), equal or lower (underuse) than the potential flow. This requires defining the conditions for sustainable use.
- **Economic units** that are relevant for **users of the service and beneficiaries**. In this report, we consider ecosystem services as the direct and indirect contributions of ecosystems to human wellbeing, following The Economics of Ecosystems and Biodiversity (TEEB, 2010) and the SEEA

EEA. In the ecosystem services cascade model ecosystem services are different than the benefits derived from ecosystem services. Arguably, users and beneficiaries are under some circumstances different actors.

- Indicators to quantify potential and actual flow. In the case of water purification, crop pollination and recreation a more detailed methodology is included in the annexes of this report. For other ecosystem service a review of data available at EU level is provided including the units of measurement, spatial resolution, temporal coverage and tier level showing the level of complexity and/or the degree of development to reach the best possible indicator.
- Review of other methods and tools to map the ES but data are not available or models have been applied for a different extent of the EU
- Potential contribution from JRC or other entities to the development of future ecosystem services accounts
- Final comments and conclusions

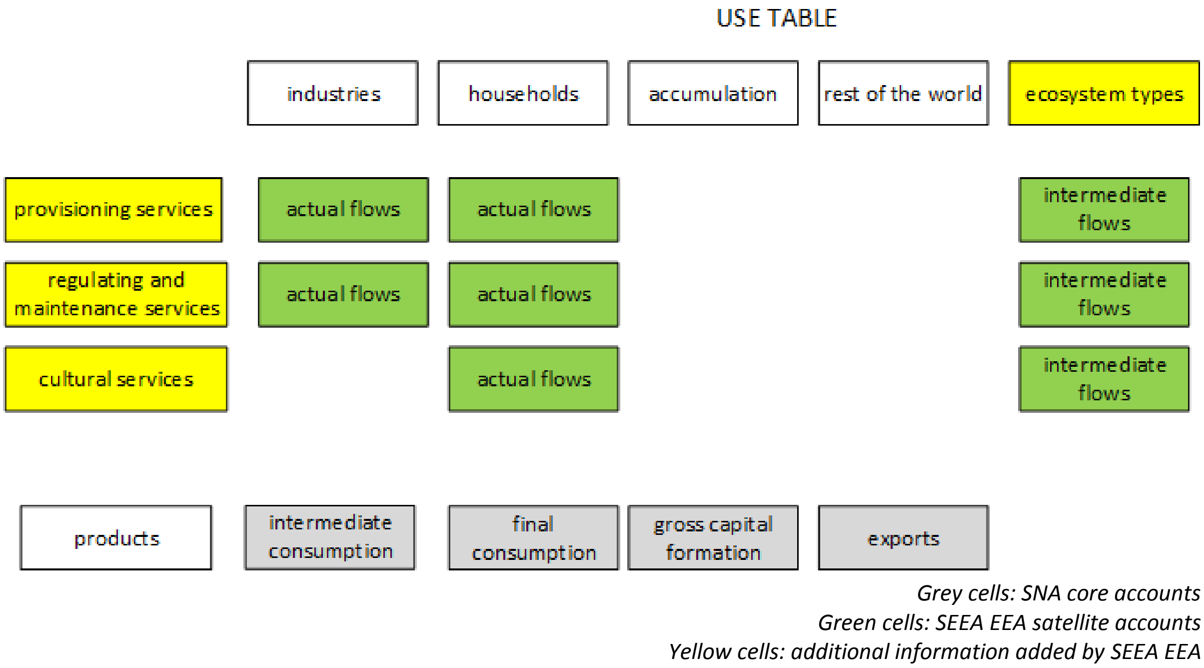
The fact sheets constitute a primary resource of information, which will be used to fill the ecosystem service supply and use tables with physical and monetary data. The supply table shows the actual flows of ecosystem services that flow from different ecosystem types to economic sectors and households during the accounting period. Also accumulation, imports and exports can be accounted for. The supply table shown below shows that economic units cannot supply ecosystem services (no data recordable) and only ecosystems can generate ecosystem services, which are grouped according to the three CICES categories (provisioning, regulating and maintenance, cultural). The structure of the ecosystem services supply and use table incorporates flows of products in order to support the joint presentation of data on (i) ecosystem services used by economic units, and (ii) the products (i.e. SNA benefits) to which those ecosystem services contribute. The scope of products is all goods and services produced in an economy but in practice, a focus will be on products to which ecosystem services contribute. Of course, ecosystems cannot directly supply products (economic processing is necessary).



Grey cells: SNA core accounts
Green cells: SEEA EEA satellite accounts
Yellow cells: additional information added by SEEA EEA

Supply table in the SEEA EEA (graphical simplification)

In accounting terms, supply equals use. Therefore, the numbers reported in the supply table come back in the use table. The use table records the use of ecosystem services by types of economic units as (i) input to further production, or (ii) final consumption. In the SEEA EEA technical recommendations there is the possibility to record the use of ecosystem services by other ecosystem types, i.e. as intermediate ecosystem services. The 'product' section shows the use of products by different economic units. No data are recorded from products to ecosystem units because ecosystem types cannot use products.



Use table in the SEEA EEA (graphical simplification)

The main purpose of supply and use tables for ecosystem services is to show where the actual flow of the service is coming from (ecosystem types) and who is using it (institutional units). Starting from the biophysical assessment, we then can proceed with the economic valuation of those flows, which allows a direct comparison with SNA accounts and thus a conjoint ecological-economic analysis.

A main guiding principle for monetary valuation of ecosystem services is that the choice of the valuation technique is largely determined by the specific purpose and context of use, with the overriding objective of supporting decision making consistent with sustainable development. Our first step proposal to monetary valuation follows two general guidelines: an effective coupling between biophysical and monetary accounts and the use of exchange values. Coupling biophysical with monetary accounts ensures that changes in the physical supply of ecosystem services drive the valuation. In turn, valuation results in a common unit among all ecosystem services and between ecosystem service accounts and SNA accounts. Using exchange values ensures comparability with the system of national accounts. Clearly, these two principles apply for national accounting. In a broader framing, one can also consider other types of valuation where the use of welfare values or non-monetary estimates is more appropriate and investigate what form is most appropriate for decision making. This will form part of the work at later stages once some initial testing is carried out.

A critical note on the supply and use tables of the SEEA EEA Technical Recommendations

SEEA EEA supply and use tables are, for KIP INCA, the starting point to develop pilot applications. They provide a base structure to develop a comprehensive and consistent accounts for ecosystem services. However, the accounts remain experimental indeed and require further refinement and testing. Four issues need to be addressed when developing a set of pilot accounts in KIP INCA:

1. Actual flows of ecosystem services do not allow inferences to be made about the sustainable use of ecosystems. Ecosystems are often overexploited and this often h cannot be observed based on actual use of ecosystem services. Further work is needed to test how condition and capacity accounts can record the sustainable use of ecosystem services.
2. The complementarity with the SEEA-Central Framework should be tested. The SEEA EEA records provisioning services such as timber and water, which are also recorded in central framework. More clarity is needed to in terms of reporting which data under which accounts.
3. The difference between SNA and non-SNA benefits should clarified.
4. Separating ecosystem services from benefits might require defining different categories of users. Specifically, in the case of sink-related services, the actual flow of ecosystem services is determined by the enabling actors. Identification of enabling actors allows the establishment of the causality nexus between the economic activities that modify the flow and the changes in the service flow.

This report sets out the initial methodological frame adopted for the implementation and testing of experimental ecosystem service accounts at European scale. Although more conceptual research and framing is still needed to fully address questions related to sustainability or monetary valuation, this report marks the start of practical work including the development of pilot accounts, setting up data infrastructure and testing accounts with users.

1 Introduction

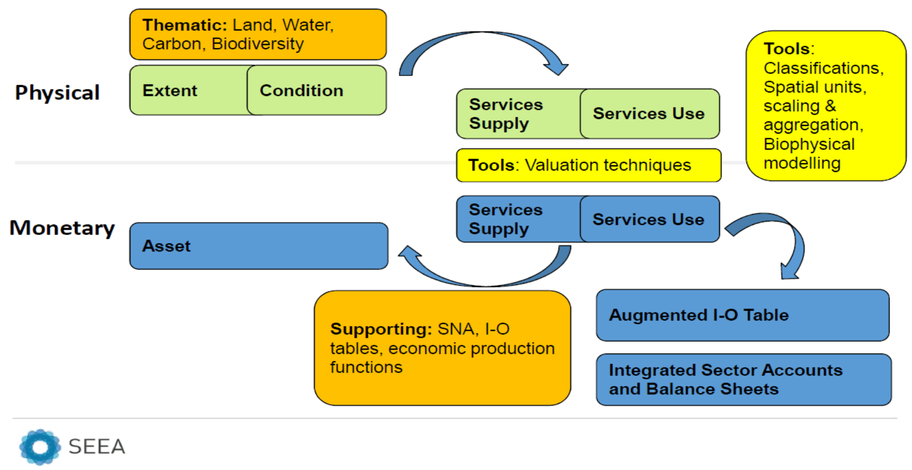
The 7th Environment Action Programme and the EU Biodiversity Strategy includes objectives to develop natural capital accounting (NCA) in the EU, with a focus on ecosystems and their services. Ecosystem accounting complements the system of national accounts (SNA). It builds on the System of Environmental-Economic Accounting – Central Framework (SEEA CF) which provides methodological guidelines for setting up accounts for environmental assets as individual resources such as timber resources or water resources. The UN SEEA EEA (Experimental Ecosystem Accounting) goes beyond the central framework to give guidance on setting up accounts that reflect the role of ecosystems and their services. It is still in an experimental phase but may become a UN standard at a later stage.

A Knowledge Innovation Project on an Integrated system for Natural Capital and ecosystem services Accounting (KIP INCA) was set up by the European Commission (including JRC, DG Environment, DG Research and Innovation, and Eurostat) and the European Environment Agency. This project aims to design and implement an integrated accounting system for ecosystems and their services in the EU by connecting relevant existing projects and data collection exercises to build up a shared platform of geo-referenced information on ecosystems and their services. KIP INCA builds on the first phase of the EU initiative on Mapping and Assessment of Ecosystems and Services (MAES), which aims to map and assess ecosystems and their services in the EU, and supports the second phase of MAES, which aims to value ecosystem services and integrate them into accounting and reporting systems by 2020.

The starting point of the KIP INCA is the UN System of Environmental-Economic Accounting-Experimental Ecosystem Accounts. Figure 1.1 illustrates the different components of SEEA EEA, which includes accounts of ecosystem extent, ecosystem condition, ecosystem services and thematic accounts as well as monetary accounts, which should help to integrate the results of ecosystem accounting with the System of National Accounts (SNA).

Although, ecosystem extent and condition have a direct influence on ecosystem services, available technical guidance under SEEA EEA acknowledges that the different components of the SEEA EEA often need to be developed in parallel. Likewise, for reasons of practicality, this report only focuses on the accounting of ecosystem services, without explicitly addressing the relationship between ecosystem condition and services. Note, however, that the accounts of ecosystem services will be based on (spatially explicit) biophysical models, which usually include as input dataset land cover maps describing the ecosystem extent. Condition is only partially considered for some ecosystem services only when the environmental pressure (i.e. level of pollutants) affects the capacity of the ecosystem to deliver the service reducing, therefore, the actual service flow (i.e. water purification).

This report sets out initial methodological choices adopted by the JRC for developing ecosystem service accounts at European scale. It does not contain actual accounts but outlines how different accounts will be developed and approaches will be further expanded and refined in the coming years. on the starting point for this work are the technical recommendations of the SEEA EEA, but will also aim to critically evaluate, test and improve this framework during its current experimental phase. The choices for certain indicators, methods, models or valuation techniques to quantify accounts largely depend on in-house knowledge and expertise, the possibility for obtaining EU wide data coverage, and available resources. This report does therefore not contain an exhaustive overview of available indicators, methods, models and valuation techniques, which are available and appropriate for ecosystem services accounts.



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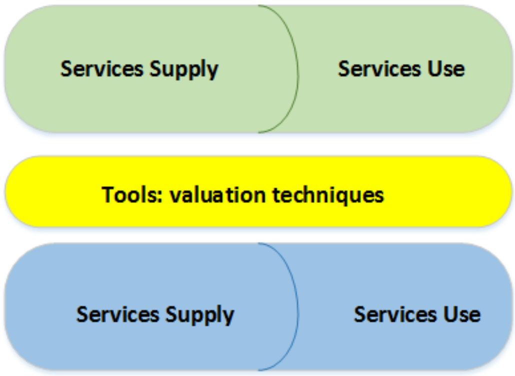
Green: physical terms
Blue: monetary terms

Figure 1.1 - Components of the UN SEEA EEA (source: European Commission, 2016)

The first phase of KIP INCA focused on feasibility and design (European Commission, 2016). It reviewed data collection instruments at EU and international level, and explored options for implementing an integrated accounting system for ecosystems and their services at EU level, as well as resources needed. The report made proposals for the development of a data architecture and the ecosystem types to consider in accounting tables. It also includes a list of ecosystem services for which pilot accounts will be carried out. During the second phase of the KIP INCA the following experimental accounting tables will be developed:

- Ecosystem extent accounts which delineate ecosystem and changes in areas covered by ecosystems
- Ecosystem condition accounts which capture parameters which are linked to essential ecosystem processes, per type of ecosystem
- Ecosystem service supply and use tables are connecting the generation of ecosystem services by ecosystems to the use by economic sectors and activities
- Experimental asset accounts are monetary accounts based on the net present value of the expected flow of ecosystem services
- Capacity accounts are expressing the ability of an ecosystem to generate ecosystem services under sustainable ecosystem management
- Additional thematic accounts (e.g. land, biodiversity, water, fish) are considered as well.

This report focusses on presenting ecosystem service supply and use tables in physical and monetary terms (Figure 1.2). JRC is the KIP partner responsible for the development of this set of accounts.



Legend:
Green: physical terms
Blue: monetary terms

Figure 1.2 – Components of the UN SEEA EEA to be developed by the JRC within KIP INCA

Since the supply and use framework to be adopted will affect all the applications, it is important to specify:

- what is meant by ecosystem services and which is the conceptual framework behind their definition (Chapter 2);
- how supply and use tables develop and evolve from the SNA and through the SEEA CF until the SEEA EEA current proposal (Chapter 3.1);
- what are main issues need to be addressed in pilot applications on selected ecosystem services by the JRC (Chapter 3.2).

Furthermore the report includes a number of ecosystem service fact sheets (Chapter 4). KIP INCA has proposed in the first phase report a number of ecosystem services for which experimental accounts will be developed. The fact sheets review the available information for each of these services with a view to define conceptual models, indicators, accounting methods, data sources and possible collaborations needed to complete the work.

Finally, an annex on water purification, crop pollination and outdoor recreation describes more in depth how these accounts will be quantified.

2 The ecosystem services framework

The ecosystem services framework is intended to support environmental policy and decision making by combining the ecological and economic perspectives. This framework enables the link between environment and human activities to be conceptualised, the systematic assessment of the benefits provided by functioning ecosystems to socio-economic systems, and the design of appropriate management policies. As a problem-solving framework, the added value arises from establishing ecosystem services as the link between ecosystems and the ways in which people benefit from them. The Common International Classification for the Ecosystem Services (CICES) represents a well-established classification by European Commission's work on ecosystem services (Maes et al., 2014). CICES, like other classification systems (e.g. TEEB 2010), is based on a conceptual model represented by the ecosystem services cascade (Haines-Young & Potschin 2010). Although referring to the ES cascade, literature provides examples where applications undertook very different interpretations as summarised by Potschin et al. 2016. Specifically, in most applications instead of assessing and representing services, the focus was on what is generated by services, i.e. benefits (Boerema et al., 2016); in many cases ecosystem services are poorly quantified, only one side of the cascade is considered, what is used are simplified indicators or proxies for the actual ecosystem service.

2.1 The cascade model

The cascade framework proposed by Haines-Young and Potschin (2010) links natural systems to elements of human well-being, following a pattern similar to a production chain: from ecological structures and processes generated by ecosystems, to the services and benefits eventually derived by humans. The cascade was also instrumental for defining the MAES conceptual model for mapping and assessment of ecosystems and ecosystem services. The advantage of this framework is that it shows how society depends on ecosystems.

2.1.1 The ecological structure, the function, the service and the benefit

The cascade model is commonly represented as shown in Figure 2.1 in which ecological structures and processes created or generated by living organisms are clearly distinct from the benefits that people eventually derive. According to Palmer and Febria (2012), the components of an ecosystem (that represent the structure) interact with dynamic biophysical processes (that are functions) to produce goods and services on which people rely.

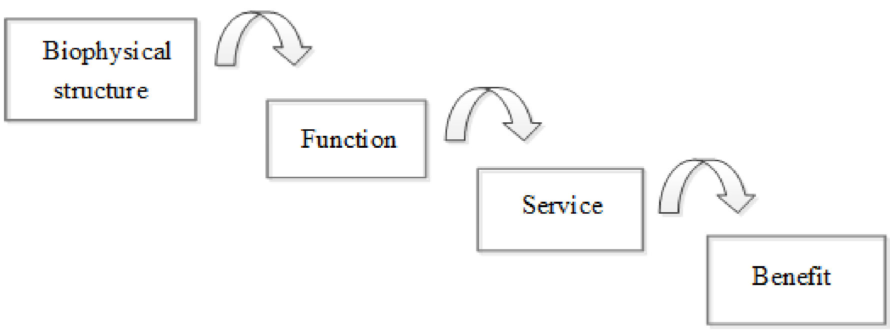


Figure 2.1 – Simplified[1] representation of the ecosystem services cascade model
(Adapted from Haines Young and Potschin, 2010)

[1] We use a simplified version to facilitate the correspondence between the cascade model and the accounting model.

Ecosystems are shaped by the interaction of communities of living organisms with the abiotic environment. Structural and functional metrics can be used to assess the potential of ecosystems to provide services and to determine the levels of services, e.g. the trophic structure of fish communities (Maes et al., 2013).

Ecosystem functions are defined as the capacity or the potential to deliver ecosystem services. They are constituted by combinations of processes, traits and structures and represent the potential that ecosystems have to deliver services, irrespective whether or not they are useful for humans. (Maes et al., 2013). Biophysical structures and functions still are perceived at the ecosystem holistic level.

Ecosystem services are derived from ecosystem functions and represent the realised flow of services for which there is demand. In contrast to ecosystem functions, ecosystem services imply access and demand by humans. In CICES ecosystem services are grouped according into three major categories: provisioning, regulating and maintenance, cultural. Provisional services include all material, food and biota-dependent energy outputs from ecosystems; they are tangible things that can be exchanged, traded and consumed. Most provisioning services, in order to be beneficial and valuable to humans, normally require additional inputs (e.g. investments, energy, labour, management) by people. This feature must be explicitly considered in an integrated accounting approach. Regulating and maintenance services include all the ways in which ecosystems control or modify biotic or abiotic parameters that define the environment where people live; they affect the performance of individuals, communities and populations and their activities. Cultural services includes all non-material ecosystem outputs that have symbolic, cultural or intellectual significance (Maes et al., 2013).

Benefits are what lead to positive changes in human well-being. Human well-being depends substantially, but not exclusively, on ecosystem services. Four major categories can be considered: nutrition, health, safety, and enjoyment, which can all be delivered by multiple ecosystem services (Maes et al., 2013). Both ecosystem services and benefits are perceived individually, one-by-one since a specific human need and use can be identified.

A few comments about the use of the cascade. Ecological structure is often poorly distinguished from processes. According to Wallace ecological structures are tangible entities described in terms of amount while processes are generally described in terms of rates (2007 p. 237). About the second box in Figure 2.1, the word function is sometimes used interchangeably with ecological process and/or ecosystem service. In relation to the third box, although ecosystem services are generally defined as the ecosystem structural elements and processes considered useful to humans (MA 2005, TEEB 2010), some studies use services and benefits as synonyms. Benefits are in some cases considered as tangible natural resources derived from provisioning services (e.g. crops, wood, water), or some regulating services (e.g. clean water for multiple uses provided by water purification). Benefits, however, can also be intangible (e.g. recreation opportunities offered by nature). Before accounting for ecosystem services we need to clarify what ecosystem services are for our purpose; otherwise any accounting structure whose object is ambiguous risks to be inconsistent. Distinguishing between the different components of the cascade frame offers greater precision in understanding how different pressures and management decisions affect ecosystems and human well-being (Maes et al., 2016). The intent of current and future applications is in fact to clearly separate services and benefits in order to link in a consistent way with the SEEA CF and the SNA.

La Notte et al. (2017a) provide a 'systems ecology' perspective of the ecosystem services cascade that reconfirms that accounting tables should clearly make a distinction between ecosystem services and benefits derived from ecosystem services. In fact, by considering the degree of complexity attributed to the cascade components, ecosystem services should not be considered as individual ecosystem components or goods but rather the interactions between and among biotic and abiotic components that lead to a change in human well-being. Ecosystem services are not the benefits, but generate benefits as an output, often measured in terms of biomass. A service implies that there is exchange of information and/or interaction. Goods are thus interpreted as material vehicles for ecosystem service enjoyment. Moreover, ecosystem functions are not services, but ecological structures and processes that act at ecosystem level and generate flows of services. Functional characteristics should be maintained to ensure a sustainable flow of services. It is important to acknowledge that functions should be conceived with a more holistic and bio-centric approach compared to ecosystem services, which can be individually identified and assessed. Ecosystem services are the contribution of ecosystem to generate benefits.

2.2 The SEEA EEA model

Compared to traditional accounting frameworks, SEEA EEA has to deal with many issues that go beyond economics: ecology, natural sciences, spatial analysis, and conservation planning determine biophysical measurements and what enters into the accounts will be correct only if the biophysical measurements are accurate. The SEEA EEA should integrate perspectives from ecology and natural science disciplines to properly measure and report on ecosystem condition and ecosystem services. Figure 2.2 shows the SEEA EEA theoretical framework (UNSD et al. 2014b). According to SEEA EEA definitions, the stocks in ecosystem accounting are represented by spatial areas, which constitute ecosystem assets. They provide a flow of ecosystem services with a direct use for humans (e.g. flood protection, recreation). Each ecosystem asset has a range of ecosystem characteristics that can be fixed, such as slope and altitude, and variable, such as rainfall, land cover and biodiversity. The flows in ecosystem accounting are of two types: (i) there are flows within and between ecosystem assets (e.g. intra- and inter-ecosystem flows); (ii) there are flows generated by ecosystem assets and directed to people: ecosystem services. Flows of ecosystem services only consider final ecosystem services and relate either to flows of natural inputs from the environment to the economy or to flows of residuals to the environment due to economic and other human activity.

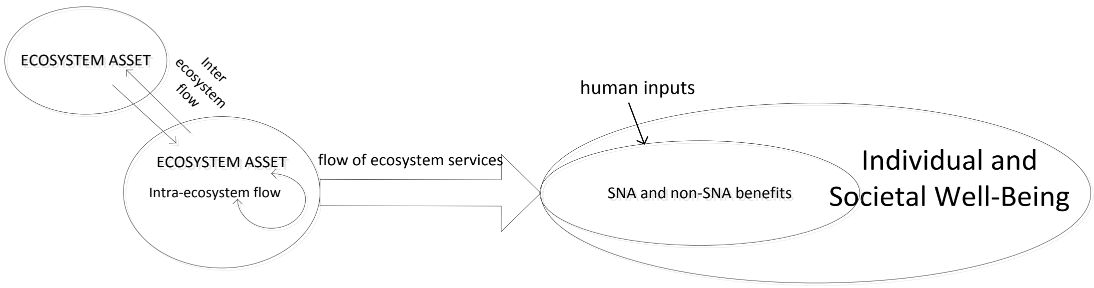


Figure 2.2 – SEEA EEA conceptual model (adapted from UNSD et al., 2014a)

Final ecosystem services provide the link between ecosystem assets and the benefits derived and enjoyed by people. Thus, the SEEA EEA discriminates clearly between ecosystem services and benefits and, importantly, considers ecosystem services as 'flows'. In Figure 2.3 we attempt to establish a correspondence between the cascade model and the SEEA EEA model: both models agree that services are different from the benefits. The SEEA EEA specifically identifies benefits as the SNA products. Therefore, in KIP INCA the general approach involves 'supply' and 'use' tables for ecosystem services separated from 'supply' and 'use' tables for benefits.

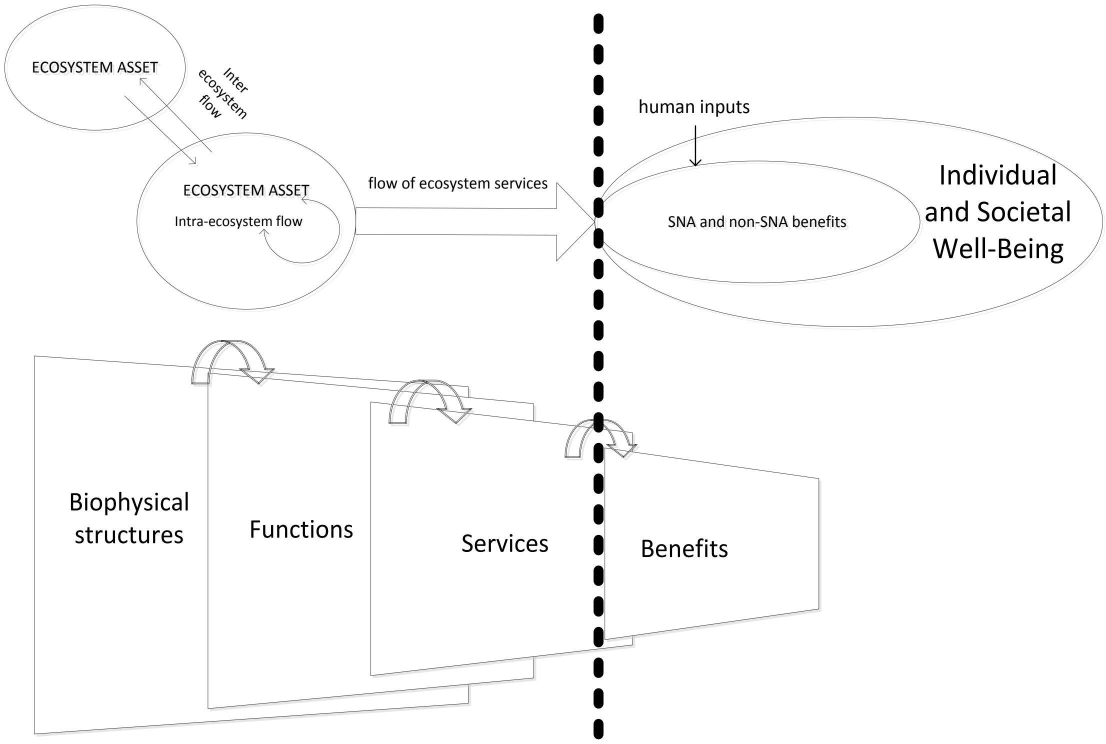


Figure 2.3 – Matching between the SEEA EEA theoretical framework and the cascade model[2]

[2]We used here the 'telescopic' version of the cascade model (La Notte et al., 2017a) to highlight benefits' lower level of complexity compared to services, functions and biophysical structures.

3 Supply and use tables in accounting systems

The System of National Accounts (SNA) is the internationally agreed standard set of recommendations on how to compile measures of economic activity in accordance with strict accounting conventions based on economic principles (ref. 1.1 EC. et al., 2009).

A great strength of the SNA is the robust articulation that allows a certain flexibility to be applied while still remaining integrated, internally consistent and economically complete. However, in some cases trying to work with SNA in a flexible may: (i) overburden national accounts with detail; and, (ii) introduce conflicting requirements. In fact, some types of analysis need to focus on specific fields within the context of national accounts to highlight aspects that are partially or completely hidden in the standard economic accounts. In other types of analysis the economic process itself might be represented differently and thus generate complementary or alternative aggregates.

Since the 1993 version (EC. et al, 1993), the SNA recognizes the need for flexibility and incorporated the concept of satellite accounts, which represent additional accounts that are closely linked to the main SNA but not restricted to the same concepts and/or data. There are two types of satellite accounts.

The first type, called internal satellite accounts, takes the full set of accounting rules and conventions of the SNA but focuses on a particular aspect of interest by moving away from the standard classifications and hierarchies (e.g. tourism satellite accounts). The main reason for developing such a satellite accounts is that encompassing all the detail for all sectors of interest as part of the standard system would simply overburden it, and distract attention from the main features of the accounts. Many elements shown in a satellite account are invisible in the central accounts. They are either explicitly estimated in the making of the central accounts, but then merged for presentation using more aggregated figures, or they are only implicit components of transactions that are estimated globally.

The second type, called external satellite account, adds non-economic data, modifies some of the accounting conventions, or does both. It is a way to explore new areas in a research context. The second type of satellite analysis is mainly based on concepts that are alternatives to those of the SNA, e.g. a different production boundary, an enlarged concept of consumption or capital formation, an extension of the scope of assets, and so on. This second type of analysis allows experimentation with new concepts and methodologies, with a much wider degree of freedom than is possible within the central system (UN. et al, 2009).

The System of integrated Environmental and Economic Accounts (SEEA) is a set of satellite accounts. In the SEEA Central Framework (SEEA CF, UN. et al. 2014a) both internal (e.g. environmental protection expenditures) and external (e.g. non-produced environmental assets) satellite accounts are embedded, while the SEEA Experimental Ecosystem Accounting (SEEA EEA, UN et al. 2014b) focuses on external (ecosystem and ecosystem services) satellite accounts. This experimental perspective allows the use of the SNA articulation to frame, in a consistent economic context, an enlarged production and asset boundary that includes ecosystem units that play an active role.

The experimental perspective is very important since ultimately the accounting framework needs to support decision-making that encompasses ecological, social, and economic dimensions. For this reason many disciplines need to be involved (e.g. environmental science, hydrology, forestry, fisheries, economics, statistics) each with its own concepts and structures. Thus, while the underlying accounting structure is based on national accounts, perspectives from other disciplines influence the concepts and methodologies, and can be critical in determining the practical usefulness of the final accounting system.

The focus of this report is the accounting of ecosystem services that in the SEEA EEA can be found in the supply and use tables (UN et al, 2014b). This chapter aims at describing how supply and use tables evolve from the SEEA CF to the SEEA EEA.

3.1 Structure of supply and use tables

The SEEA CF is a multipurpose framework that describes the interactions between the economy and the environment, and the stocks as well as the changes in stocks of environmental assets. It organizes the information of the various stocks and flows of the economy and the environment in a series of tables and accounts. Specifically:

(a) supply and use tables in physical and monetary terms showing flows of natural inputs, products and residuals;

(b) asset accounts for individual environmental assets in physical and monetary terms showing the stock of environmental assets at the beginning and the end of each accounting period and the changes in the stock;

(c) a sequence of economic accounts highlighting depletion-adjusted economic aggregates; and,

(d) functional accounts recording transactions and other information about economic activities undertaken for environmental purposes (UN et al., 2014a).

The SEEA EEA complements the SEEA CF and is meant to report flows of ecosystem services, changes in ecosystem assets and to link this information to economic and other human activities (UN, 2014b).

This chapter shows how supply and use tables are constructed in the different frameworks. We will start from their structure and purpose in the SNA to check how they evolved first in the SEEA CF and then in the SEEA EEA.

3.1.1 Supply and use tables in the SNA

In the SNA supply and use tables are compiled in monetary terms and record all flows of products in an economy between different economic units in order to describe the structure of the economy and the level of economic activity.

Products are ‘supplied’ within the economy when they are:

(a) Produced by industries in the national economy (output).

(b) Brought in from the rest of the world (imports).

All products that are supplied should be recorded as being ‘used’:

(a) Used by other industries to make different products (intermediate consumption).

(b) Consumed by households (household final consumption expenditure).

(c) Consumed by governments (government final consumption expenditure).

(d) Sold to the rest of the world (exports).

(e) Held as inventories for later use[3].

(f) Used as assets (e.g., machines) over a longer period of time to produce other products (these longer-term uses are flows known as gross fixed capital formation[4]).

As shown in Figure 3.1, flows are classified by type of product in the rows and by type of economic unit (enterprises[5], households, government and the rest of the world) in the columns.

SUPPLY TABLE

	industries	households	government	accumulation	rest of the world
products	output				imports

USE TABLE

	industries	households	government	accumulation	rest of the world
products	intermediate consumption	final consumption	final consumption	gross capital formation	exports

Grey cells: SNA core accounts

Figure 3.1 – Monetary supply and use tables in the SNA (graphical simplification)

The total supply of each product should equal the total use of each product. The supply and use identity is a fundamental identity in national accounts.

When compiling supply and use tables it is important to use a consistent classification for economic units and products. Industries are consistently classified using the International Standard Industrial Classification of All Economic Activities (ISIC), products are classified using the Central Product Classification (CPC), and the determination of whether particular economic units are within a particular national economy is based on the concept of residence[6].

Relevant economic units are those that interact with each other and that are able to make decisions about the production, consumption and accumulation of goods and services. An institutional unit is an economic entity that is capable, in its own right, of:

(a) owning assets;

[3] When products are withdrawn from inventories in subsequent accounting periods, they are effectively resupplied to the economy at that time. By accounting convention, the change in inventories (additions to inventories less withdrawals) during an accounting period is recorded as a use of products

[4] Gross capital formation is equal to gross fixed capital formation plus changes in inventories

[5] Enterprises are classified to industries on the basis of their principal activity

[6] According to the concept of residence, a unit has its centre of predominant economic interest in a particular economic territory. We need to consider the following cases: (a) Units intending to operate in a country for less than a year; (b) Resident producing units that may operate outside of the national territory (e.g. ships and aircraft); (c) Residents of a national territory that may stay temporarily in other countries for work or leisure. The consumption undertaken by such residents in other countries will be recorded as an import of the country in which the person is resident and an export of the country visited.

(b) incurring liabilities; and

(c) engaging in transactions and other economic activities with other entities.

Groupings of institutional units that are similar in their purposes, objectives and behaviours are defined as institutional sectors. Five types of institutional sectors are identified in the SNA: households, financial corporations, nonfinancial corporations, general government and non-profit institutions.

3.1.2 Supply and use tables in the SEEA CF

An economy cannot function without using natural resources in the form of flow of inputs from the environment, and by using the environment to absorb the unwanted by-products of economic production through the release of residuals.

The framework to measure physical and monetary flows of natural inputs and residuals is based on the structure of the monetary supply and use tables used to measure economic activity. In the SNA supply and use tables show transactions in products between industries, households, government and the rest of the world; the SEEA CF includes supply and use tables record the underlying physical flows relating to the transactions between the different economic units. Natural resource flows are in fact connected with the assessment of some production processes: many of the flows of products recorded in monetary terms relate to the use of natural inputs from the environment (e.g. the manufacture of wood products, processing of fish in the food industry). The recording of the products that flow within the economy is the same as that for the recording of these flows in the SNA (UN, 2014a).

Natural input and residual flows can be linked in by adding relevant columns and rows to the SNA monetary supply and use tables. Figure 3.2 shows which satellite accounts are added to the core SNA supply and use tables.

SUPPLY TABLE

	industries	households	accumulation	rest of the world	environment
natural inputs					flows from environment
products	output			imports	
residuals	generated by industries	generated by households	from scrapping and demolition	imported	

USE TABLE

	industries	households	accumulation	rest of the world	environment
natural inputs	extraction				
products	intermediate consumption	final consumption	gross capital formation	exports	
residuals	recycled		landfills	exported	flow to environment

Grey cells: SNA core accounts
Blue cells: SEEA CF satellite accounts
Yellow cells: additional information added by SEEA CF

Figure 3.2 – Supply and use tables in the SEEA CF (graphical simplification)

Comments on the rows of Figure 3.2

The rows for natural inputs and residuals represent an extension of SNA supply and use tables. Natural inputs are all physical inputs moved from their location in the environment directly used in economic production or as a part of production processes. The SEEA CF reports three broad classes of natural inputs: natural resource inputs, inputs of energy from renewable sources and other natural inputs. The class most relevant for ecosystem service accounts is “natural resource inputs” which comprises inputs from mineral and energy resources, soil resources, natural timber resources, natural aquatic resources, other natural biological resources and water resources. Most natural resource inputs that enter the economy become products: e.g. water abstracted for distribution, removals of timber for manufacturing, extracted minerals. Some natural resource inputs (termed natural resource residuals) do not become products but instead immediately return to the environment[7].

Some relevant features need to be noted. First, all natural resource inputs are recorded as entering the economy from outside the SNA production boundary (i.e. the environment). Second, it is acknowledged that some amount of economic production should be undertaken before a natural resource can be considered extracted; it thus becomes crucial to determine the point at which the

[7] Examples of natural resource residuals are losses during extraction, unused extraction, and reinjections, which are natural resources that are extracted but are immediately returned to the deposit and may be re-extracted at a later time (e.g., water reinjected into an aquifer and natural gas reinjected into a reservoir).

flow of natural resource enters the economy as part of a longer production process. Third, for the same reason 'natural resource inputs' exclude the flows from cultivated biological assets that are considered as produced within the economy and thus fall inside the production boundary.

Residuals are flows of solid, liquid and gaseous materials, and energy that are discarded, discharged or emitted by establishments and households through processes of production, consumption or accumulation; they can be discarded, discharged or emitted directly to the environment or be captured, collected, treated, recycled or reused by economic units (UN et al., 2014a). Residuals include solid waste, wastewater, emissions, dissipative use of products, dissipative losses and (already mentioned) natural resource residuals. Emissions can be further grouped into emissions to air, to water and to soil.

Two interesting features of emissions are important to consider with a view on ecosystem services and benefits. First, the environmental impact imposed by residuals relate to residual flows that not only depend on the current period but also on past periods because residuals can accumulate. Continuing the existing flow of residuals may assume considerable importance when looking at the level already accumulated at the beginning of the accounting period and the damage inflicted by the ambient concentrations of a residual often increases non-linearly with the amount of residual generated.

Second, there is no single classification of all residuals because the various groups of residuals may overlap: depending on purpose, a flow may appear in several accounts. A solution adopted in the SEEA CF is to provide a detailed table that gives an indication of the types of materials that are commonly included in the different groupings. This information can support analysis by clarifying whether the focus is on the purpose behind the discard (e.g. disposal of solid waste), the destination of the substance (e.g. emissions to air) or the processes leading to the emission (e.g. dissipative losses). A similar problem needs to be faced when trying to classify SNA-benefits and non SNA-benefits generated by ecosystem services. A tool similar to that adopted for residuals might be considered when addressing this issue.

Comments on the columns of Figure 3.2

A difference from the SNA supply and use tables is that the column "Government" is missing. This is justified by the fact that government expenditure represents the acquisition and consumption by governments of their own output without any associated physical flow; all of the physical flows related to the intermediate consumption of and residuals generated by governments are recorded in the first column under the relevant industry class. It is important to consider that in SNA "Government" acts as an economic sector: it cannot be used as a proxy for 'society'.

The column "Accumulation" covers changes in the stock of materials and energy in the economy. Accumulation flows are recorded because they concern supply in the current accounting period that is not used in the current period but rather accumulated for future use or sale in the form of inventories or of fixed assets. From a supply perspective, this column records reductions in the physical stock of produced assets. From a use perspective, the accumulation column records additions to the physical stock of produced assets (gross capital formation) and the accumulation over an accounting period of materials in controlled landfill sites.

The column "Rest of the World" recognizes the exchanges between national economies in the form of imports and exports of products and flows of residuals. Residuals received from the rest of the world and residuals sent to the rest of the world primarily relate to the movement of solid waste between different economies.

The additional external satellite account is 'Environment', where flows to and from the environment are recorded. The incorporation of this column allows for a full accounting of flows of natural inputs and residuals, which would otherwise not be possible. However, one important element to consider is that within the SEEA CF 'Environment' is a passive entity that does not contribute to production, consumption or accumulation in the same way as units inside the economy (UN. et al., 2014a).

Within the SEEA, the supply and use identity that applies in monetary terms also applies in physical terms: for each product measured in physical terms the quantity of output and imports should equal the quantity of intermediate consumption, household final consumption, gross capital formation and exports. The identity also applies to the total supply and use of natural inputs and the total supply and use of residuals. In addition to the supply and use identity, the SEEA incorporates an additional identity concerning flows between the environment and the economy. This input-output identity requires that the total flows into the economy over an accounting period, either are returned to the environment or accumulate in the economy. Both the supply and use identity and the input-output identity are based on the law of the conservation of mass and energy[8], which implies for accounting that mass and energy flows should balance across natural inputs, products and residuals.

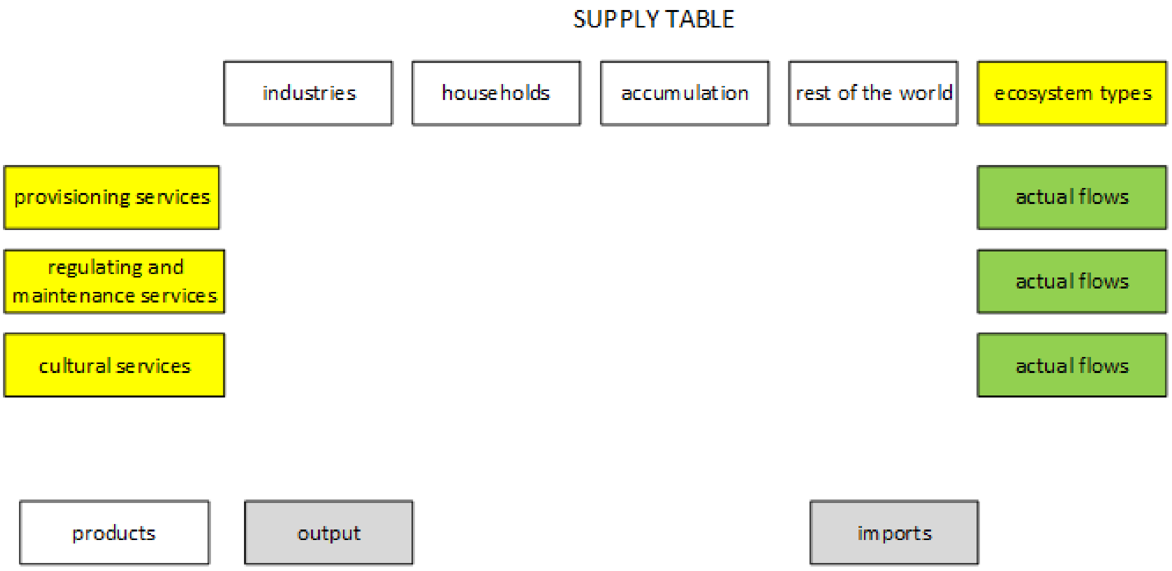
3.1.3 Supply and use tables in the SEEA EEA

In the SEEA EEA supply and use tables are used to describe the flow of ecosystem services. These tables relate to a given ecosystem territory and are structured by type of ecosystem service. The accounts are compiled first in physical and then in monetary terms.

SEEA EEA only records the actual flows of ecosystem services supplied by ecosystem types and used by economic units during an accounting period: ecosystem services are considered to reflect transactions or exchanges that take place between ecosystem assets on the one hand and economic units, including businesses and households on the other. In accounting terms, supply must equal use, the unit of measurement applied for each ecosystem service must be the same in both the supply and use table to obtain a balance.

The supply table (Figure 3.3) shows that economic units cannot supply ecosystem services (no data recordable) and only ecosystems can generate ecosystem services, which are grouped according to the three CICES groups (provisioning, regulating and maintenance, cultural). The structure of the ecosystem services supply and use table incorporates flows of products in order to support the joint presentation of data on: (i) ecosystem services used by economic units; and (ii) the products (i.e. SNA benefits) to which those ecosystem services contribute. The scope of products is all goods and services produced in an economy but in practice, a focus will be on products to which those ecosystem services contribute. Of course, ecosystems cannot directly supply products (economic processing is necessary).

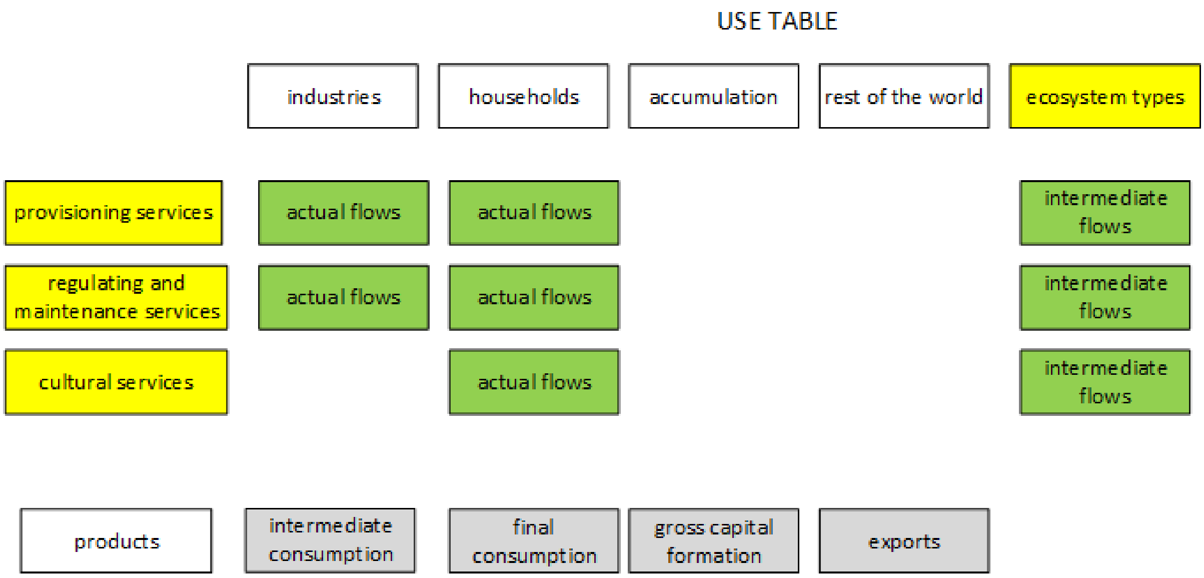
[8] The law of the conservation of mass and energy states that the mass and energy of a closed system will remain constant.



Grey cells: SNA core accounts
Green cells: SEEA EEA satellite accounts
Yellow cells: additional information added by SEEA EEA

Figure 3.3 – Supply table in the SEEA EEA (graphical simplification)

The use table (Figure 3.4) records the use of ecosystem services by types of economic units as: (i) input to further production; or (ii) final consumption. The SEEA EEA Technical Recommendations (TR) recognises the possibility of recording the use of ecosystem services by other ecosystem types, i.e. intermediate ecosystem services. The 'product' section shows the use of products by different economic units. No data are recorded from products to ecosystem units because ecosystem types cannot use products.



Grey cells: SNA core accounts
Green cells: SEEA EEA satellite accounts
Yellow cells: additional information added by SEEA EEA

Figure 3.4 – Use Table in the SEEA EEA (graphical simplification)

The main purpose of supply and use tables for ecosystem services is to show where the actual flow of the service originates (ecosystem types) and who is using it (institutional units). Starting from the biophysical assessment, we can proceed with the economic valuation of these flows, which allows a direct comparison with SNA accounts and thus a conjoint ecological-economic analysis.

It is important to properly structure economic units and ecosystem types to allow all relevant information to be included. We here report our proposal.

The source of economic units is NACE rev.2: sections concerning the primary sector have been expanded, section concerning the secondary sector have been left as reported in the SEEA EEA TR and most of the sections concerning the tertiary have been folded (Figure 3.5). Three exceptions are made: 'Water supply' of which 'Water collection, treatment and supply' are extrapolated because of the water purification service; 'Professional activities' of which 'Research and experimental development on natural sciences and engineering' are extrapolated because of the 'genetic material' (provisioning) and 'information' (cultural) services; and 'Education' for the 'opportunities of reduction and training' service.

In the case of ecosystem types (Figure 3.6), the source is the MAES classification at the higher hierarchical level, combined with CORINE classification at the lower hierarchical level (ref. to the Look-up table in Annex V for more details). There are in fact groups such as 'Cropland' and "Sparsely vegetated land' that need to be further specified for a few ecosystem services. Moreover, for urban we need to extrapolate 'Green urban areas' for the air filtration service; and we need to separate natural grassland from pasture for the animal husbandry service.

agriculture							forestry				fishing										water supply		professional activities						
Growing of non-perennial crops	Growing of perennial crops	Plant propagation	Animal production	Mixed farming	Support activities to agriculture and post-harvest crop activities	Hunting, trapping and related service activities	Silviculture and other forestry activities	Logging	Gathering of wild growing non-wood products	Support services to forestry	Marine fishing	Freshwater fishing	Marine aquaculture	Freshwater aquaculture	mining and quarrying	manufacturing	construction	trasportation and storage	accomodation and food service activities	electricity, gas supply	Water collection, treatment and supply	other water supply activities	Research and experimental development on natural sciences and engineering	Other professional scientific and technical activities	education	other industries	households	accumulation	rest of the world

Figure 3.5 – Table format proposal for the Economic Units

	Urban		Cropland										grassland				sparsely vegetated land									
	Green urban areas	other artificial surface	non-irrigated arable land	permanently irrigated land	rice fields	vineyards	fruit trees and berry plantation	olive groves	annual crops associated with permenenet crops	complex cultivation patterns	land occupied by agriculture and natural vegetation	agroforestry areas	natural grassland	pastures	heatland and shrub	woodland and forest	beaches, dunes, sands	bare rocks	sparsely vegetated areas	burnt areas	sparse natural vegetated areas	permanent snow and glaciers	wetlands	rivers and lakes	coastal water and inter-tidal areas	sea and marine areas

Figure 3.6 – Table format proposal for Ecosystem types

3.1.4 Monetary valuation for ecosystem service accounts

Accounting for ecosystem services includes both a biophysical assessment and a valuation that is typically in monetary terms. Our proposal to monetary valuation follows two general principles: a coupling between biophysical and monetary accounts and the use of exchange values.

Firstly, there is an effective coupling between the biophysical and monetary accounts. In particular, any change over time detected and recorded as result of the biophysical assessment of ecosystem services is followed by changes in the monetary value because biophysical values are translated in monetary terms (La Notte *et al.,* 2015). So (modelled or observed) ecological changes drive the valuation. In turn, valuation results in a common unit (i) among all ecosystem services and (ii) between ecosystem service accounts and SNA accounts.

Secondly, in order to match the methodological approach of SEEA EEA (UN *et al.*, 2014b) and draft SEEA EEA TR (UNEP *et al.*, 2015) the comparison between ecosystem service accounts and SNA accounts requires valuation techniques based on exchange values. On the one hand, exchange values represent the monetary value of the ecosystems to economic production and consumption; on the other hand, the welfare value concept considers the changes in consumer surplus, which represent the difference between consumers' full willingness to pay and the price they actually pay which is typically smaller. Welfare values in principle may provide an overestimation of the exchange value.

There is currently an ongoing debate on valuation issues: although the exchange value concept is relevant for national accounting purposes, the choice of the valuation technique is largely determined by the specific purpose and context of use. Wherever the purpose is to integrate the ecosystem service tables with SNA tables the choice for using the exchange value concept (Obst *et al.*, 2016) is justified. There might be situations where the exchange values cannot be imputed. It might be considered to use welfare values, where they can be assumed to approximate exchange values. This choice would need to be clearly noted and justified in the accounts construction. Moreover, there might be cases where the difference between welfare and exchange values is significant. It could be useful to attempt to report both values, however further work is required to find out how this could be achieved.

By referring to the schemes provided in UNEP et al. (2015), we identify a range of possible valuation techniques consistent with the exchange value principle. Also throughout the Fact Sheets published in this report we list a review of valuation studies which are appropriate for accounting. However, valuation studies and the valuation techniques here reported are not exhaustive. The information provided follows the two assumptions just described and does not capture all the possible valuation techniques that could be potentially applied nor does it consider social or non-monetary valuation methods. In a broader framing, one can also consider other types of valuation where the use of welfare values or non-monetary estimates is more appropriate, and investigate what form of broader framework of accounting is most appropriate for decision making. A range of these aspects will be experimented with and tested further in the context of KIP INCA work – in particular to ensure that accounting will support decision making relating to biodiversity, ecosystems in ways appropriate to supporting sustainable development

3.2 Toward a refinement of the SEEA EEA supply and use tables

SEEA EEA supply and use tables are for KIP INCA the starting point for developing pilot applications. They provides us with the base structure to start a comprehensive and consistent accounting for ecosystem services. However, a few issues identified in the SEEA EEA need to be resolved.

First, to consider the actual flow of ecosystem services is unlikely to be sufficient to analyse the issue of sustainability because the use of some ecosystem services may be higher than their natural regeneration rate, or be beyond their sustainability threshold. When ecosystem services are overused, degradation occurs. It is important to measure and account for degradation. To report what is actually used can also be misleading especially for sink-related services, since a higher actual use implies a higher impact (in this case a higher flow implies more pollution). Linked with the notion of sustainability is the notion of 'capacity', the implications of which are currently under debate (UN. et al. 2014b, UNEP et al. 2015). Seen as the ability to generate the ecosystem service, capacity is intended as highlighting the critical ecological functioning needed to sustain the yearly flows of each service. As currently proposed, it should be the Net Present Value of the actual flow. The appropriateness of calculating capacity as NPV of actual flow needs to be addressed for all the reasons mentioned above.

Second, the complementarity with the SEEA CF may be reinforced. SEEA EEA contains similarities and modifications in relation to the SEEA CF. The main similarity is the use of the common base structure of the account (the physical supply and use tables of the SEEA CF). The first difference is that there is more than one column representing the environment in the form of multiple columns each representing an ecosystem type. The second difference is that the SEEA CF contains three types of flows (i.e. natural inputs, products and residuals) whereas the SEEA EEA focuses on two types of flows (i.e. ecosystem services and products).

A further development of the framework would be beneficial to establish a direct complementarity between the SEEA EEA and the SEEA CF in order to avoid:

(i) the risk of overlapping provisioning services and natural inputs: although the ecosystem services use table is structured to provide the first hint to link with the national accounts datasets by including 'products', still a major ambiguity generates from mixing services with benefits; and

(ii) the role of residual flows: although it is acknowledged that ecosystems play a regulating and filtering role in reducing the impact of residual flows on humans, there is no clear indication on how to combine the physical flows from economic units into the environment (i.e. pollutant emissions) with the flow of regulating services (sink-related services) from ecosystems to economic units.

Third, the definition of SNA and non-SNA benefits should be further explored. As a consequence of the previous comment, the notion of benefit should be integrated as much as possible with the definition of goods and services provided by the SNA and the SEEA CF.

Fourthly, separating services from benefits requires distinguishing between enabling actors and beneficiaries. This is especially true for sink-related services, such as air filtration, water purification and carbon sequestration. A crucial role for these services is played by enabling actors: those services exist because there are economic sectors and/or households that pollute. The service of 'cleaning' generates benefits that will be used by different categories of beneficiaries. The allocation of the sink-related services to enabling actors or to beneficiaries needs further reflection and analysis. According to this specific allocation it would be possible (or not) to establish a causality nexus between those human activities that modify the service flow and the change that occurs in the service flow itself. In our view the causality nexus could be an important piece of information to be provided by a system which integrates economic and ecosystem service accounts.

In presenting the fact sheets for each ecosystem service (Chapter 4), we consider these issues and, based on a first pilot application (La Notte et al., 2017b) we made hypotheses on the most conceptually appropriate disaggregation that could support future applications.

In Annex IV we also present the *table of content* of what will likely be the standards report format for the ecosystem service applications: alongside the SEEA EEA accounts we report complementary accounts that might help addressing the aforementioned issues and add information for the policy makers.

4 Ecosystem service assessment in INCA

The focus of KIP INCA is the development of accounts of the ecosystem services included in Table 4.1. Biophysical accounts will be the basis for the monetary accounts once the appropriate valuation method has been chosen.

Table 4.1 – List of ecosystem services for the biophysical and monetary accounts

Section	CICES V 5.0 correspondence (classes)	Service (KIP INCA)	Is overuse possible?[1]
PROVISIONING	Cultivated plants (terrestrial) and their outputs	Arable cropping	Yes
	Wild animals and their outputs [aquatic]	Marine fish	Yes
	Reared animals (terrestrial) and their outputs	Outdoor animal husbandry	Yes
	Fibres and other materials from cultivated or wild plants for direct use or processing	Timber	Yes
	Surface and ground water for drinking and non-drinking purposes	Water	Yes
REGULATING AND MAINTENANCE	Pollination	Crop pollination	No
	Mass stabilization and control of erosion rates	Erosion control	No
	Regulation of the chemical condition of freshwaters by living processes	Water purification	Yes
	Filtration/sequestration/storage/accumulation by plants	Air purification	Yes
	Regulation of chemical composition of atmosphere	Global climate regulation[2]	No
	Hydrological cycle and water flow maintenance (Including flood control)	Flood control	No
CULTURAL	Physical and experiential interactions with natural environment	Outdoor recreation	Yes

[1]The overuse of the ecosystem service should be defined by a sustainability threshold, above which ecosystem degradation may take place

[2]For terrestrial ecosystem, since levels of acidity in the ocean as a consequence of CO_2 uptake generates ecosystem degradation

Each ecosystem service listed in Table 4.1. has been described in a fact sheet summarizing all the relevant information for the ecosystem service accounting. Although each ES presents its own characteristics, it is possible to distinguish two main groups of ES depending on whether the service can be overused or not. Overuse takes place when the use of the service exceeds what can be provided or used in a sustainable way. Above this sustainability threshold, ecosystem degradation takes place.

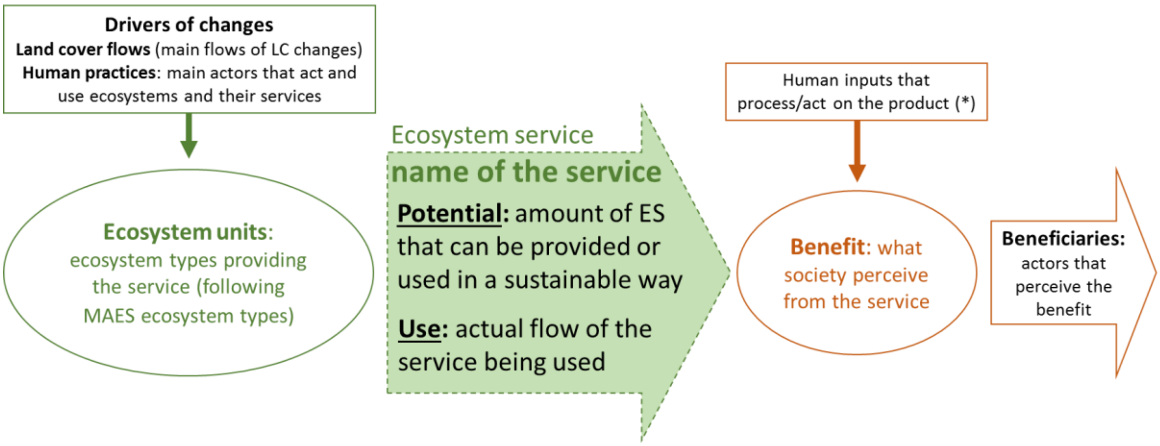
Fact sheets include:

- The **definition of the ecosystem service**, composed by an ecological clause (i.e. ecosystem-related) and a use clause (i.e. service-related) following the structure of CICES version 5.0 (still unpublished at the time of publication of this report). Although CICES has been used as the classification framework of ecosystem services, we have slightly modified the name of the service for operational purposes in KIP INCA, referring sometimes to services that are more specific. For instance, we focus on crop pollination instead of pollination in the broad sense. However, the CICES 5.0 class name on which it is based is provided as a cross reference in Table 4.1.

- Ecosystem service providing unit (i.e. **ecosystem type**) based on the MAES terrestrial ecosystem types (European Commission, 2013). The MAES ecosystem types were mapped based on the combination of land cover data and habitat-related information according to the European habitat classification (EUNIS) by integrating relevant environmental information such as elevation, soil and climate (EEA, 2015). However, given the lack of temporal updates of the ecosystem maps to assess trends over time we are using data on land cover types as proxies of the ecosystems. The ecosystem units will be integrated in the supply tables to quantify the amount of the service that is provided by each ecosystem type.

- **Economic units** that are relevant for **users of the service and beneficiaries**. In this report, we consider ecosystem services as the direct and indirect contributions of ecosystems to human wellbeing, following The Economics of Ecosystems and Biodiversity (TEEB, 2010). In the ecosystem services cascade model (Haines-Young *et al.*, 2012) ecosystem services are different from the benefits derived from ecosystem services. Arguably, users and beneficiaries are under some circumstances different actors. Consider outdoor recreation. Households are the users of this cultural ecosystem service, while the beneficiaries may include the tourism sector because they benefit from the higher number of people going to the outdoor recreational areas. In this example, the user of the services directly interact with the ecosystem affecting the actual flow: the more people go to the attraction areas the higher will be the actual flow. However, for sink-related ecosystem services such as air and water purification, the changes in the actual flow are not driven by the users, but by those actors enabling the service. The **enabling actors** are, in this case, understood as the economic activities contributing to the increase of pollutants in the environment, increasing thus also the actual ecosystem service flow. In absence of pollutants, the service would not be considered as a service any longer as there would no longer be a demand for it. The definition of enabling actor for this type of service allows stablishing the causality nexus (see section 3.2). The economic units (sectors) for users, enabling actors and beneficiaries are identified following the European statistical classification of economic activities (NACE classification).

- The **graphic representation** of the model for the measurement of ecosystem services is developed from the scheme proposed by the SEEA EEA on page 47 (UN, 2014). It shows the relationship between ecosystem units and the benefit they provide through the flow of the ecosystem services (Figure 4.1). On the ecosystem units, different drivers of changes may act (MA 2005). Among these drivers, land cover changes and human practices are the most relevant ones for the accounting framework (i.e. supply and use tables) (see also chapter 5 about the drivers of changes in ecosystem services). The most relevant land cover changes for each ecosystem service are defined according to the land cover flows described in EEA (2006). The human practices relate to all actors/economic activities that modify the ecosystem condition, thus changing the ecosystem potential to supply the service. However, for practical reasons, accounts for ecosystem extent, condition and services is usually developed in parallel according to the technical recommendations for the SEEA EEA framework. In this scheme (Figure 4.1), the most important part for ecosystem service accounts is the service flow (green arrow) that can be quantified as the ecosystem service potential and the actual use.



(*) Human inputs on the benefit are only considered for provisioning ecosystem services and crop pollination

Figure 4.1 – Measurement approach for the accounting of ecosystem service

- **Conceptual definition** of the indicators used to assess:
  - **Ecosystem services**:
    - **The potential** measures the amount of ES that can be provided or used in a sustainable way in a certain region given current land use and ecosystem properties and conditions (Burkhard & Maes, 2017): this will be defined by the ecological production function. Depending on the ES potential, a given annual flow of the service will be offered by the ecosystem (i.e. potential flow). However, for some ecosystem services, the use of the service above the maximum capacity (i.e. overuse) may yield ecosystem degradation, compromising, therefore, the potential to provide the service in the future. Thus, for those ecosystem services for which the overuse of the service may yield ecosystem degradation (Table 4.1), a sustainability threshold should be defined, above which ecosystem degradation may take place. For instance, the use of water purification above a threshold of 1 mg of Nitrogen per litre would results in ecosystem degradation (see La Notte *et al.* (2017) for further details.
    - **The use** is the actual flow of the service being used. The actual flow is detailed accounted for in the SEEA EEA: the actual flow delivered by the ecosystem units that is directly used by the economic units.
  - **Socio-economic system** benefiting from ES:
    - The **demand** in the fact sheets is generally defined as the demand for the service; directly modifying the actual flow. Thus, in the case of air purification, for instance, the level of pollutants will determine the actual flow of the service; in a given location the higher the level of pollutants, the higher will be the actual flow. However, for some ecosystem services (i.e. air purification) the demand for the benefit (i.e. clean air) is also defined in the fact sheets, because of its relevance for the society (i.e. positive effect on human health). In addition, there is still a debate as to how demand is interpreted. In some cases, demand can be understood as the use according to Wolff *et al.* (2015) and (Burkhard *et al.*, 2014). However, it can also be understood as the wishes, needs or desires of the users or beneficiaries of the service (Wolff *et al.*, 2015). In the fact sheets, we refer to demand as this last notion (wishes, needs or desires).

    - An **unmet demand** may take place when the demand refers to the wishes, needs or desires if the actual use of the service does not cover the needs of the users or beneficiaries.
    - Finally, the use of the service will result in a **benefit** for the society, which is also described for each service and will be part of the use table.
- The **valuation methods** section includes some examples of references selected according to the monetary valuation techniques suggested in the SEEA EEA (UNEP et al. 2015).
- **Indicators** to be used in INCA; in the case of water purification, crop pollination and recreation. For other ES a review of data available at EU level is provided including the units of measurement, spatial resolution, temporal coverage and tier level showing the level of complexity and/or the degree of development to reach the ideal indicator. All indicators are proxies of the service in the absence of a direct measure.
- Review of other methods and tools to map the ES but data are not available or models have been applied for a different extent of the EU.
- Final comments and conclusions.

4.1 Ecosystem services fact sheets

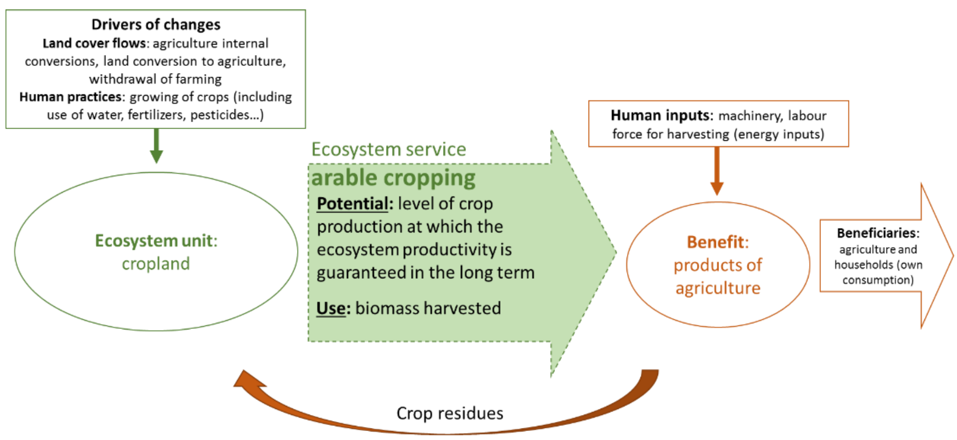
In the fact sheets presented in this section, ecosystem services are described one by one. Each ecosystem service is delivered by one or more ecosystem types, and each ecosystem type delivers a different subset of ecosystem services (Table 4.2). As mentioned before, for an operational purpose in KIP INCA, some services are more specific than the broad definition given in CICES V 5.0. Therefore, this matrix (Table 4.2) is illustrating the most relevant ecosystem types for each service following the specific definition of the service given in the fact sheets. This means that, for instance, for water purification, forest may also play a key role but, according to the definition given in the fact sheet, only freshwater ecosystems are included. For a more comprehensive assessment of the services delivered by the different ecosystem types, other studies can be consulted (Burkhard et al. 2014).

Table 4.2 – Matrix of ecosystem types and services of KIP INCA

ECOSYSTEM SERVICES	ECOSYSTEM TYPES								
	Urban	Cropland	Grassland	Heathland and shrub	Woodland and forest	Sparsely vegetated land	Wetland	Rivers and lakes	Marine
Arable cropping		x							
Marine fish									x
Outdoor animal husbandry			x						
Timber					x				
Water								x	
Crop pollination		x	x	x	x	x	x		
Erosion control	x*	x	x	x	x		x		
Water purification								x	
Air purification**	x*		x	x	x				
Global climate regulation		x	x	x	x		x	x	x
Flood control		x	x	x	x	x	x		
Outdoor recreation	x*	x	x	x	x	x	x	x	x
TOTAL	**3**	**6**	**7**	**6**	**7**	**5**	**5**	**4**	**3**

*Green urban areas
**Only assessed for functional urban areas

4.1.1 Provisioning ecosystem services

ARABLE CROPPING		
Definition	The contribution of ecosystems to the growth of cultivated crops that can be harvested and used for food, fodder, fibre and energy (CICES V5)	
Ecosystem types	Cropland	
Economic unit	Users of the service	Crop production (perennial and non-perennial) and households (own consumption)
	Beneficiaries	Crop production (perennial and non-perennial)
SEEA EEA ecosystem accounting model		

CONCEPTUAL DEFINITION OF INDICATORS		
ECOSYSTEM SERVICE		
Potential	Capacity (stock)	Ecosystem potential to produce crops (tonne; tonne/ha)
	Potential flow	Level of crop production at which the ecosystem productivity is guaranteed in the long term. It implies that production practices (i.e. fertilizers, water) do not yield ecosystem degradation (tonne/ha/year)
Use	Actual flow of the biomass harvested (tonne/ha/year)	
SOCIO-ECONOMIC SYSTEM		
Demand	Expected or desired harvested production (tonne/ha/year)	
Unmet demand	When the actual flow is below the expected harvested production (tonne/ha/year)	
Benefit	Harvested crop production (tonne/ha/year)	

VALUATION METHODS

Resource rent:

- Remme et al (2015). Monetary accounting of ecosystem services: A test case for Limburg province, the Netherlands. Ecological Economics 112 (2015) 116–128.
- La Notte et al. (2011) Economic valuation of ecosystem services at local level for policy makers and planners. The case of the island of St. Erasmo in the Lagoon of Venice. Environmental Economics, Volume 2, Issue 3, 87-103

Production function:

- UK National Ecosystem Assessment Follow-on (2014) The UK national ecosystem assessment. UNEP-WCMC, Cambridge.
- Fezzi, C, & Bateman, I. J. (2011). Structural agricultural land use modelling for spatial agro-environmental policy analysis. American Journal of Agricultural Economics, 93, 1168-1188
- UK National Ecosystem Assessment (2011) The UK national ecosystem assessment. UNEP-WCMC, Cambridge.

ARABLE CROPPING

Avoided costs:

- FAO (2015) Natural Capital Impacts in Agriculture. Supporting better business decision making. Report.
- Sandhu et al (2013) Experimental Assessment of Ecosystem Services in Agriculture. In Ecosystem Services in Agricultural and Urban Landscapes. Wiley and Sons.

Replacement costs:

- Nahuelhuel et al (2007) Valuing Ecosystem Services Of Chilean Temperate Rainforests. Environment, Development and Sustainability (2007) 9:481–499.

AVAILABLE INDICATORS (review)

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	• Soil biomass productivity maps of grasslands, pastures and croplands (Tóth *et al.*, 2013): score values from 0-10, year 2000, at 1x1 km spatial resolution (http://esdac.jrc.ec.europa.eu/content/soil-biomass-productivity-maps-grasslands-and-pasture-coplands-and-forest-areas-european)
	Potential flow	• Land productivity dynamics in the EU from 1982 to 2010, at 5x5 km resolution, categorical map with 5 different classes, Tier III (Cherlet *et al.*, 2013). Useful to identify areas with changes in the productivity (http://publications.jrc.ec.europa.eu/repository/bitstream/JRC80540/lb-na-26500-en-n%20.pdf) To determine areas where there agricultural practices do not yield ecosystem degradation, different indicators could be considered: • Map of agricultural land use intensity, for 2000, at 1x1 km resolution, tier III (http://www.ivm.vu.nl/en/Organisation/departments/spatial-analysis-decision-support/ag-intensity/index.aspx) • Use of pesticides: FAO data, at country level from 1990 to 2010 (http://faostat3.fao.org/browse/E/EP/E)
Use	• Harvested crop production (tonne/ha/year) attributable to the ecosystem contribution: [apro] tables for different products http://ec.europa.eu/eurostat/data/database. Data at country level, from 2000 to 2016 Only a certain share of the reported crop production can be attributed to the ecosystem. Human inputs should be considered when calculating the share. Proxies to consider human inputs: • average yearly inputs expenditures: for two time periods 1995-1997 and 2005-2007 at NUTS2 level: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Average_yearly_inputs_expenditures_(EURha),_2005-2007,_EU-27_and_change_between_the_average_yearly_(1995-1997)_and_(2005-2007)_inputs_expenditures_(%25),_EU-27.png • Use of pesticides: FAO data, at MS level from 1990 to 2010 (http://faostat3.fao.org/browse/E/EP/E)	
SOCIO-ECONOMIC SYSTEM		
Demand	• The expected harvested production can be estimated based in the maximum yield of a long term period: [apro] tables for different products in http://ec.europa.eu/eurostat/data/database or http://www.fao.org/faostat/en/#data/QC (tonne/ha). See also http://ec.europa.eu/eurostat/statistics-explained/index.php/Agricultural_production_-_crops for more information	

ARABLE CROPPING

	• Vegetation productivity index (VPI) and vegetation condition index (VCI): (http://land.copernicus.eu/global/products/vpi , http://land.copernicus.eu/global/products/vci respectively). VPI is a percentile ranking of the current NDVI value against its historical range of variability (in %). It indicates if the current observation corresponds with the historical minimum (worst vegetation state), median (normal) or maximum (best situation) ever observed. CVI compares the current NDVI to the range of values observed in the same period in previous years. The VCI is expressed in % and gives an idea where the observed value is situated between the extreme values (minimum and maximum) in the previous years. Data are available every 10 days between January 2013 until present, at 1 km x 1 km resolution
Unmet demand	• Similarly to the demand, using VPI and VCI, the unmet demand will take place when the values do not correspond to the maximum values.
Benefit	• Crop production: yield at country level in [apro] tables for different products http://ec.europa.eu/eurostat/data/database, or http://www.fao.org/faostat/en/#data/QC

OTHER METHODS AND TOOLS (review)

METHODS

- Assessment of energy flows in agricultural production to disentangle the contribution of the ecosystem contribution and human inputs (Pérez-Soba M., 2015)
- Land use intensity on cropland (based on NDVI from 2000 to 2012) (Stephan *et al.*, 2016) http://iopscience.iop.org/article/10.1088/1748-9326/11/2/024015
- Assessment of crop areas, yield and net primary production at Global level for the year 2000 at 10x10 km resolution (Monfreda *et al.*, 2008)
- Study assessing time series for 1990–2000, 2000–2006, and 2000–2030; reporting units: the NUTS-X regions, bioclimatic regions and the dominant landscape types, based on Net Primary Production (Haines-Young *et al.*, 2012)
- Study revealing turning points in ecosystem functioning over the Northern Eurasian agricultural frontier by using a method to highlight hotspots of potentially altered ecosystems and allowing for disentangling human from climatic disturbances between 1982 and 2011 (Horion *et al.*, 2016)
- The Netherlands Environmental Assessment Agency (PBL) has developed a model based on crop yields from Monfreda *et al.* (2008) for different crop types and farming intensity for Europe (i.e. land use intensity model of Temme and Verburg (2011)), but only 2000 is assessed
- Human appropriation of net primary production has been used as a proxy of food provisioning (i.e. use/actual flow) (Cerqueira *et al.*, 2015)

TOOLS

- Land Utilisation & Capability Indicator (LUCI) (http://www.lucitools.org/) models agricultural production based on slope fertility, drainage and aspect

POTENTIAL CONTRIBUTION

Comments:

To date, there is no commonly agreed methodology to map and assess agricultural biomass production as ecosystem service. A commonly used indicator is yield expressed in different units of measure (tonne/ha; MJ/ha; DM/ha). Such indicator, though, does not take into consideration the fact that agricultural biomass production would not be supplied by ecosystems without substantial human intervention which greatly relies on fossil fuel energy (Pérez-Soba M., 2015). Therefore, for arable cropping assessment, human inputs would need to be considered. A relatively simple approach would be to estimate the share of the crop production attributable to the ecosystem based on literature review. In this sense, studies based on the assessment of energy flows (Pérez-Soba M., 2015) may constitute a key reference for this approach.

References:

Cerqueira, Y., Navarro, L.M., Maes, J., Marta-Pedroso, C., Pradinho Honrado, J. & Pereira, H.M. (2015) Ecosystem Services: The Opportunities of Rewilding in Europe. In H.M. Pereira and L.M. Navarro

ARABLE CROPPING

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Horion, S., Prishchepov, A.V., Verbesselt, J., de Beurs, K., Tagesson, T. & Fensholt, R. (2016) Revealing turning points in ecosystem functioning over the Northern Eurasian agricultural frontier. *Global Change Biology*, 22, 2801-2817. doi - 10.1111/gcb.13267

Monfreda, C., Ramankutty, N. & Foley, J.A. (2008) Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles*, 22, n/a-n/a. doi - 10.1029/2007gb002947

Pérez-Soba M., E.B., Kempen M., Braat L., Staristky I., Wijngaart R. van der , Kaphengst T., Andersen E., Germer L., Smith L., Rega C., Paracchini M.L. (2015) *Agricultural biomass as provisioning ecosystem service: quantification of energy flows* (EUR27538 EN). Retrieved from - http://publications.jrc.ec.europa.eu/repository/bitstream/JRC97764/lb-na-27538-en-n.pdf

Stephan, E., Tobias, K., Christian, L., Matthias, B. & Patrick, H. (2016) Mapping cropland-use intensity across Europe using MODIS NDVI time series. *Environmental Research Letters*, 11, 024015. doi -

Temme, A.J.A.M. & Verburg, P.H. (2011) Mapping and modelling of changes in agricultural intensity in Europe. *Agriculture, Ecosystems & Environment*, 140, 46-56. doi - http://dx.doi.org/10.1016/j.agee.2010.11.010

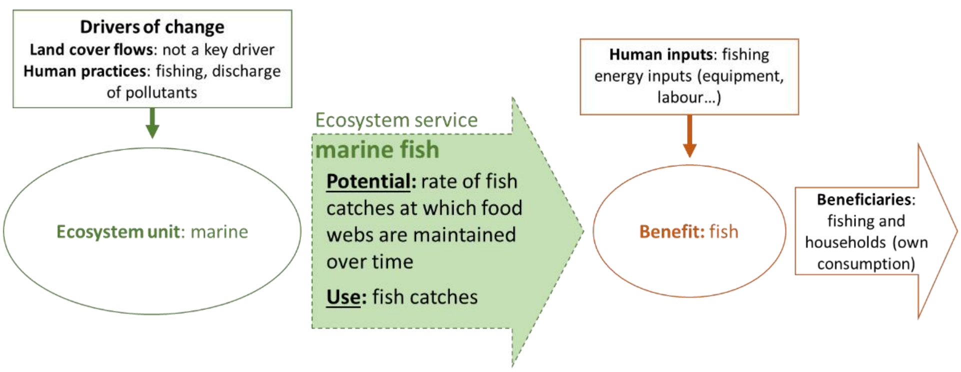
Tóth, G., Gardi, C., Bódis, K., Ivits, É., Aksoy, E., Jones, A., Jeffrey, S., Petursdottir, T. & Montanarella, L. (2013) Continental-scale assessment of provisioning soil functions in Europe. *Ecological Processes*, 2, 32. doi - 10.1186/2192-1709-2-32

*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

MARINE FISH

Definition	Non-domesticated, wild fishes that can be harvested and used as raw material for food (modified from CICES V.5)	
Ecosystem types	Marine	
Economic unit	Users of the service	Fishing and households (own consumption)
	Beneficiaries	Fishing

SEEA EEA ecosystem accounting model



CONCEPTUAL DEFINITION OF INDICATORS

ECOSYSTEM SERVICE

MARINE FISH		
Potential	Capacity (stock)	Ecosystem potential to produce fish biomass (tonne)
	Potential flow	Rate of fish catches at which food webs are maintained over time to guarantee the ecological integrity of marine ecosystems (tonne/ha per year)
Use	Actual flow of catches by fishing area (tonne/ha per year)	
SOCIO-ECONOMIC SYSTEM		
Demand	Expected fish caught (tonne/ha per year)	
Unmet demand	Difference between the expected fish caught and the actual flow of catches; usually limited by the fishing quotas	
Benefit	Caught fish	

VALUATION METHODS

Resource rent:

- Anna (2017) Indonesian shrimp resource accounting for sustainable stock management, Biodiversitas 18 (1): 248-256
- Obst (2010) Issue #12: Valuation of Assets: A case study on the valuation of fish stocks, Prepared for the London Group of Experts on Environmental Accounting

INDICATORS TO BE USED IN INCA

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	• Based on the stock database from the Data collection from International Council for the Exploration of the Seas (ICES): covering most European marine regions, annual data between 2006-2013 (http://www.ices.dk/marine-data/tools/Pages/stock-assessment-graphs.aspx) to calculate surplus production as the catches plus the changes in fish biomass)
	Potential flow	• In the accounting called sustainable intensity of biomass use: estimated as the surplus production divided by the total use of marine fish biomass. When the ratio is below 1 indicate unsustainable use of fish biomass
Use	• Data collection from International Council for the Exploration of the Seas (ICES): covering most European marine regions, annual data between 2006-2013 (http://www.ices.dk/marine-data/tools/Pages/stock-assessment-graphs.aspx)	
SOCIO-ECONOMIC SYSTEM		
Demand	• Estimated as the largest fish caught during the last years. When previous years are not available, the largest fish caught for the time period with available data can be taken	
Unmet demand	• Difference between the actual flow, usually limited by the fishing quotas, and the expected fish caught	
Benefit	• Actual flow of fish catches	

OTHER METHODS AND TOOLS (review)

- Fisheries/catches by fishing area at MS level. Annual data from 2000 to 2015 for different type of fishery products in tonnes live weight (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=fish_ca_main&lang=en; also available at http://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx)
- The sustainable intensity of use of the fish biomass will be found when the ratio between the increase in stocks (i.e. surplus production) and the fish catches is greater than one. Tier I approach (Piet *et al.*, 2017b; Piet *et al.*, 2017a)
- Study analysing the spatial expansion and ecological footprint of fisheries at global level between 1950 to 2005 (Swartz et al., 2010)
- Study quantifying, among other services, fish provisioning in the Mediterranean see based on the Ecopath with Ecosim model (EwE) (Liquete et al., 2016). EwE (http://ecopath.org/) is a free ecological/ecosystem

MARINE FISH

modelling software that allows addressing ecological questions and evaluate ecosystem effects of fishing among other multiple application
- Comparison of different models to mapping, among other services, fisheries production for St. Croix (USVI) in relation to the ecological integrity (Yee *et al.*, 2014)
- Study presenting ecologically based fishery production model for Gulf of Mexico blue crabs and penaeid shrimp (Jordan *et al.*, 2012)
- Multi-scale Integrated Model of Ecosystem Services (MIMES): modelling tool that simulating the interactions of coupled human and natural systems (Boumans *et al.*, 2015)

Comments:

The EEA has developed an Integrated Marine Fish Accounts (key deliverable Task 1.6.3.b).
Data on landing of fisheries products within the EU could be used to analyse the dependency of countries on the fish biomass in other countries. This would represent an added value of the EU assessment.
Ultimately, consideration of ecological food webs could be integrated in a refined fish biomass accounting for a proper sustainability assessment; however, this would require a thorough modelling exercise.

References:

Boumans, R., Roman, J., Altman, I. & Kaufman, L. (2015) The Multiscale Integrated Model of Ecosystem Services (MIMES): Simulating the interactions of coupled human and natural systems. *Ecosystem Services*, 12, 30-41. doi - http://dx.doi.org/10.1016/j.ecoser.2015.01.004

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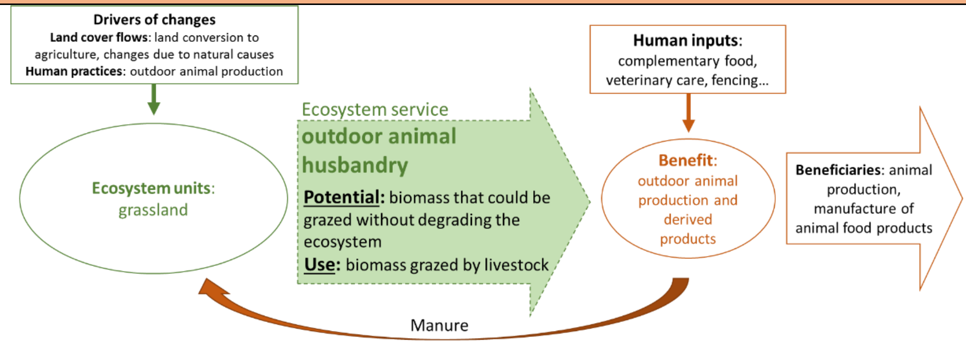
*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

OUTDOOR ANIMAL HUSBANDRY

Definition	The ecological contribution to the rearing of domesticated land-based animals and their outputs that can be used as raw material for the production of food (modified from CICES V5)	
Ecosystem types	Grassland (forage)	
Economic units	Users of the service	Animal production/raising of animals
	Beneficiaries	Animal production/raising of animals, manufacture of food products and textiles (wool)
SEEA EEA ecosystem accounting model		

OUTDOOR ANIMAL HUSBANDRY



CONCEPTUAL DEFINITION OF INDICATORS

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	Grassland potential to produce forage/biomass (tonne/ha)
	Potential flow	Amount of biomass that could be grazed without degrading the ecosystem (i.e. below its carrying capacity) (tonne/ha/year)
Use	Actual flow of biomass grazed (tonne/ha/year) by grazing livestock	

SOCIO-ECONOMIC SYSTEM	
Demand	FOR THE SERVICE: expected outdoor biomass production (tonne/ha/year) FOR THE BENEFIT: expected outdoor animal production and derived products (meet, milk, wool…) (tonne/year)
Unmet demand	FOR THE SERVICE: when the actual flow is below the expected biomass production FOR THE BENEFIT: when the outdoor animal production is below the expected production
Benefit	Outdoor animal production and derived products (meet, milk, wool, …)

VALUATION METHODS

Direct market pricing:

- La Notte et al. (2015) Livestock and Ecosystem Services: An Exploratory Approach to Assess Agri-Environment-Climate Payments of RDP in Trentino. Land, 4, 688-710
- Stevenson (2011) Reviewing the costs: The economics of moving to higher welfare farming. Compassion in world farming. Report.

AVAILABLE INDICATORS (review)

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	• Soil biomass productivity maps of grasslands, pastures and croplands (Tóth *et al.*, 2013): score values from 0-10, year 2000, at 1x1 km spatial resolution, tier III (http://esdac.jrc.ec.europa.eu/content/soil-biomass-productivity-maps-grasslands-and-pasture-coplands-and-forest-areas-european) • Net Primary Production (NPP) for grasslands (from 2000 to 2010, kg C/m^2, 1x1 km, Tier III): https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod17a3 • Soil biomass productivity of grasslands in the EU, 2006, 1x1 km: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Soil_biomass_productivity_of_grasslands_in_the_EU_(expressed_in_relative_terms_with_indices_without_measurement_units),_2006,_EU-27.png • Grassland productivity at NUTS2 level, in decitons per hectare (dt ha^{-1}), the 10-year average from 1995 to 2004 were used to calculate regional productivity (Smit *et al.*,

OUTDOOR ANIMAL HUSBANDRY

		2008)
	Potential flow	• Calculated as the annual variation in the NPP • It can be defined by the carrying capacity (calculates as the forage supply minus the costs, and divided by the herbivore requirements). It is usually expressed in units of energy. Costs are here considered as the portion of herbaceous production that is unavailable (see García-González (2008) for further details on the carrying capacity)
Use	No comprehensive official statistics reports the amount of grazed biomass in the European Union (Ronzon *et al.*, 2015). The estimation can be based on the supply-side approach or a demand-side approach based on the requirement of the existing grazing livestock: SUPPLY-SIDE: • Not currently available DEMAND-SIDE: • Grazed biomass: a product by FAO on downscaled stocks of grazing animals for year 2000, at 1x1 km resolution (tier II) (map not available). Source: https://unstats.un.org/unsd/envaccounting/seeaLES/egm/Issue4_Ivanov.pdf Other relevant information: broad definition of extensive/intensive grasslands can potentially be used to distinguish areas with different types of use: http://www.ivm.vu.nl/en/Organisation/departments/spatial-analysis-decision-support/ag-intensity/index.aspx#accept	
SOCIO-ECONOMIC SYSTEM		
Demand	FOR THE SERVICE: expected biomass production (tonne/ha/year) FOR THE BENEFIT: expected outdoor animal production (heads/year) To be completed/reviewed	
Unmet demand	FOR THE SERVICE: when the actual flow is below the expected biomass production FOR THE BENEFIT: when the outdoor animal production is below the expected production To be completed/reviewed	
Benefit	• Grazing livestock densities 2005-2010: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Livestock_pattern_%E2%80%93_total_and_grazing_livestock_densities,_EU-28,_IS,_NO,_CH_and_ME,_2005-2010.png • To be completed/reviewed	

OTHER METHODS AND TOOLS (review)

METHODS

- Study at global level assessing synergies and trade-offs between grazing and other ecosystem services. They also calculated grazing intensity and net primary production that could be potential used in INCA, however, the scale is too coarse to be used at European level only. In fact, only the south of Europe is represented (Petz *et al.*, 2014)
- Study mapping livestock production on natural grasslands by combining global data on livestock distributions, producer prices, and current and potential vegetation (Naidoo *et al.*, 2008)
- Long term assessment of the potential grassland productivity and in grass-fed ruminant livestock density in Europe over 1961–2010 (Chang *et al.*, 2015). However, in their assessment they include grassland productivity for grazing and non-grazing animals

TOOLS

- DataM: quantify biomass availability (Ronzon *et al.*, 2015)

Conclusions:

Outdoor animal husbandry focusses only on the contribution of grasslands; animal production based on fodder (harvested crop) is not included. Fodder production is usually contemplated within arable crops, as it requires

OUTDOOR ANIMAL HUSBANDRY

substantial energy inputs whereas the ecosystem contribution is relatively small.
Given the lack of available indicators to be applied in INCA, the methods described in (Petz *et al.*, 2014) could be potentially applied to model this service at European level, provided that required data are available.

References:

Chang, J., Viovy, N., Vuichard, N., Ciais, P., Campioli, M., Klumpp, K., Martin, R., Leip, A. & Soussana, J.-F. (2015) Modeled Changes in Potential Grassland Productivity and in Grass-Fed Ruminant Livestock Density in Europe over 1961–2010. *PLoS One*, 10, e0127554. doi - 10.1371/journal.pone.0127554

García-González, R. (2008) *Management of Natura 2000 habitats. 6170 Alpine and subalpine calcareous grasslands.* . European Commission Retrieved from - http://ec.europa.eu/environment/nature/natura2000/management/habitats/pdf/6170_Alpine_calcareous_grasslands.pdf

Naidoo, R., Balmford, A., Costanza, R., Fisher, B., Green, R.E., Lehner, B., Malcolm, T.R. & Ricketts, T.H. (2008) Global mapping of ecosystem services and conservation priorities. *Proceedings of the National Academy of Sciences of the United States of America*, 105, 9495-9500. doi - 10.1073/pnas.0707823105

Petz, K., Alkemade, R., Bakkenes, M., Schulp, C.J.E., van der Velde, M. & Leemans, R. (2014) Mapping and modelling trade-offs and synergies between grazing intensity and ecosystem services in rangelands using global-scale datasets and models. *Global Environmental Change*, 29, 223-234. doi - http://dx.doi.org/10.1016/j.gloenvcha.2014.08.007

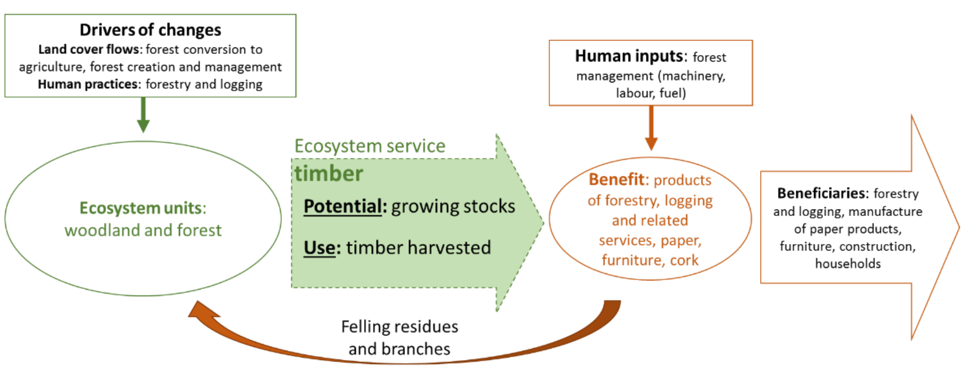
Ronzon, T., Piotrowski, S. & Carus, M. (2015) *DataM – Biomass estimates (v3): a new database to quantify biomass availability in the European Union. EUR 27291 EN.* (JRC Technical Report). Retrieved from - http://publications.jrc.ec.europa.eu/repository/bitstream/JRC96246/datam-be_tkreport.pdf

Smit, H.J., Metzger, M.J. & Ewert, F. (2008) Spatial distribution of grassland productivity and land use in Europe. *Agricultural Systems*, 98, 208-219. doi - http://dx.doi.org/10.1016/j.agsy.2008.07.004

Tóth, G., Gardi, C., Bódis, K., Ivits, É., Aksoy, E., Jones, A., Jeffrey, S., Petursdottir, T. & Montanarella, L. (2013) Continental-scale assessment of provisioning soil functions in Europe. *Ecological Processes*, 2, 32. doi - 10.1186/2192-1709-2-32

*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

TIMBER

Definition	The ecological contribution of the ecosystem to the production of timber that can be harvested and used as raw material	
Ecosystem types	Woodland and forests	
Economic unit	Users of the service	Forestry, logging and households (own consumption)
	Beneficiaries	Forestry and logging, support services to forestry, manufacture of paper and paper products, manufacture of wood and of products of wood, manufacture of furniture, households (firewood)
SEEA EEA ecosystem accounting model		

TIMBER

CONCEPTUAL DEFINITION OF INDICATORS			
ECOSYSTEM SERVICE			
Potential	Capacity (stock)	Ecosystem potential to produce timber (m^3, tonne, tonne/ha)	
	Potential flow	Flow of timber provisioning at which the ecosystem productivity is guaranteed in the long term (m^3/ha/year, tonne/ha/year)	
Use	Actual flow of timber harvested (m^3/year, m^3/ha/year)		
SOCIO-ECONOMIC SYSTEM			
Demand	Desired level of forest logging corresponding to the maximum sustainable yield (tonne/ha/year)		
Unmet demand	When the actual flow is below the desired level of forest logging (m^3/year, m^3/ha/year)		
Benefit	Products of forestry, logging and related services, furniture, paper, wood		

VALUATION METHODS

Resource rent:

- Busch et al. (2012) Potentials of quantitative and qualitative approaches to assessing ecosystem services. Ecological Indicators, 21, 89-103

Adjusted market price:

- Nahuelhuel et al (2007) Valuing Ecosystem Services Of Chilean Temperate Rainforests. Environment, Development and Sustainability (2007) 9:481–499

AVAILABLE INDICATORS (review)

ECOSYSTEM SERVICE			
Potential	Capacity (stock)	Country statistics	• Growing stocks on forest: m^3 in Table A1.7, m^3/ha in table A1.11, tier I (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=for_vol&lang=en, http://www.foresteurope.org/docs/SoEF/Output_Tables_extended-for-web.xls) • Wood volume of growing stocks in forests and on other wooded land, units are thousands of cubic meters, tier I (http://ec.europa.eu/eurostat/cache/metadata/en/tsdnr520_esmsip.htm#unit_measure1470217329996)
		Mapped ES	• Growing stock: ~ 2000, 1 x 1 km resolution, tier III (Päivinen *et al.*, 2009) • Land cover area-based downscale of Eurostat statistics, tier II (Maes *et al.*, 2015). More refined downscale could be done by integrating climate data, topography and other biophysical factors
	Potential flow	Country statistics	• Forest utilisation rate per country (annual felling as a percentage of annual increment): Growing stock decreases if the ratio of felling to increment is over 100% (http://www.eea.europa.eu/data-and-maps/indicators/forest-growing-stock-increment-and-fellings/forest-growing-stock-increment-and-4)
		Mapped ES	• Pan-European map of above ground woody forest biomass increment:

TIMBER			
			calculated as the yearly increase of the biomass stored in forests in their woody above-ground tissues, estimates for the period 2000-2010, at 1 x 1 km resolution, measured in tonne of dry matter per hectare an year, tier III (Busetto *et al.*, 2014) • Wood production: based on the disaggregation of wood production statistics by using productivity, tree species and ruggedness, for the period between ~ 2000-2010, at 1 x 1 km resolution, measured in m^3 ha^{-1} land yr^{-1} (Verkerk *et al.*, 2015)
Use	Country statistics	• Annual felling for 1990, 2000, 2005 and 2010 at MS. Table A3.1 in http://www.foresteurope.org/docs/SoEF/Output_Tables_extended-for-web.xls	
	Mapped ES	• Land cover area-based downscale of Eurostat statistics on timber removal (Maes *et al.*, 2015) • Wood harvest biomass: http://luh.umd.edu/data.shtml (transitions data, units: kg C, year 850-2100, resolution 0.25 x 0.25 degree (~28 x 28 km)	
SOCIO-ECONOMIC SYSTEM			
Demand	• Expected timber logging can be estimated based in the maximum sustainable logging during of a long term period (based on the use statistics)		
Unmet demand	• Differences between the actual use and the potential flow		
Benefit	• SNA products related to forestry, logging and related services		
DRIVERS OF CHANGES IN THE MODELLING FRAMEWORK			
INCLUDED IN THE MODELS: land use changes (related to forest extent) and management (in EFDM)			

OTHER METHODS AND TOOLS (review)

METHODS

- Regional approach using forestry exploitation surface logging area as main proxies (García-Nieto *et al.*, 2013)

TOOLS/MODELS

- European Forestry Dynamics Model (EFDM) for even-aged forests is freely available to be run for other users (https://ec.europa.eu/jrc/en/european-forestry-dynamics-model). For further information: https://forestwiki.jrc.ec.europa.eu/efdm/index.php/Main_Page
- European Forest Information SCENario (EFISCEN) is a large-scale forest model that projects forest resource development on regional to European scale. The model is suitable for the projection of forest resource development for a period of 50 to 60 years (http://www.efi.int/portal/virtual_library/databases/efiscen)
- Global Forest Model (G4M) to study complex problems of integrated land and ecosystems management with an emphasis on forests and their sustainable management (http://www.iiasa.ac.at/web/home/research/modelsData/G4M.en.html)
- FORCLIM model of forest dynamics (Busing *et al.*, 2007)

Conclusions:

Given the large data availability for timber provisioning, comparison of two different approaches could be made: one based on the Eurostat statistics and the other on model-based data. However, the model-based assessment could potentially be developed in collaboration with the JRC unit responsible for the EFDM model. This would allow assessing an important source of uncertainty in ecosystem services accounting.

References:

Busetto, L., Barredo, J.I. & San-Miguel-Ayanz, J. (2014) Developing a spatially-explicit pan-European dataset of

TIMBER

forest biomass increment. *22nd European Biomass Conference and Exhibition* Hamburg, 23-26 June. Retrieved from - http://www.etaflorence.it/proceedings/?detail=9867

Busing, R.T., Solomon, A.M., McKane, R.B. & Burdick, C.A. (2007) FOREST DYNAMICS IN OREGON LANDSCAPES: EVALUATION AND APPLICATION OF AN INDIVIDUAL-BASED MODEL. *Ecological Applications*, 17, 1967-1981. doi - 10.1890/06-1838.1

García-Nieto, A.P., García-Llorente, M., Iniesta-Arandia, I. & Martín-López, B. (2013) Mapping forest ecosystem services: From providing units to beneficiaries. *Ecosystem Services*, 4, 126-138. doi - http://dx.doi.org/10.1016/j.ecoser.2013.03.003

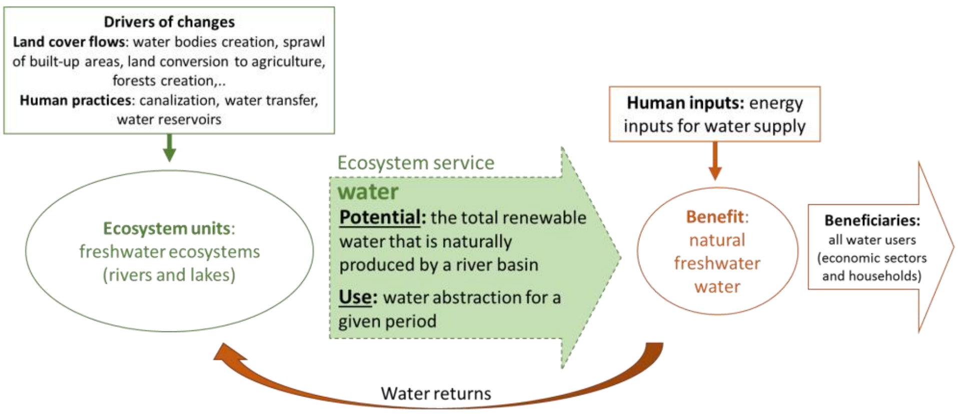
Maes, J., Fabrega, N., Zulian, G., Barbosa, A., Vizcaino, P., Ivits, E., Polce, C., Vandecasteele, I., Marí-Rivero, I., Guerra, C., Perpiña-Castillo, C., Vallecillo, S., Baranzelli, C., Barranco, R., Silva, F.B.e., Jacobs-Crisoni, C., Trombetti, M. & Lavalle, C. (2015) *Mapping and Assessment of Ecosystems and their Services: trends in ecosystems and ecosystem services in the European Union between 2000 and 2010. JRC Science and Policy Report. EUR 27143 EN.* European Commission. Retrieved from - http://publications.jrc.ec.europa.eu/repository/bitstream/JRC94889/lbna27143enn.pdf

Päivinen, R., Van Brusselen, J. & Schuck, A. (2009) The growing stock of European forests using remote sensing and forest inventory data. *Forestry: An International Journal of Forest Research*, 82, 479-490. doi - 10.1093/forestry/cpp017

Verkerk, P.J., Levers, C., Kuemmerle, T., Lindner, M., Valbuena, R., Verburg, P.H. & Zudin, S. (2015) Mapping wood production in European forests. *Forest Ecology and Management*, 357, 228-238. doi - http://dx.doi.org/10.1016/j.foreco.2015.08.007

*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

WATER PROVISIONING

Definition	Natural, surface and ground water bodies that provide drinking and non-drinking water (modifies from CICES V5)	
Ecosystem types	Freshwater ecosystems: rivers and lakes	
Economic unit	Users of the service	All water users: economic sectors and households
	Beneficiaries	All water users: economic sectors and households
SEEA EEA ecosystem accounting model		

CONCEPTUAL DEFINITION OF INDICATORS

ECOSYSTEM SERVICE

Potential	Capacity (stock)	The total renewable water that is naturally produced by a river basin (millions m^3, hm^3)
	Potential flow	Flow of renewable water, including stream flow plus net groundwater recharge, that is annually and naturally produced by a river basin (m^3/year)

<table>
<tr><th colspan="3">WATER PROVISIONING</th></tr>
<tr><td>Use</td><td colspan="2">Actual flow of water abstraction for a given period (m^3/year, m^3/per capita/year)</td></tr>
<tr><td colspan="3">SOCIO-ECONOMIC SYSTEM</td></tr>
<tr><td>Demand</td><td colspan="2">FOR THE SERVICE: water abstraction
FOR THE BENEFIT: water used/consumed</td></tr>
<tr><td>Unmet demand</td><td colspan="2">When public authorities are compelled, under water scarcity situations, to set temporal restrictions in the water use, forcing users (mainly agriculture and households), to reduce their consumption below their needs</td></tr>
<tr><td>Benefit</td><td colspan="2">Natural water effectively used (water abstraction-returns; because water abstraction is usually different from water use since water losses often take place in the water supply process)</td></tr>
<tr><td colspan="3">VALUATION METHODS</td></tr>
<tr><td colspan="3">Payments for ecosystem services and fiscal instruments:
• Kumar P. (2005) Market for Ecosystem Services, International Institute for Sustainable Development (IISD). Report

Replacement costs:
• Remme et al (2015) Monetary accounting of ecosystem services: A test case for Limburg province, the Netherlands. Ecological Economics, 112, 116–128</td></tr>
<tr><td colspan="3">AVAILABLE INDICATORS (review)</td></tr>
<tr><td colspan="3">ECOSYSTEM SERVICE</td></tr>
<tr><td rowspan="2">Potential</td><td>Capacity (stock)</td><td>• Stock calculation in rivers is challenging and very high data demanding. No such data is available at the European scale
• Alternatively, capacity might also be indirectly estimated through the valuation method</td></tr>
<tr><td>Potential flow</td><td>• Renewable water resources calculated as the: External inflow +Precipitation – Actual Evapotranspiration – change in reservoirs (and groundwater aquifers) (EEA water accounts)
• Total renewable water measured as the long term average of the stream flow plus net groundwater recharge (m^3/yr, tier I, based on the Budyko approach (Grizzetti et al., 2017)</td></tr>
<tr><td>Use</td><td colspan="2">• Total gross abstraction (m^3/year, annual data from 2000-2014, but not all MS report data for all years, see Eurostat data [env_wat_bal])
• Water abstraction by sector in 2006, at 5 x 5 km (no metadata available) (http://water.jrc.ec.europa.eu/waterportal)
• EEA water accounts produces information on water abstraction by economic sectors at the sub basin scale on monthly resolution</td></tr>
<tr><td colspan="3">SOCIO-ECONOMIC SYSTEM</td></tr>
<tr><td>Demand</td><td colspan="2">FOR THE BENEFIT
• Annual total consumptive water use 2006 (no metadata available) (http://water.jrc.ec.europa.eu/waterportal)</td></tr>
<tr><td>Benefit</td><td colspan="2">• Annual total consumptive water use 2006 (no metadata available) (http://water.jrc.ec.europa.eu/waterportal)
• Water consumption (no data available in Eurostat [env_wat_bal]</td></tr>
<tr><td>Unmet demand</td><td colspan="2">• Not currently quantifiable</td></tr>
<tr><td colspan="3">OTHER METHODS AND TOOLS (review)</td></tr>
<tr><td colspan="3">METHODS
• Study at global level estimates water used for irrigation, industry, domestic consumption, and livestock production based on the global hydrological model WaterGAP which provides spatially explicit estimates of water availability and water use for various economic sectors (Naidoo et al., 2008)
• Soil water storage capacity per unit area (FAO et al., 2012)</td></tr>
</table>

WATER PROVISIONING

- Total annual water yield per unit area and potential annual agricultural yield per unit area (Koschke *et al.*, 2014)
- Mapping water provisioning services to support the ecosystem–water–food–energy nexus in the Danube river basin, based on the SWAT model (Karabulut *et al.*, 2016)
- Assessment of climate change impact on water provisioning an erosion control at basin level based on water yield and water scarcity estimates (Bangash *et al.*, 2013)

TOOLS

- WaterWorld Modelling software: modelling of an area to establish service values for various aspects of hydrology. WaterWorld can calculate the hydrological and water resources baseline and water risk factors associated with specific activities under current conditions and under scenarios for land use, land management, and climate change (http://www.policysupport.org/waterworld)
- Soil and Water Assessment Tool (SWAT): allows, among other application, model and map water provisioning (http://swat.tamu.edu/)

Comments:

The EEA has a set of water accounts available, based on data reported by Member States, which can be used in KIP INCA. Water accounts are also thematic accounts, so the focus of the ecosystem service accounts of water as provisioning ecosystem services could focus on the role of different ecosystems to retain and supply water. Although there are available some indicators on water retention (Maes *et al.*, 2015), they were developed for a simulated scenario. Therefore, the assessment of the capacity of ecosystems to retain water for KIP INCA would require a modelling exercise based on representative data time series.

References:

Bangash, R.F., Passuello, A., Sanchez-Canales, M., Terrado, M., López, A., Elorza, F.J., Ziv, G., Acuña, V. & Schuhmacher, M. (2013) Ecosystem services in Mediterranean river basin: Climate change impact on water provisioning and erosion control. *Science of The Total Environment*, 458–460, 246-255. doi - http://dx.doi.org/10.1016/j.scitotenv.2013.04.025

FAO, IIASA, ISRIC, ISSCAS & JRC (2012) Harmonized World Soil Database (version 1.2) R. Fao, Italy and Iiasa, Laxenburg, Austria. from - http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/

Grizzetti, B., Liquete, C., Pistocchi, A., Vigiak, O., Reynaud, A., Lanzanova, D., Brogi, C., Cardoso, A.C. & Zulian, G. (2017) *Reports on stressor classification and effects at the European scale: Impact of multi-stressors on ecosystem services and their monetary value*. JRC, Joint Research Centre. Retrieved from - http://www.mars-project.eu/index.php/deliverables-overview.html

Karabulut, A., Egoh, B.N., Lanzanova, D., Grizzetti, B., Bidoglio, G., Pagliero, L., Bouraoui, F., Aloe, A., Reynaud, A., Maes, J., Vandecasteele, I. & Mubareka, S. (2016) Mapping water provisioning services to support the ecosystem–water–food–energy nexus in the Danube river basin. *Ecosystem Services*, 17, 278-292. doi - http://dx.doi.org/10.1016/j.ecoser.2015.08.002

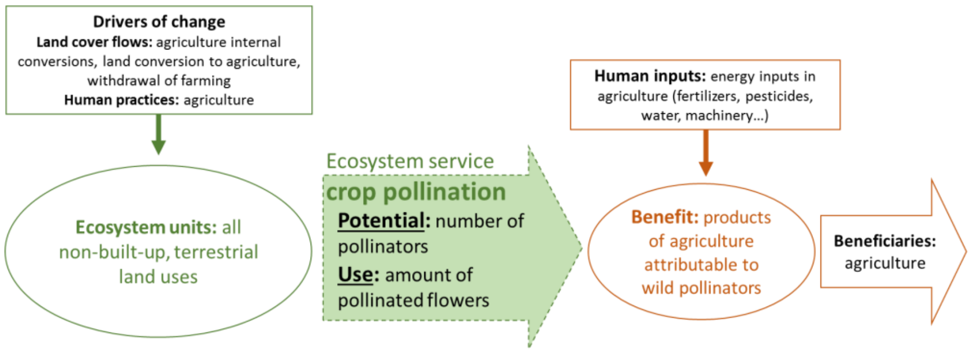
Koschke, L., Lorz, C., Fürst, C., Lehmann, T. & Makeschin, F. (2014) Assessing hydrological and provisioning ecosystem services in a case study in Western Central Brazil. *Ecological Processes*, 3, 2. doi - 10.1186/2192-1709-3-2

Maes, J., Fabrega, N., Zulian, G., Barbosa, A., Vizcaino, P., Ivits, E., Polce, C., Vandecasteele, I., Marí-Rivero, I., Guerra, C., Perpiña-Castillo, C., Vallecillo, S., Baranzelli, C., Barranco, R., Silva, F.B.e., Jacobs-Crisoni, C., Trombetti, M. & Lavalle, C. (2015) *Mapping and Assessment of Ecosystems and their Services: trends in ecosystems and ecosystem services in the European Union between 2000 and 2010. JRC Science and Policy Report. EUR 27143 EN.* European Commission. Retrieved from - http://publications.jrc.ec.europa.eu/repository/bitstream/JRC94889/lbna27143enn.pdf

Naidoo, R., Balmford, A., Costanza, R., Fisher, B., Green, R.E., Lehner, B., Malcolm, T.R. & Ricketts, T.H. (2008) Global mapping of ecosystem services and conservation priorities. *Proceedings of the National Academy of Sciences of the United States of America*, 105, 9495-9500. doi - 10.1073/pnas.0707823105

*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

4.1.2 Regulating and maintenance ecosystem services

CROP POLLINATION		
Definition	The fertilisation of crops by insects that maintains or increases the crop production (modified from CICES V5)	
Ecosystem types	All non-built-up, terrestrial land covers	
Economic unit	Users of the service	Agriculture (pollination-dependent crops)
	Beneficiaries	Agriculture (pollination-dependent crops)
SEEA EEA ecosystem accounting model		

CONCEPTUAL DEFINITION OF INDICATORS		
ECOSYSTEM SERVICE		
Potential	Capacity (stock)	Number of pollinators (species number and abundance)
Use	Actual flow of pollinated flowers (n/ha per year)	
SOCIO-ECONOMIC SYSTEM		
Demand	Amount of agricultural flowers demanding pollination (n/ha per year)	
Unmet demand	Crop pollination deficit: quantitative or qualitative inadequate pollen receipt that limits agricultural output in yield or economic terms	
Benefit	Increased quality and/or quantity of crop production. It can be measured as share of the crop production attributable to the pollination flow	

VALUATION METHODS

Multiple methods:

- Breeze T.D. et al. (2016) Economic Measures of Pollination Services: Shortcomings and Future Directions. Trends in Ecology & Evolution
- Melathopoulos A.P. et al. (2015) Where is the value in valuing pollination ecosystem services to agriculture? Ecological Economics 109, 59–70
- Hanley N. et al. (2015) Measuring the economic value of pollination services: Principles, evidence and knowledge gaps. Ecosystem Services, 14, 124–132

Replacement cost:

- Winfree R. et al. (2011) Valuing pollination services to agriculture. Ecological Economics 71 80–88
- Allsopp M.H. et al (2008) Valuing Insect Pollination Services with Cost of Replacement. PLoS ONE 3(9): e3128. doi:10.1371/ journal.pone.0003128

Production function:

- Ricketts and Lonsdorf (2013) Landscape effects on crop pollination services: Are there general patterns? Ecol. Lett. 11, 499–515
- Jonsson et al. (2014) Ecological production functions for biological control services in agricultural landscapes; Methods in Ecology and Evolution 5, 243-252

Adjusted market price:

- Garrad et al (2014) Avoiding a bad apple: Insect pollination enhances fruit quality and economic value Agriculture, Ecosystems and Environment 184 (2014) 34–40

CROP POLLINATION		
INDICATORS TO BE USED IN INCA		
ECOSYSTEM SERVICE		
Potential	Capacity (stock)	• Potential pollination supply based on the combination of two complementary models: Expert-based Model (EBM from ESTIMAP) and a Species Distribution Model (SDM) using empirical data (see Appendix III for further details of the whole model). Final output: 100 x 100 m resolution (Tier III)
Use	• Overlap between suitable areas of supply and demand (ha) for each year (Tier II)	
SOCIO-ECONOMIC SYSTEM		
Demand	• The share of pollinator-dependent crops derived from the proportion of LUCAS points. The inferred crop extent will be always in agreement with the EUROSTAT reporting data (Tier II)	
Unmet demand	• The lack of overlap between suitable areas of supply and demand (ha) for each year. This is, extent of pollinator-dependent crops where pollination supply is low or absent (Tier II)	
Benefit	• Crop production deficit: percentage reduction of the aggregate production of crops (Tier II) (Zulian *et al.*, 2013)	
DRIVERS OF CHANGES IN THE MODELLING FRAMEWORK		

INCLUDED IN THE MODELS:

- Land cover changes derived from the LC maps for the different years (i.e. CORINE Land Cover)
- LUCAS data: for the assessment of demand (in accordance with Eurostat data)

OTHER METHODS AND TOOLS (review)

METHODS

- Application of species distribution models for crop pollination in Great Britain (Polce *et al.*, 2013)
- Mapping of ecosystem services (i.e. pollination) based on the distribution of functional traits, instead of land use/land cover models (Lavorel *et al.*, 2011)
- Lautenbach *et al.* (2012) derived global-scale pollination benefits maps (5' x 5'lat-lon grid, about 10 x 10 km at the equator) for 60 insect pollinators dependent crops, and their correlation with climatic variables (mean temperature and precipitation) and distribution of cropland.
- Trend analysis insect pollinated crops, insect pollinators and US Agriculture showing that US producers have a continued and significant need for insect pollinators and that a diminution in managed or wild pollinator populations could seriously threaten the continued production of insect pollinated crops (Calderone, 2012)
- Breeze *et al.* (2014) analysed the mismatches between honeybee stocks and crop pollinators demand throughout Europe and provide sources for honeybee data.
- Demand and supply of pollination in the European Union were mapped at 1x1 km resolution based on CORINE Land Cover 2000 (Schulp *et al.*, 2014)

TOOLS

- InVest: Supply: potential sources of pollination services: dimensionless between 0-1. Land-use map dependent. Demand: abundance index of visiting bees at each agricultural cell. More info: http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/croppollination.html

Conclusions:
There is lack of indicators for representative time series. The JRC has a broad experience on modelling crop pollination. Therefore, the accounting of crop pollination will be based on the JRC model, adjusted for KIP INCA. See Annex II of this report for further details on this model.

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Breeze, T.D., Vaissière, B.E., Bommarco, R., Petanidou, T., Seraphides, N., Kozák, L., Scheper, J., Biesmeijer, J.C., Kleijn, D., Gyldenkærne, S., Moretti, M., Holzschuh, A., Steffan-Dewenter, I., Stout, J.C., Pärtel, M., Zobel, M. & Potts, S.G. (2014) Agricultural Policies Exacerbate Honeybee Pollination Service Supply-Demand Mismatches Across Europe. *PLoS One*, 9, e82996. doi - 10.1371/journal.pone.0082996
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CROP POLLINATION

Aggregate Data for the Period 1992–2009. *PLoS One*, 7, e37235. doi - 10.1371/journal.pone.0037235

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Schulp, C.J.E., Lautenbach, S. & Verburg, P.H. (2014) Quantifying and mapping ecosystem services: Demand and supply of pollination in the European Union. *Ecological Indicators*, 36, 131-141. doi - http://dx.doi.org/10.1016/j.ecolind.2013.07.014

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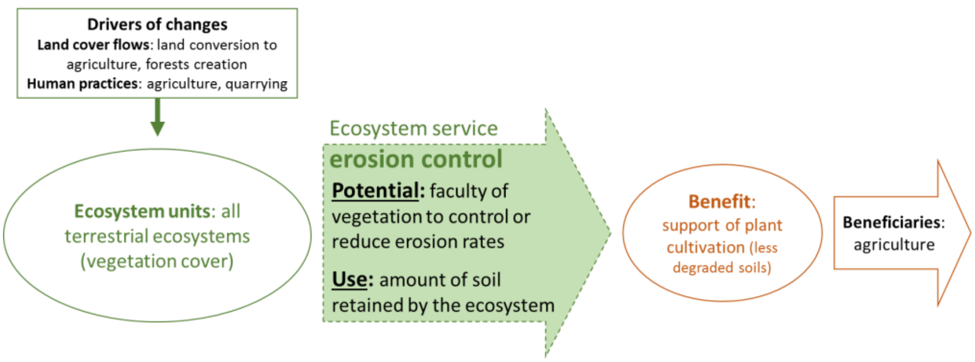
*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

EROSION CONTROL

Definition	The reduction in the loss of soil by virtue of the stabilising effects of the vegetation that mitigates the potential damage of human use to the environment (modified from CICES V5)	
Ecosystem types	All ecosystems with vegetation cover	
Economic unit	Users of the service	Agriculture, forestry (quarrying as enabling actor)
	Beneficiaries	Agriculture, forestry
SEEA EEA ecosystem accounting model		

CONCEPTUAL DEFINITION OF INDICATORS

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	Ability of vegetation to control or reduce erosion rates compared to those occurring in bare areas (tonne/ha)
Use	Actual flow of soil retained by the ecosystem (tonne/ha/year)	
SOCIO-ECONOMIC SYSTEM		
Demand	Need of soil erosion control due to potential soil loss by water and wind erosion	
Unmet demand	Soil loss by water and wind erosion (erosion rate in tonne/ha/year)	
Benefit	Support of plant cultivation by the provision of less degraded soils (i.e. maintenance of soil organic matter) (non-SNA benefit)	

VALUATION METHODS

Multiple methods (review studies):

- Telles et al (2013) Valuation and assessment of soil erosion costs. Sci. Agric. v.70, n.3, p.209-216

EROSION CONTROL
Protection [against erosion] costs: • Busch et al. (2012) Potentials of quantitative and qualitative approaches to assessing ecosystem services. Ecological Indicators, 21, 89-103 Avoided cost: • Barry et al (2011) Valuing Avoided Soil Erosion by Considering Private and Public Net Benefits, Presented Tahuna Conference Centre – Nelson, New Zealand. August 25-26, 2011 • Rosales, R.M.P. et al. (2005) Balancing the returns to catchment management. IUCN Water, Nature and Economics Technical Paper 5, IUCN, ecosystems and livelihoods group Asia, Colombo. • Emerton, L (ed) (2005) Values and rewards: counting and capturing ecosystem water services for sustainable development. IUCN Water, Nature and Economics Technical Paper No. 1, IUCN — The World Conservation Union, Ecosystems and Livelihoods Group Asia. Production function: • Dixon, J.A. and G. Hodgson (1988) Economic evaluation of coastal resources: The El Niño study. Tropical Coastal Area Management (August): 5-7. Replacement cost: • Yoshida (2014) The economic value of ecosystem services from agricultural and rural landscapes in Japan. In Ninan K.N (Ed.) Valuing Ecosystem Services. Methodological Issues and Case Studies. Edward Elgar Publishing. • Samonte-Tan, G.P.B. et al. (2007) Economic Valuation of Coastal and Marine Resources: Bohol Marine Triangle, Philippines. Costal Management 35(2): 319-338. • Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, P. Sphpritz, L. Fitton, R. Saffouri and R. Blair (1995) Environmental and economic costs of soil erosion and conservation benefits. Science 267: 1117-1123. • Emerton, L. and E. Muramira (1999) Uganda biodiversity - economic assessment. Prepared with National Environment Management Authority, Kampala. IUCN, Gland, Switzerland.

AVAILABLE INDICATORS (review)		
ECOSYSTEM SERVICE		
Potential	Capacity (stock)	• Vegetation cover factor (C-factor): estimated for 2000 and 2010, dimensionless [0-1], at 100 m x 100 m spatial resolution, tier III. Assessment for 2010 correspond to the Updated Reference Scenario simulated under the LUISA platform (http://data.europa.eu/89h/4ccdbbf0-fc7c-4fd7-bd8b-f11a06f5df0b, see also Maes *et al.* (2015)) • Capacity of ecosystems to avoid soil erosion (LUISA Platform REF2014): estimated between 2010 and 2050, dimensionless [0-1], at NUTS2 level, tier III (http://data.jrc.ec.europa.eu/dataset/jrc-luisa-lf521-capacity-of-ecoystems-to-avoid-soil-erosion-ref-2014) • Cover management factor (C-factor) for the EU: at 100 m resolution for 2010, tier III including management practices as well (http://esdac.jrc.ec.europa.eu/content/cover-management-factor-c-factor-eu)
Use	• Soil retention: estimated for 2000 and 2010, in thousands of tonnes per hectare and year, at 100 m x 100 m spatial resolution, Tier III. Assessment for 2010 correspond to the Updated Reference Scenario simulated under the LUISA platform (http://data.europa.eu/89h/4ccdbbf0-fc7c-4fd7-bd8b-f11a06f5df0b, see also Maes *et al.* (2015)) • Soil retention (LUISA Platform REF2014): estimated between 2010 and 2050, dimensionless [0-1], at NUTS2 level, tier III (http://data.jrc.ec.europa.eu/dataset/jrc-	

EROSION CONTROL	
	luisa-lf522-soil-retention-ref-2014)
SOCIO-ECONOMIC SYSTEM	
Demand	Related to the potential soil erosion by water, where the following factors should be considered: • Rainfall erosivity (R-factor) at EU level: at 500 m resolution, from 2000 to 2010, in MJ mm/ha h yr, tier III (http://esdac.jrc.ec.europa.eu/content/rainfall-erosivity-european-union-and-switzerland) • Soil erodibility (K-factor) for 2009: 500 m resolution, at EU level, derived from the LUCAS 2009 soil survey exercise and the European Soil Database, tier III (http://data.europa.eu/89h/jrc-esdac-29) • Topography (Slope Length and Steepness , LS-factor): 25 m and 100 m resolution, dimensionless, tier III (http://esdac.jrc.ec.europa.eu/content/ls-factor-slope-length-and-steepness-factor-eu) Related to the soil loss potential due to wind erosion in agricultural soils (Revised Wind Erosion Equation Model): • Land susceptibility to wind erosion: 500 m spatial resolution, for the period 1981–2010, qualitative assessment from high susceptibility to none, tier III (http://esdac.jrc.ec.europa.eu/content/Soil_erosion_by_wind)
Unmet demand	• Soil loss by water erosion (RUSLE 2015): at 100 m resolution for 2010, in tonne ha^{-1} $year^{-1}$, tier III (http://esdac.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015) • Soil erosion map (MAPPE model): at 1 km resolution for 2006, in tonne ha^{-1} $year^{-1}$, tier III http://data.jrc.ec.europa.eu/dataset/jrc-mappe-europe-setup-d-16-erosion
Benefit	• Currently not quantifiable
DRIVERS OF CHANGES IN THE MODELLING FRAMEWORK	
• Model based on Maes *et al.* (2015): land-cover changes are the main driver of change • Based on Guerra *et al.* (2016) changes in the NDVI values between 2001 and 2013	

OTHER METHODS AND TOOLS (review)

METHODS

- Application of the RUSLE for the Mediterranean region between 2001 and 2013 analysing changes between the actual use and capacity of soil erosion control and potential (Guerra *et al.*, 2016). They estimate the capacity of soil erosion control based on NDVI values
- Study where soil retention was modelled as a function of vegetation or litter cover and soil erosion potential in South Africa, at catchment level (Egoh *et al.*, 2008)
- Study at regional level on soil erosion regulation using the USLE2D tool developed by the University of Leuven (Bastian *et al.*, 2013)
- Study at regional level including soil erosion data following the *USLE methods (historic trend 1992–2006)* (García-Nieto *et al.*, 2013)

TOOLS

- InVest: Nearshore Waves and Erosion model quantifies the protective services provided by natural habitats of nearshore environments in terms of avoided erosion and flood mitigation (http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/coastal_protection.html)
- LUCI (http://www.lucitools.org/) models erosion control based on slope, curvature, contributing area, land use and soil type

Conclusions:

Data/method to be used in INCA: there is available a broad list of soil erosion indicators at EU level that could be potentially used for the accounting of soil erosion control (mainly derived from the European Soil Data Centre (ESDAC, http://esdac.jrc.ec.europa.eu/resource-type/datasets). However, none of them presents an assessment of changes through time, which is crucial for ecosystem services accounting. Only the indicators calculated for the simulated scenario of LUISA (Lavalle *et al.*, 2015) make available supply and use data per decade between 2010 and 2050. Therefore, accounting of soil erosion control will be based on a modelling exercise for a representative time series .

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EROSION CONTROL

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Egoh, B., Reyers, B., Rouget, M., Richardson, D.M., Le Maitre, D.C. & van Jaarsveld, A.S. (2008) Mapping ecosystem services for planning and management. *Agriculture, Ecosystems & Environment*, 127, 135-140. doi - http://dx.doi.org/10.1016/j.agee.2008.03.013

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Guerra, C.A., Maes, J., Geijzendorffer, I. & Metzger, M.J. (2016) An assessment of soil erosion prevention by vegetation in Mediterranean Europe: Current trends of ecosystem service provision. *Ecological Indicators*, 60, 213-222. doi - http://dx.doi.org/10.1016/j.ecolind.2015.06.043

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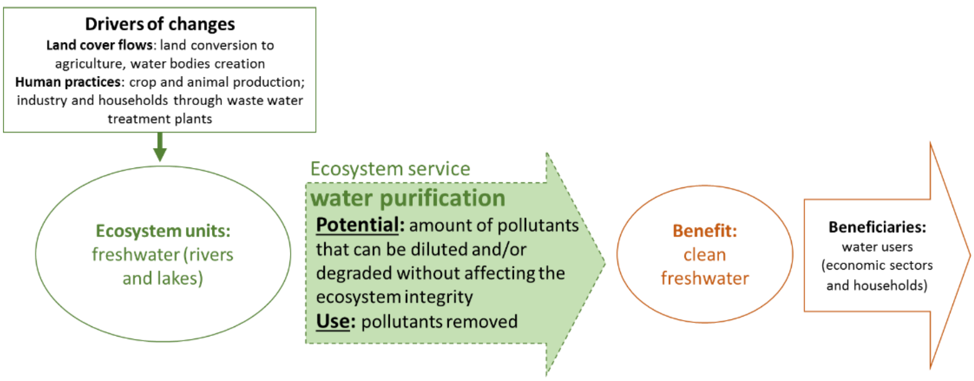
*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

WATER PURIFICATION

Definition	The reduction in concentration of pollutants by mixing and degrading in a freshwater ecosystem that mitigates its harmful effect and reduces the costs of disposal by other means (modified from CICES V5)	
Ecosystem types	Freshwater: rivers and lakes	
Economic unit	Enabling actors	Crop and animal production; industry and households through waste water treatment plants
	Beneficiaries	All water users: economic sectors and households
SEEA EEA ecosystem accounting model		

CONCEPTUAL DEFINITION OF INDICATORS

ECOSYSTEM SERVICE

WATER PURIFICATION

Potential	Capacity (stock)	Potential of water flow to dilute and/or degrade pollutants without affecting the ecosystem integrity (mg/l)
	Potential flow	Amount of pollutants that can be diluted and/or degraded without affecting the ecosystem integrity (tonne/year; tonne/km per year) (i.e. below a critical threshold)
Use	Actual flow of pollutants yearly removed (tonne/year; tonne/km per year)	
SOCIO-ECONOMIC SYSTEM		
Demand	DEMAND FOR THE SERVICE: • Level of pollutants emitted to freshwater ecosystems by polluting sectors (i.e. agriculture and waste water treatment discharges from industry and households) (tonne per year) DEMAND FOR THE BENEFIT: • Need of clean freshwater to avoid the damage of pollutants or reduce the costs of disposal	
Unmet demand	FOR THE SERVICE: • When the level of the pollutants is above the ES potential and the accumulation of pollutants in the ecosystem yields degradation (tonne/year). When the ES potential is not considered the demand would be always satisfied FOR THE BENEFIT: • When the level of pollutants is above a critical threshold, at which the ecosystems starts to degrade	
Benefit	Clean freshwater	

VALUATION METHODS

Replacement cost:

- La Notte et al. (2017) Physical and monetary ecosystem service accounts for Europe: A case study for in-stream nitrogen retention. Ecosystem Services,23, 18–29
- La Notte et al (2012) Spatially explicit monetary valuation of water purification services in the Mediterranean biogeographical region. International Journal of Biodiversity Science, Ecosystem Services & Management, 8, 26-34
- Karanja, F. et al. (2001) Assessment of the economic value of pallisa district wetlands, Uganda. Biodiversity Economics for Eastern Africa & Uganda's National Wetlands Programme, IUCN Eastern Africa Programme.
- Schuijt, K. (2002) Land and water use of wetlands in Africa: economic values of African Wetlands. Interim Reports. International Institute for Applied Systems Analysis, Laxenburg, Austria.
- De la Cruz, A. and J. Benedicto (2009) Assessing Socio-economic Benefits of Natura 2000: a Case Study on the ecosystem service provided by SPA PICO DA VARA / RIBEIRA DO GUILHERME. Output of the project Financing Natura 2000: Cost estimate and benefits of Natura 2000.

Avoided costs:

- Mueller et al. (2016) Evaluating services and damage costs of degradation of a major lake ecosystem, Ecosystem Services 22: 370–380

INDICATORS TO BE USED IN INCA

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	• Constructed wetlands equivalent hectares of nitrogen removal tonnes with reference to the sustainability threshold (Number of hectares)
	Potential flow	• Tonnes of nitrogen yearly removed withdrawn from GREEN (Grizzetti *et al.*, 2012; Grizzetti *et al.*, 2015) that are below or equal to the sustainability threshold of 1mg/l; from 1985 to 2005 (Tier III)
Use	• Actual flow of nitrogen removed withdrawn from GREEN (tonne/year, from 1985-2005, average sub-catchment size of 180 km^2) (Tier III)	

WATER PURIFICATION	
SOCIO-ECONOMIC SYSTEM	
Demand	FOR THE SERVICE • N inputs by the polluting activities (agriculture and waste water treatment discharges from industry and households) (tonne/year)
Unmet demand	• Sub-catchment where the difference between total inflow and sub-catchment outflow is positive (i.e. ecosystem degradation)
Benefit	• Sub-catchment where the difference between total inflow and sub-catchment outflow is negative (i.e. clean water below 1mg/l)
DRIVERS OF CHANGES IN THE MODELLING FRAMEWORK	
INCLUDED IN THE MODEL: Human practices: nitrogen inputs derived from the agricultural sector (diffuse sources) and other industries and households (point sources: discharges from waste water treatment plants)	

OTHER METHODS AND TOOLS (review)

METHODS

- Assessment of water purification in marine ecosystems using 3-D General Estuarine Transport Model (GETM) (Liquete *et al.*, 2016)
- Mapping water quality-related ecosystem services that also identifies areas in which nitrogen retention is highest or which areas face the highest ecological risk due to pesticides (Lautenbach *et al.*, 2012)
- Estimates of watershed degradation over the last century and its impact on water-treatment costs for the world's large cities based on SPARROW model to quantify the ecosystem service (McDonald *et al.*, 2016)

TOOLS

- Soil and water assessment tool (http://swat.tamu.edu/), SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time.
- i-Tree Hydro (http://www.itreetools.org/hydro/index.php): stand-alone application designed to simulate the effects of changes in urban tree cover and impervious surfaces on the hydrological cycle, including streamflow and water quality
- The InVEST Water Purification model estimates the nutrient retention capacity of a land parcel under current and future land use scenarios. It then uses data on water treatment costs to calculate the economic value contributed by each part of a watershed to water purification. (http://www.naturalcapitalproject.org/invest/). Example of applications: (Kovacs & West, 2016)
- SPARROW Surface Water-Quality Modeling: the model relates in-stream water-quality measurements to spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and aquatic transport (https://water.usgs.gov/nawqa/sparrow/)
- Geography-Referenced regional exposure assessment tool for European rivers (GREAT-ER) model: is the simulation of the fate of (organic) chemicals discharged from point sources into rivers (http://great-er.org.acelis.net/pages/home.cfm) applied to water purification of pharmaceutical residues (Boithias *et al.*, 2013)

Conclusions:
The method to be used in INCA for water purification accounting is based on the study published in La Notte *et al.* (2017). See Annex I of this report for further details on the model to apply.

References:

Boithias, L., Marce, R., Acuna, V., Aldekoa, J., Osorio, V., Petrovic, M., Ginebreda, A., Frances, F., Perez, S. & Sabater, S. (2013) Towards a better understanding of the links between stressors, hazard assessment and ecosystem services under water scarcity. *4th SCARCE International Conference*. At Cádiz, Spain. Retrieved from - https://www.researchgate.net/publication/258927717_Assessment_of_the_water_purification_ecosystem_service_regarding_in-stream_pharmaceutical_residues_Exploring_the_GREAT-ER_model_parameters_based_on_data_uncertainty

Grizzetti, B., Bouraoui, F. & Aloe, A. (2012) Changes of nitrogen and phosphorus loads to European seas. *Global Change Biology*, 18, 769-782. doi - 10.1111/j.1365-2486.2011.02576.x

Grizzetti, B., Passy, P., Billen, G., Bouraoui, F., Garnier, J. & Lassaletta, L. (2015) The role of water nitrogen

WATER PURIFICATION

retention in integrated nutrient management: Assessment in a large basin using different modelling approaches. *Environmental Research Letters*, 10. doi - 10.1088/1748-9326/10/6/065008

Kovacs, K. & West, G. (2016) The influence of groundwater depletion from irrigated agriculture on the tradeoffs between ecosystem services and economic returns. *PLoS One*, 11. doi - 10.1371/journal.pone.0168681

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Liquete, C., Piroddi, C., Macías, D., Druon, J.N. & Zulian, G. (2016) Ecosystem services sustainability in the Mediterranean Sea: Assessment of status and trends using multiple modelling approaches. *Scientific Reports*, 6. doi - 10.1038/srep34162

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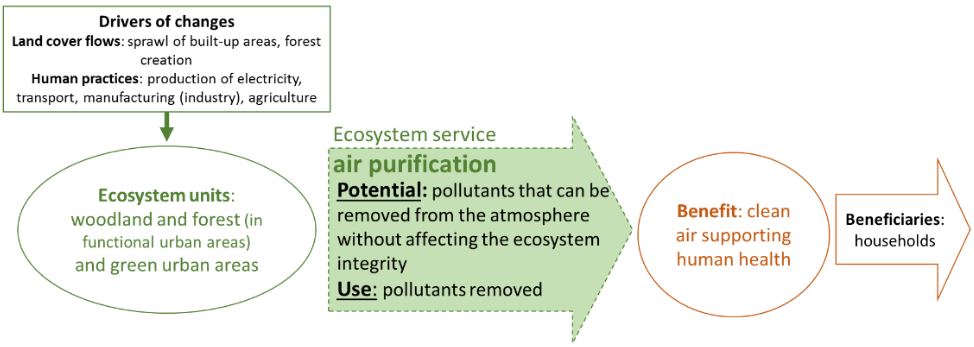
*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

AIR PURIFICATION

Definition	The capture/filtering of pollutants by the ecosystem that mitigates its harmful effects and reduces the costs of disposal by other means (modified from CICES V5)	
Ecosystem types	Forest and semi-natural vegetation with vegetation cover in functional urban areas (zone of influence of urban areas), including green urban areas	
Economic unit	Enabling actors	Production of electricity, transport, manufacturing (industry), agriculture
	Beneficiaries	Households

SEEA EEA ecosystem accounting model



CONCEPTUAL DEFINITION OF INDICATORS

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	Capability of vegetation to capture/filter pollutants in relation to their leaf surface without affecting the ecosystem integrity
	Potential flow	Amount of pollutants that can be effectively removed from the atmosphere without affecting the ecosystem integrity (tonne/year; tonne/km per year) (i.e. below a critical threshold)
Use	Actual flow of pollutants (i.e. NO_x, SO_x, particulate matter) removed from the atmosphere	

AIR PURIFICATION

	(kg/ha/year)
SOCIO-ECONOMIC SYSTEM	
Demand	DEMAND FOR THE SERVICE • Reduction of the current level of pressure of polluting activities (i.e. atmospheric pollution) DEMAND FOR THE BENEFIT: given the direct relationship between the benefit of this service and the human health, demand for the benefit is here also considered: • Population needs to live under a given level of exposure to the air pollutants harmless to their health
Unmet demand	Population living in areas where concentration of pollutants is above the security threshold (i.e. 40 µg m^{-3} for NO_2)
Benefit	Clean air supporting human health

VALUATION METHODS

Direct market pricing:

- Curtis, I.A. (2004) Valuing ecosystem goods and services: a new approach using a surrogate market and the combination of a multiple criteria analysis and a Delphi Panel to assign weights to the attributes. Ecological Economics 50: 163-194.

Avoided costs:

- Remme et al (2015) Monetary accounting of ecosystem services: A test case for Limburg province, the Netherlands. Ecological Economics, 112, 116–128.

Replacement costs:

- Yoshida (2014) The economic value of ecosystem services from agricultural and rural landscapes in Japan. In Ninan K.N (Ed.) Valuing Ecosystem Services. Methodological Issues and Case Studies. Edward Elgar Publishing.

AVAILABLE INDICATORS (review)

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	• Dry deposition velocity based on the wind speed and the leaf surface of vegetation (µg/m^3, 100 m x 100 m resolution, years 2000 and 2010 [Updated Reference Scenario-LUISA platform], Tier II) (Maes *et al.*, 2015)
	Potential flow	• Level of pollutants removed below or equal to the critical load for each ecosystem type (i.e. level of exposure to pollutants below which significant harmful effects do not take place) (eq/ha/annum, Tier III). Information available at Bobbink and Hettelingh (2010): http://www.rivm.nl/media/documenten/cce/Publications/EmpNBobbink/executive_summary.pdf
Use	• Removal of $\mathbf{NO_2}$ by urban vegetation: ESTIMAP coupled with the LUISA platform, simulated data 2010-2050, µg/m^3, at urban level (Functional Urban Areas), Tier III. Source data: http://data.europa.eu/89h/jrc-luisa-ui-air-removal-capacity-no2-ref-2014 (Kompil *et al.*, 2015) • Removal capacity of **PM10** by vegetation: ESTIMAP coupled with the LUISA platform, simulated data 2010-2050, µg/m^3, at urban level (Functional Urban Areas), Tier III. Source data: http://data.europa.eu/89h/jrc-luisa-ui-air-removal-capacity-no2-ref-2014 (Kompil *et al.*, 2015)	
SOCIO-ECONOMIC SYSTEM		
Demand	• Population exposure as estimated at Batista e Silva *et al.* (2014) for air quality (percentage of population under different levels of NO_2)	
Unmet demand	• Population living in areas where concentration of pollutants is above the security threshold (40 µg m^{-3} for NO_2): population exposure (Batista e Silva *et al.*, 2014)	

AIR PURIFICATION	
Benefit	• Currently not quantifiable
DRIVERS OF CHANGES IN THE MODELLING FRAMEWORK	
INCLUDED IN THE MODELS: land use changes and population changes	

OTHER METHODS AND TOOLS (review)

METHODS

- Study quantifying tree and forest effects on air quality and human health in the United States using the (Nowak *et al.*, 2014) EPA Environmental Benefits Mapping and Analysis Program (BenMAP) model (https://www.epa.gov/benmap). Information on tree cover and leaf-area index was combined for the assessment
- Study applying Earth Observation data and leaf-area index (LAI) to estimate removal of PM_{10} and O^3 in Florence (Italy) (Bottalico *et al.*, 2016)
- Modelling the influence of peri-urban trees in the air quality of Madrid region (Spain) using the V200603par-rc1 version of the CHIMERE air quality model for Ozone (Alonso *et al.*, 2011)
- Study reviewing the effectiveness 'greening' of urban areas in reducing human exposure to ground-level ozone concentrations, UV exposure and the 'urban heat island effect' (Knight *et al.*, 2016)
- Study combining dispersal modelling and land-use regression modelling shows the potential of improving estimates of air pollutant concentrations based on DM, by incorporating further spatial characteristics of the immediate surroundings (Korek *et al.*, 2016)
- Study showing that coniferous trees are better at accumulating airborne PM2.5 particles on their foliage than broadleaved species because of their thicker wax layer (Nguyen *et al.*, 2015)
- Urban forests with diversified species and biomass structures are better for mitigating air pollution as overall canopy is increased (Jim & Chen, 2008)
- Under some circumstances, use of urban vegetation for alleviating a local air pollution hotspot is not expected to be a viable solution (Vos *et al.*, 2013)

TOOLS

- i-Tree Landscape is a freely available tool that allow estimating the benefit of urban trees such as the reduction in air pollution (https://canopy.itreetools.org/resources/i-Tree_Canopy_Air_Pollutant_Removal_and_Monetary_Value_Model_Descriptions.pdf)
- i-Tree Eco v6 is a model that uses tree measurements and other data to estimate ecosystem services and structural characteristics of the urban or rural forest (Selmi *et al.*, 2016)

Conclusions:

Method to be used in INCA: although there are some indicators available for long time series (i.e. those applied to the LUISA platform), they have been designed to make projections under future land use scenarios. But the method has been also used for applications at regional level (Baró *et al.*, 2016). A similar method could be applied in INCA, however the model may benefit from further developments to integrate available information on past changes in vegetation capacity to remove pollutants. For instance leaf area index (LAI) available from Earth Observation data (http://land.copernicus.eu/global/products/lai) may be included to better assess the capacity of ecosystems to remove pollutants

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AIR PURIFICATION

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*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

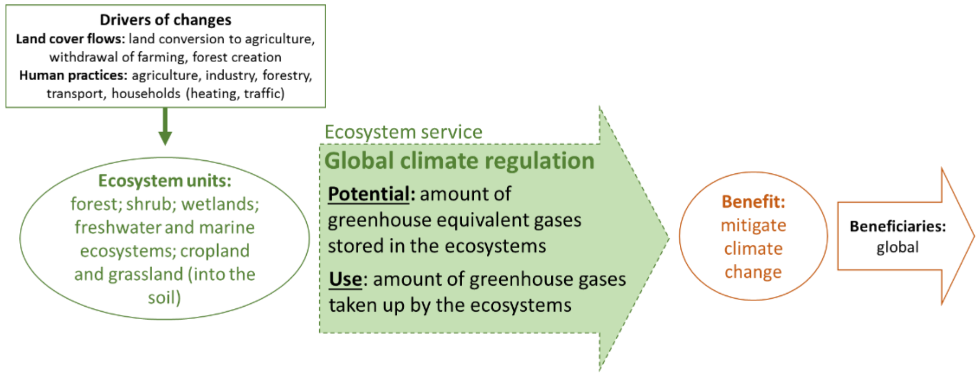
GLOBAL CLIMATE REGULATION

Definition	Reduction of the concentrations of greenhouse gases by the ecosystems that impact on global climate (modified from CICES V5)	
Ecosystem types	Forest (above-ground biomass and soil), heathland and shrub, wetlands, freshwater and marine ecosystems Cropland and grassland (into the soil)	
Economic unit	Enabling actors	Agriculture, forestry, industry, transport, households (heating, traffic)

GLOBAL CLIMATE REGULATION

	Beneficiaries	Global

SEEA EEA ecosystem accounting model



CONCEPTUAL DEFINITION OF INDICATORS

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	Amount of greenhouse equivalent gases stored in the ecosystems (tonnes of CO_2 equivalent)
Use	Actual flow of greenhouse gases taken up by the ecosystem (tonnes of CO_2 equivalent/year) (i.e. carbon sequestration)	
SOCIO-ECONOMIC SYSTEM		
Demand	Reduction in the greenhouse emissions by agriculture, forestry, industry, transport and households (tonnes of CO_2 equivalent/year)	
Unmet demand	Increase in the greenhouse gases concentration in the atmosphere (ppm CO_2 equivalent/year)	
Benefit	Mitigate impact of climate change	

VALUATION METHODS

Carbon market price:

- Busch et al. (2012) Potentials of quantitative and qualitative approaches to assessing ecosystem services. Ecological Indicators, 21, 89-103
- La Notte et al. (2011) Economic valuation of ecosystem services at local level for policy makers and planners. The case of the island of St. Erasmo in the Lagoon of Venice. Environmental Economics, Volume 2, Issue 3, 87-103

Avoided cost:

- Van Beukering, P.J.H. et al. (2003) Economic valuation of the Leuser National Park on Sumatra, Indonesia. Ecological Economics 44(1): 43-62.
- Naidoo, R. and T.H. Ricketts (2006) Mapping the economic costs and benefits of conservation. PLoS Biology 4(11): 2153-2164.
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- Yoshida (2014) The economic value of ecosystem services from agricultural and rural landscapes in Japan. In Ninan K.N (Ed.) Valuing Ecosystem Services. Methodological Issues and Case Studies. Edward Elgar Publishing
- Li et al. (2014) Prioritizing protection measures through ecosystem services valuation for the Napahai Wetland, Shangri-La County, Yunnan Province, China. International Journal of Sustainable Development &

<table>
<tr><td colspan="3">GLOBAL CLIMATE REGULATION</td></tr>
<tr><td colspan="3">World Ecology 22:2, 142-150</td></tr>
<tr><td colspan="3">INDICATORS AVAILABLE (review)</td></tr>
<tr><td colspan="3">ECOSYSTEM SERVICE</td></tr>
<tr><td>Potential</td><td>Capacity (stock)</td><td>ALL ECOSYSTEM TYPES
ABOVEGROUND
• NPP (from 2000 to 2016, global data 0.1 degree resolution [~12 km x 12 km], g C/m^2/day, Tier II): http://neo.sci.gsfc.nasa.gov/view.php?datasetId=MOD17A2_M_PSN
• NPP (from 2000 to 2010, kg C/m^2, 1 km x 1 km, Tier II): https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod17a3
BELOWGROUND
• SOC modelling based on LUCAS points (only for 2009, 1 km x 1 km resolution, g C kg^{-1}, Tier III): http://eusoils.jrc.ec.europa.eu/content/topsoil-soil-organic-carbon-lucas-eu25
• Soil organic carbon-stock changes in mineral soils 0-30 cm estimated for the Updated Reference Scenario 2014 (LUISA platform) according to the LC changes between 2010 and 2050 (IPCC Tier I method): http://data.jrc.ec.europa.eu/dataset/jrc-luisa-lf532-c-stocks-ref-2014

CROPLAND AND GRASSLAND
BELOWGROUND
• Pan-European C stocks in agricultural land (in tonnes C ha^{-1} in the layer 0-30 cm, for the year 2010, with also projections for 2020, 2050, 2080 and 2100, 1 km x 1 km resolution, Tier III) http://esdac.jrc.ec.europa.eu/content/pan-european-soc-stock-agricultural-soils
FOREST
• Above and below-ground forest carbon stocks (only for 2006, tonnes/ha, 1 km x 1 km resolution, IPCC Tier I method): http://data.jrc.ec.europa.eu/dataset/8dcd61eb-c97f-4c92-886f-5027bad233ed</td></tr>
<tr><td>Use</td><td colspan="2">Actual flow of C sequestration can be estimated by the changes in the C stocks (described above) through time
• Forest C potential assessing changes in C stocks in forests between 2000 and 2010 (100 m x 100 m, % of change, Tier III based on Community Land Model): http://data.jrc.ec.europa.eu/dataset/ae111193-b95e-40ac-901c-02290613bf0f
• Greenhouse gas emissions derived from land use, land use changes and forestry (emissions mainly with negative sign [removal from the atmosphere], yearly data from 2005 to 2014, at MS level): http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en</td></tr>
<tr><td colspan="3">SOCIO-ECONOMIC SYSTEM</td></tr>
<tr><td>Demand</td><td colspan="2">• Greenhouse gas emissions by source sector (yearly data from 2005 to 2014, at MS level) http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en</td></tr>
<tr><td>Unmet demand</td><td colspan="2">• Increase in the greenhouse gas concentrations resulting from a level of emissions larger than the actual flow (ppm CO_2 equivalent at EU level): http://www.eea.europa.eu/data-and-maps/daviz/observed-trends-in-total-global-</td></tr>
</table>

GLOBAL CLIMATE REGULATION	
	4#tab-chart_3
Benefit	• Not available yet for this report
DRIVERS OF CHANGES IN THE MODELLING FRAMEWORK	
INCLUDED IN THE MODELS/DATA: for NPP models: changes in climate conditions and land cover and land use changes	

OTHER METHODS AND TOOLS (review)

ALL ECOSYSTEM TYPES

- NASA-CASA (Carnegie-Ames-Stanford) ecosystem model used to predict NPP and terrestrial carbon balance on a global scale (Potter *et al.*, 2012)
- Earth observation data show an increase in net primary productivity across North America between 1982–1998 related to C sinks (Hicke *et al.*, 2002)
- Assessment of changes in SOC between 1971 and 2100 across 10 climate scenarios at Global level shows that, besides the limitation, soil C sequestration is a viable option for reducing the short term atmospheric CO_2 concentration (t C ha^{-1}) (Smith, 2012)
- InVEST: Carbon Storage and Sequestration model estimates the current amount of carbon stored in a landscape and values the amount of sequestered carbon over time (http://www.naturalcapitalproject.org/invest/#invest-models)
- A study done at global level showed a net positive cumulative impact of the three greenhouse gases on the planetary energy budget, with a best estimate (in petagrams of CO_2 equivalent per year) of 3.9 ± 3.8 (top down) and 5.4 ± 4.8 (bottom up) based on the GWP100 metric (global warming potential on a 100-year time horizon) (Tian *et al.*, 2016)
- Study analysing the compilation of the CO_2, CO, CH_4 and N_2O balances of Europe between 2001 and 2005 shows that the European ecosystems are unlikely to contribute to mitigating the effects of climate change (Luyssaert *et al.*, 2012)
- Study summarizing published estimates of global SOC stocks through time. It provides an overview of the likely impacts of management options on SOC stocks (Scharlemann *et al.*, 2014)
- Simple approach at global level using Net Carbon Exchange (Naidoo *et al.*, 2008)
- Land Utilisation & Capability Indicator (LUCI) (http://www.lucitools.org/) models carbon sequestration based on the Tier I of the IPCC (soil and vegetation)

AGRICULTURE (soil)

- Assessment of potential carbon sequestration of European arable soils by modelling a comprehensive set of management practices demonstrates that the conversion into grassland showed the highest soil organic carbon (SOC) sequestration rates (Lugato *et al.*, 2014). The use of the CENTURY agroecosystem model allows making projections from 2010 till 2100
- Study assessing the carbon budget for tree cover in agricultural land between 2000 and 2010. The method used combines geographically and bioclimatically stratified Tier I model of the IPCC at Global level, at 250 m x 2050 m resolution (Zomer *et al.*, 2016). However, it is based on the assumption that agricultural land between 2000 and 2010 remained constant (GLC2000)
- Global estimates of soil carbon sequestration between 1980 and 1995 demonstrate that livestock waste can increase the soil carbon gains (Fellman *et al.*, 2009)

FOREST

- Review of regional and global estimates of carbon stocks and carbon sequestration capacity in forest ecosystems stress the importance of combining different methodologies for the assessment of uncertainty (Liu *et al.*, 2015)
- Changes in forest production, biomass and carbon stocks derived from the 2015 UN FAO Global Forest Resource Assessment (Köhl *et al.*, 2015): comparisons are presented at continental level
- Approach based on an inventory-based model to calculate forest carbon stock changes as affected by harvest and natural disturbances (2000-2012) at Member State level (Pilli *et al.*, 2016a)
- Modelling of the C stock changes between 1994 and 2004 using the Carbon Budget Model at MS level (EU) (Pilli *et al.*, 2016b). Model predictions are then compared with the Greenhouse Gas Inventories (GHGIs) submitted to the United Nations Framework Convention on Climate Change (UNFCCC)

GLOBAL CLIMATE REGULATION

- Temporal analysis of urban forest carbon storage using NDVI derived from Landsat imagery (Myeong *et al.*, 2006)
- Carbon sequestration status and change 1990–2012 in the Canadian urban tree canopy cover (McGovern & Pasher, 2016)
- Estimation of carbon mass fluxes over Europe using the C-Fix model and Euroflux data (Veroustraete *et al.*, 2002)

Conclusions:

Data/method to be used in INCA: a first assessment of C sequestration could be made based on NPP data provided by MODIS: at 1 km x 1 km of resolution between 2000 and 2010 and at ~12 km x 12 km from 2010 till 2016. Although the use of NPP as a proxy of C sequestration present some limitations (i.e. it does not capture processes that may also be important in the C cycle such as soil respiration (Hicke *et al.*, 2002)), it easily allows tracking changes, thus, becoming highly suitable for the ecosystem service accounting.

For a more comprehensive assessment of C sequestration a new model should be run, based on those described above.

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Myeong, S., Nowak, D.J. & Duggin, M.J. (2006) A temporal analysis of urban forest carbon storage using remote sensing. *Remote Sensing of Environment*, 101, 277-282. doi - http://dx.doi.org/10.1016/j.rse.2005.12.001

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GLOBAL CLIMATE REGULATION

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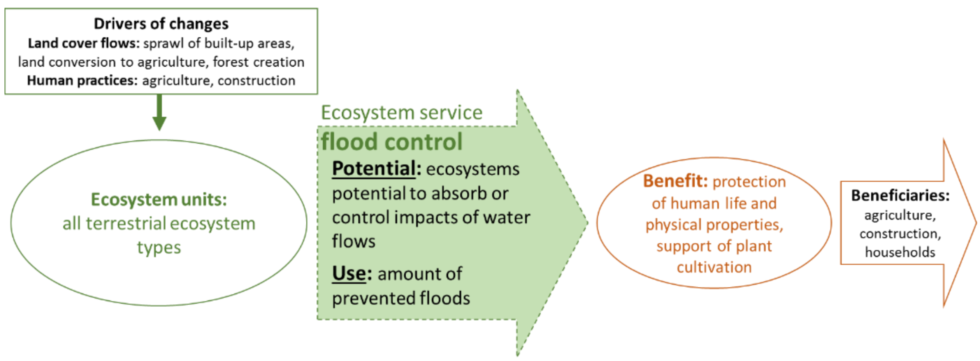
http://www.nature.com/articles/srep29987#supplementary-information

*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

FLOOD CONTROL

Definition	The reduction in the speed and volumes of water flows by virtue of the presence of ecosystem features (i.e. vegetation) that mitigates or prevents damage to the human environment (modified from CICES V5)	
Ecosystem types	All terrestrial ecosystem types	
Economic unit	Users of the service	Agriculture, construction
	Beneficiaries	Agriculture, construction, households
SEEA EEA ecosystem accounting model		

CONCEPTUAL DEFINITION OF INDICATORS

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	Ecosystems potential to absorb or control impacts of water flows depending on their biophysical properties (e.g. soil, vegetation type), but also on their spatial location (altitude, slope)
Use	Amount of prevented floods	
SOCIO-ECONOMIC SYSTEM		
Demand	Reduction of the flood risk in sensitive areas: urban areas and croplands	
Unmet demand	Flood events not prevented	

FLOOD CONTROL

Benefit	Protection of human life and physical properties, support of plant cultivation

VALUATION METHODS

Protection [against flooding] costs:

- La Notte et al. (2011) Economic valuation of ecosystem services at local level for policy makers and planners. The case of the island of St. Erasmo in the Lagoon of Venice. Environmental Economics, Volume 2, Issue 3, 87-103

Avoided costs:

- Kramer, R.A. et al. (1997) Ecological and Economic Analysis of Watershed Protection in Eastern Madagascar. Journal of Environmental Management 49: 277-295.
- Everard, M. (2009) Using science to create a better place: ecosystem services case studies. Better regulation science programme. Environment Agency.

Replacement costs:

- Ricardo Energy & Environmnet (2016) Valuing flood-regulation services for inclusion in the UK ecosystem accounts. Report
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AVAILABLE INDICATORS (review)

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	• Categorical links between land cover types and the flood control potential based on Burkhard *et al.* (2012) and averaging final values at city level (Tier I) (Schulp *et al.*, 2014) • Capacity of terrestrial ecosystems to temporarily store surface water (mm, 1 km resolution, year 2000, Tier III) (Pistocchi A, 2010) • Water retention index (dimensionless, 100 m resolution, year 2000, 2006 and LUISA projections, Tier III) (see Maes *et al.* (2015) for further details and Vandecasteele *et al.* (2016) for updated information on the method) • The inverse of the level of imperviousness in urban areas provided by Copernicus (http://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/view). Data show level of sealed soil (in %), 100 m resolution, Tier I to II approach, available for 2009 and 2012. More data will become available during the first trimester of 2017. Soil sealing has been considered a key factor determining vulnerability to urban flooding (EEA, 2012)
Use	• Reduction of flood peak discharges (i.e. attenuation in m^3/s, flood plain level, year 2012, Tier III, Grizzetti *et al.* (2017)) • Annual sub surface water flow (mm or m^3 $year^{-1}$) (Maes *et al.*, 2011)	
SOCIO-ECONOMIC SYSTEM		
Demand	PIXEL LEVEL • Flood hazard map for Europe: 10, 50, 100 and 200 -year return period. Spatial resolution varies between 100 m and 1 km (Tier III) (http://data.jrc.ec.europa.eu/dataset?q=FLOOD&sort=sort_criteria+desc)	

FLOOD CONTROL	
	REGIONAL LEVEL • Vulnerability to urban flooding in relation to climate change (urban morphological zones, 2009 and climate scenarios till 2100, Tier I, see EEA (2012) for further details) • Flood recurrence (qualitative ranges in 5 categories, NUTS 3 level, 1987-2002) (source: ESPON data set [Regional flood hazard potential], http://database.espon.eu/db2/home)
Unmet demand	• JRC Ongoing floods portal (not available yet) (http://floods.jrc.ec.europa.eu/ongoing-floods)
Benefit	• Currently not quantifiable

OTHER METHODS AND TOOLS (review)

METHODS (perspective of **urban areas**)

- Stürck *et al.* (2014) calculated the flood regulation supply, the potential increases in flood regulation supply based on potential vegetation and the demand at catchment level based on dimensionless indicators from 0 to 1, models are based on data combining different time periods (from 2000 till 2012)
- Imperviousness and distance to outflow point were reported in a case study as stronger descriptors of flooding reports occurrence in urban areas than rainfall intensity and population density (Gaitan *et al.*, 2016). This suggests that the use of imperviousness, and its changes through time, can be especially useful to assess changes in the demand for flood control in urban areas
- A two-tiered system is applied at city level to create a 'Green Space Factor' in urban areas and assess, among other ecosystem services, flood control (Farrugia *et al.*, 2013)

METHODS (perspective of **wetland**)

- Assessment of wetland functioning at regional scale for the flood peak attenuation based on remote sensing imagery (Rapinel *et al.*, 2016)
- Assessment of ecosystem services in wetlands along a gradient of ecosystem condition stresses the importance of these ecosystems for the floodwater storage, also in landscapes intensively used (McLaughlin & Cohen, 2013)

TOOLS

- Distributed water balance and flood simulation model (LISFLOOD): hydrological rainfall-runoff model that is capable of simulating the hydrological processes that occur in a catchment (Burek *et al.*, 2013)
- i-Tree Hydro (http://www.itreetools.org/hydro/index.php): flexible tool simple enough for non-experts to use, yet robust enough to provide defensible first-looks at the potential hydrological impact of land cover changes
- Soil and water assessment tool (http://swat.tamu.edu/), SWAT, was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time.
- ARIES platform (http://aries.integratedmodelling.org/) using Bayesian modelling and defining the source (floodwater), sink (floodwater mitigation), beneficiaries (developed cells) and flow (percentage of floodwater mitigated) (Zank *et al.*, 2016)
- InVest: Nearshore Waves and Erosion model quantifies the protective services provided by natural habitats of nearshore environments in terms of avoided erosion and flood mitigation (http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/coastal_protection.html)
- WaterWorld Modelling software: modelling of an area to establish service values for various aspects of hydrology. WaterWorld can calculate the hydrological and water resources baseline and water risk factors associated with specific activities under current conditions and under scenarios for land use, land management, and climate change (http://www.policysupport.org/waterworld)
- Land Utilisation & Capability Indicator (LUCI) (http://www.lucitools.org/) models flood mitigation based on water storage and infiltration capacity as function of soil and land uses

POTENTIAL CONTRIBUTION

FLOOD CONTROL

Conclusions:

Data/method to be used in INCA: although there are many comprehensive approaches assessing supply and use of flood control, they are mainly focused in a snapshot in time. Only few studies report trend on indicators related to flood control such as the study of Maes *et al.* (2015) for the water retention index and flood exposure and sensitivity in urban areas in (Kompil *et al.*, 2015). However, these models do not provide accurate information about the actual flow, required for the supply and use table. Accounting of the actual flow of flood control requires a hydrological modelling exercise (to be potentially developed in collaboration with the JRC units in charge of modelling water flows and floods).

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FLOOD CONTROL

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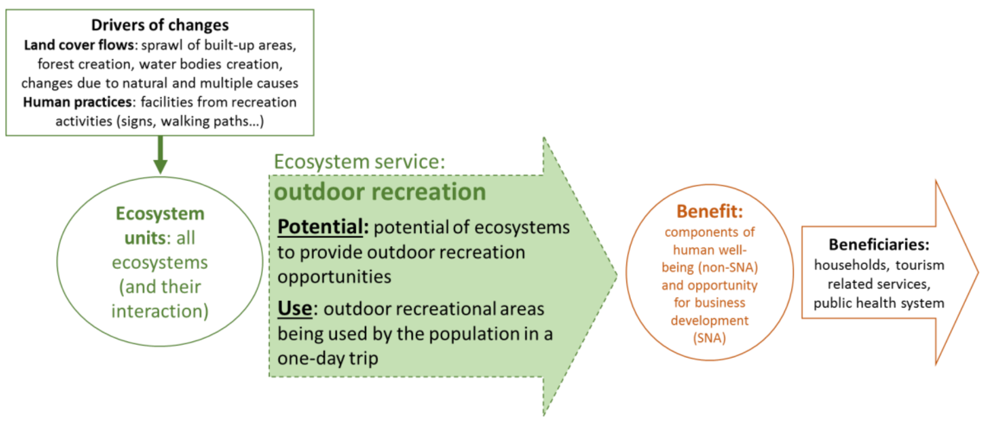
Zank, B., Bagstad, K.J., Voigt, B. & Villa, F. (2016) Modeling the effects of urban expansion on natural capital stocks and ecosystem service flows: A case study in the Puget Sound, Washington, USA. *Landscape and Urban Planning*, 149, 31-42. doi - http://dx.doi.org/10.1016/j.landurbplan.2016.01.004

*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

4.1.3 Cultural ecosystem services

OUTDOOR RECREATION		
Definition	The biophysical characteristics or qualities of ecosystems that are viewed, observed, experienced or enjoyed in a passive or active way by people in a one-day trip (modified from CICES V5)	
Ecosystem types	All ecosystem types. Interaction among different ecosystem types may be translated in a positive effect in terms of potential opportunities for recreation	
Economic unit	Users of the service	Households
	Beneficiaries	Households, sports activities and amusement and recreation activities, tourism related services (food and beverage), public health system
SEEA EEA ecosystem accounting model		
CONCEPTUAL DEFINITION OF INDICATORS		
ECOSYSTEM SERVICE		
Potential	Capacity (stock)	Ecosystems potential to provide outdoor/nature-based recreation opportunities (hectares of outdoor recreational areas)
	Potential flow	Use of the recreation opportunities below a critical threshold in which ecosystems are not degraded
Use	Actual flow of outdoor recreational areas being used by the population in a one-day trip	
SOCIO-ECONOMIC SYSTEM		
Demand	Population needs for daily recreation (one-day trip)	
Unmet demand	Population gravitating on areas with low recreation opportunities	
Benefit	Components of human well-being (non-SNA benefit such as support human health and aesthetic appreciation) and opportunities for business development (SNA benefit such as tourism related services)	

VALUATION METHODS

Direct market pricing:

- Everard, M. and S. Jevons (2010) Ecosystem services assessment of buffer zone installation on the upper Bristol Avon, Wiltshire. Environment Agency.
- Homarus Ltd. (2007) Estimate of economic values of activities in proposed conservation zone in Lyme Bay. A report for the wildlife trusts.
- Postel, S. and S. Carpenter (1997) Freshwater ecosystem services. In: G. Daily (ed), "Ecosystem services: their nature and value." Island Press, Washington, D.C., USA.
- Turpie, J. et al. (1999) Economic value of the Zambezi Basin Wetlands. Zambezi Basin Wetlands conservation and resource utilization project. IUCN Regional Office for Southern Africa.

Production function:

- Beaumont, N.J. et al. (2008) Economic valuation for the conservation of marine biodiversity. Marine Pollution Bulletin 56(3): 386-396.

OUTDOOR RECREATION

- Dubgaard, A. et al. (2002) Cost-benefit analysis of the Skjern River Project. Royal veterinary and agricultural university. Conducted for the Danish Forest and Nature Agency as part of the investigations on biodiversity and nature protection by the Wilhjelm Committee.
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Travel cost:

- UK National Ecosystem Assessment Follow-on (2014) The UK national ecosystem assessment. UNEP-WCMC, Cambridge.
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INDICATORS TO BE USED IN INCA

ECOSYSTEM SERVICE		
Potential	Capacity (stock)	• Extent of outdoor recreational areas (ha). Outdoor recreational areas will be defined for a specific threshold of recreation opportunities or for the presence/absence of certain features
	Potential flow	• Critical threshold is not available yet. For the definition, the physical-ecological component for the assessment of the tourist carrying capacity could be used (http://ec.europa.eu/environment/iczm/pdf/tcca_en.pdf). Sustainable flow might also be indirectly estimated through the valuation method
Use	• Hectares of outdoor recreational areas being used by the population in a one-day trip. Use by the population will be based on the proximity matrix (to roads and urban areas), facilities (paths), and share of population that can make use of natural areas (based on population statistics: population by age classes…)	
SOCIO-ECONOMIC SYSTEM		
Demand	• Population/infrastructures built	
Unmet demand	• Population living in areas with low or without recreation opportunities for one-day trip	
Benefit	• Components of human well-being (non-SNA benefit such as support human health and aesthetic appreciation) and opportunities for business development (not quantified in INCA)	
DRIVERS OF CHANGES IN THE MODELLING FRAMEWORK		
INCLUDED IN THE MODEL: dynamic variables: land uses; population; infrastructure (road network and public transport); geomorphology of coast (1990-2000-2006); marine water clarity; urban green infrastructure		

OTHER METHODS AND TOOLS (review)

TOOLS

- Invest (http://www.naturalcapitalproject.org/invest/) recreation model predicts the spread of person-days of recreation, based on a proxy for visitation: geotagged photographs posted to the website flickr (Wood *et al.*, 2013)

OUTDOOR RECREATION

- Social Values for Ecosystem Services (SolVES) is a value mapping application that provides a quantitative, non-monetary metric of social values. As social values recreation and aesthetic values are included (Sherrouse *et al.*, 2011)

METHODS

- Study quantifying recreation potential based on a scoring system for different landscape elements (Haines-Young *et al.*, 2012)
- Regional approach using trails and Public facilities as main proxies (García-Nieto *et al.*, 2013)
- Study assessing supply and use for recreation based on the combination of multiple methodologies (Peña *et al.*, 2015)
- Study introducing accessibility analysis in mapping cultural ecosystem services (Ala-Hulkko *et al.*, 2016)
- Outdoor recreation potential is estimated based on landscape metrics at coarse spatial scale, combined with campsite density as an indicator of the supply and benefit capture (Weyland & Laterra, 2014)
- A spatially explicit participatory mapping of the complete range of cultural ecosystem services (recreation included) and several disservices perceived by people living in a cultural landscape in Eastern Germany (Plieninger *et al.*, 2013)
- Simple quantification of green urban spaces as recreational areas (Larondelle & Haase, 2013)

POTENTIAL CONTRIBUTION

Conclusions:

The JRC has a broad experience on modelling outdoor recreation. The method to map and assess recreation in INCA is more detailed explained in the Annex III.

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*Tier level indicates the level of complexity and/or the degree of development to reach the ideal indicator. Tier I: rather simple, e.g. land cover-based, Tier II: more complex, e.g. statistics based and Tier III: complex, e.g. model-based.

5 Drivers of change in ecosystem services

Perhaps more than spatial accuracy, timeliness is crucial in accounting. Providing in due time regular updates of natural capital accounts will increase their use in different policies. Since accounts for most ecosystem services will rely on indirect observations and models and not on direct field observations, the drivers of change or input data of ecosystem services models are crucially important variables. Accurate and regular updates of ecosystem service accounts will to a large extent be dependent on updates of the input variables or the drivers of change. The accuracy and temporal resolution of the drivers of change is therefore key to deliver ecosystem service accounts.

For terrestrial ecosystems, the most important direct drivers of changes in ecosystem services flow in the past 50 years have been land cover changes and the intensification of human practices (i.e. land management) (Figure 4.1) by the application of new technologies, which have significantly contributed to increase the supply of services such as food, timber and fibre (Nelson 2005). Although land use intensity, measured as the human appropriation of net primary production (HANPP), has increased on average in Europe between 1990 and 2006 in about 43%, this was not a generalized phenomenon as some regions are also affected by land abandonment (Plutzar et al. 2016).

Actually, intensification and abandonment of agriculture practices are among the most frequently reported pressures and threats for terrestrial habitats listed in the Habitats Directive (EEA 2015b). These pressures will be thoroughly addressed in the condition accounts carried out by the EEA. Under some circumstances, information about pressures can be included into the biophysical (spatially explicit) models of ecosystem services. For instance, for water purification, information on water quality related to land use intensity (i.e. nitrogen concentration in the water) is accounted for in the model. The higher the level of pollutants; the lower will be the ecosystem capacity to purify water. However, including this information is not always possible, mainly because of the lack of coherent spatial data.

Among the indirect drivers of change, population is among the most relevant because of its important influence on land use and land cover changes (Nelson 2005). Nevertheless, the importance of population in accounting is twofold, as indirect drivers of ecosystem change, but also from the demand side. If population increases, the demand for ecosystem services will be higher.

When modelling ecosystem services, not all the drivers of change as well as their interactions can be included in the models. Therefore, in the following sections we analyse the trends of the drivers of change that are more frequently included into the biophysical models of ecosystem services: land cover and population changes, which are also more relevant for the supply and use tables.

5.1 Land cover changes

The role of land cover (LC) data in accounting is twofold. On one hand, LC maps will be the basis of the supply table, where the contribution of the ecosystem units for the actual flow is quantified (see section 3.3). On the other hand, LC maps area among the main environmental variables included in the models for mapping and projecting ES. Consequently, accounting for ecosystem services is largely dependent on the land cover changes taking place.

In recent years, there has been an increase in freely available and open data LC products, which provide time series of land cover change at European level (Table 5.1). Clearly, these land cover data have been derived for different purposes, using different methodologies and come with different spatial, temporal and thematic resolutions, with different strengths and weaknesses. Therefore, every dataset is showing a different 'picture' of the reality and their comparison may contribute to better understanding the degree and distribution of the uncertainties in land cover changes.

Some studies already provide some uncertainty analyses derived from the comparison of different land cover datasets (Fritz and See 2008, Pflugmacher *et al.*, 2011, Bai *et al.*, 2014), but to our knowledge, none of them has been specifically done at European level. In this section, we aimed at analysing the differences in the land cover estimates among seven different sources of LC data.

In this comparison, we included the following data sources (Table 5.1):

- Two LC maps derived from remote sensing imagery and/or photointerpretation: CORINE Land Cover (CLC) and the Climate Change Initiative-Land Cover v1.6.1 (CCI-LC). In CCI-LC urban areas and water bodies were extracted from reference datasets and show no changes through time (see UCL-Geomatics (2015) for further details). Validation of CCI-LC maps for Europe is still in progress. GlobCover and Modis were not included in the analysis, since the temporal comparisons of these products are discouraged in the manual for data users.

- Three different high resolution products (~30 x 30 m) providing data on single land cover types: the Global Surface Water Explorer (GSWE) (Pekel *et al*., 2016) for the water layer including rivers, lakes and water surface of wetlands, the Global Human Settlement Layer (GHSL) for built-up areas (i.e. urban) (Pesaresi *et al.*, 2016) and the Global Forest Watch (GFW) to analyse forest extent (Global Forest Watch, 2014). This last data source also includes a disclaimer about the unfeasibility of comparing the forest losses and gains they provide. However, we included this dataset in our analysis because, in spite of the disclaimer, this product is specifically addressing changes in forest extent comparing losses and gains (see Hansen *et al.* (2013); and Angelstam *et al.* (2017) and Apan *et al.* (2017) for other applications). However, we should interpret their results with caution. Although the three data sources provide only information for single land covers, their high spatial resolution proves to be useful for the comparisons with the LC maps developed at coarser resolution.

- Data derived from field survey covering the EU such as the Land Use and Coverage Area frame Survey (LUCAS) were included in the analysis as well, limited to the information on land cover (lan_lcv_ovw in Eurostat). However, for these data, only the statistics on extent at country level were compared for 2009 and 2012 (note: statistics for 2015 will become available soon).

- Finally, we also included in the analysis LC products derived from modelling exercises, such as The HIstoric Land Dynamics Assessment (HILDA) dataset (Fuchs *et al.*, 2013; Fuchs *et al.*, 2014). We included modelled data in the comparisons because this type of data are frequently used to project future scenarios, but comparisons of modelled scenarios with empirical data are seldom assessed.

Comparisons were made for the 23 countries for which all datasets provided LC data (Austria, Belgium, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, The Netherlands, Poland, Portugal, Sweden, Slovenia, Slovakia, and United Kingdom). We refer to this list of countries as EU-23 from here onwards. Land cover classification was harmonized for all datasets according to the tables included in Annex V. Annual rate of change (rate in % per year) for each dataset was estimated for the longest available period, trying to fit most of the LC data between 1990 until present (Table 5.2).

Table 5.1 – Freely available land-cover data with EU coverage

Method	Land Cover data	Resolution			Geographic coverage	Url
		Spatial	Thematic	Temporal		
Earth observation	CORINE Land Cover	100 m	44 types	1990, 2000, 2006, 2012	EU, +11 countries	http://land.copernicus.eu/pan-european/corine-land-cover/view
	CCI Land Cover (v1.6.1)	300 m	36 types	~2000, ~2005 and ~2010	Global	http://www.esa-landcover-cci.org/?q=node/158
	GlobCover[1]	300 m	22 types	2005 and 2009	Global	http://due.esrin.esa.int/page_globcover.php; http://due.esrin.esa.int/files/GLOBCOVER2009_Validation_Report_2.2.pdf
	Modis[1]	0.05 degree (~5600m)	17 types	Yearly 2001-2012	Global	http://glcf.umd.edu/data/lc/
	Global Surface Water Explorer	30 m	1 type (rivers lakes and wetlands)	1984, 2015	Global	https://global-surface-water.appspot.com/
	Global Human Settlement Layer	38 m	1 type (built up)	1975, 1990, 2000, 2014	Global	http://ghsl.jrc.ec.europa.eu/ghs_bu.php
	Global Forest Watch	30 m	1 type (forest)	Yearly 2001-2014	Global	http://www.globalforestwatch.org/
Field survey data	LUCAS data[2]	Point data over 2x2 km grid	76 types	2006, 2009, 2012, 2015. Statistics on extent: 2009 and 2012	EU28, but Croatia, Bulgaria, Cyprus, Malta and Romania (for trends)	http://ec.europa.eu/eurostat/web/lucas/overview
Modelling	Hilda dataset	1 x 1 km	6 types	1900-2010 (every 10 years)	EU, but Azores, Canary Islands and Croatia	http://www.wur.nl/en/Expertise-Services/Chair-groups/Environmental-Sciences/Laboratory-of-Geo-information-Science-and-Remote-Sensing/Models/Hilda.htm
	Land-Use Harmonization (LUH2)[3]	0.25 x 0.25 degree (28 km)	8 types	850-2100 (annually)	Global	http://luh.umd.edu/data.shtml

[1]Comparison of different years is discouraged by the authors

[2]Used for the comparative analysis, although in the metadata there is a disclaimer mentioning that comparability over time for estimates related to areas < 500 km^2 should be avoided, especially within strata with a limited coverage

[3]Not considered in the analyses because of the coarse spatial resolution

Table 5.2 – Extent of MAES ecosystem types according to different sources of land cover data

Values are shown for the longest time series available from 1990 until present and rate of changes per year. 23 countries[1] were included in the analysis, for which all datasets provide LC information for comparisons (in km^2)

Ecosystem type	Data[2]	1984	1990	2000	2009	2010	2012	2014	2015	Rate (%)/ decade[3]
Urban	**CLC**		173,305				190,253			4.45
	LUCAS				166,133		170,230			8.22
	CCI-LC			231,343		231,343				NA
	HILDA			157,145		156,342				-0.51
	GHSL		245,906					318,535		12.31
Cropland	**CLC**		1,433,505				1,417,768			-0.50
	LUCAS				953,290		946,615			-2.33
	CCI-LC			1,530,903		1,533,779				0.19
	HILDA			1,137,504		1,077,741				-5.25
Grassland	**CLC**		466,494				462,971			-0.34
	LUCAS				807,273		804,406			-1.18
	CCI-LC			346,212		346,501				0.08
Heathland and shrub	**CLC**		178,377				176,482			-0.48
	LUCAS				273,395		273,231			-0.20
	CCI-LC			117,878		118,050				0.15
Woodland and forest	**CLC**		1,439,309				1,443,808			0.14
	LUCAS				1,480,110		1,481,767			0.37
	CCI-LC			1,449,603		1,446,202				-0.23
	HILDA			1,387,144		1,417,157				2.16

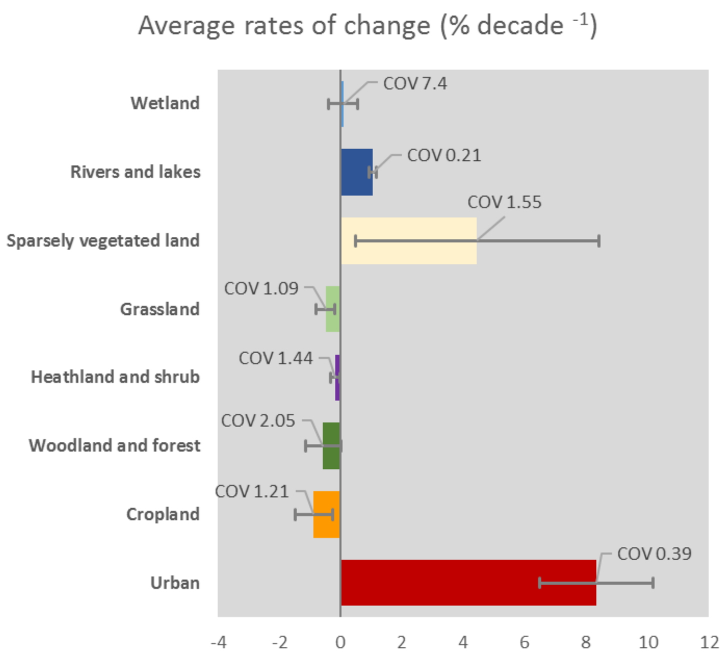
Ecosystem type	Data[2]	1984	1990	2000	2009	2010	2012	2014	2015	Rate (%)/ decade[3]
	GFW			1,439,200			1,395,251			-2.54
Sparsely vegetated land	**CLC**		55,463				54,356			-0.91
	LUCAS				65,858		68,656			14.16
	CCI-LC			78,565		78,630				0.08
	HILDA			60,144		60,166				0.04
Wetlands	**CLC**		95,710				94,493			-0.58
	LUCAS				67,649		67,803			0.76
	CCI-LC			94,561		94,561				NA
Rivers and lakes	**CLC**		101,941				103,989			0.91
	LUCAS				130,454		130,798			0.88
	CCI-LC			95,180		95,180				NA
	GSWE	103,088							107,416	1.35

[1]List of countries included: Austria, Belgium, Czech Republic,, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, The Netherlands, Poland, Portugal, Sweden, Slovenia, Slovakia, and United Kingdom

[2]CLC - Corine Land Cover; LUCAS - Land use and land cover survey; CCI-LC - Climate Change Initiative Land Cover, HILDA - HIstoric Land Dynamics Assessment; GHSL - Global Human Settlement Layer; GFW- Global Forest Watch; GSWE - Global Surface Water Explorer

[3]NA values are assigned when no change where found for the CCI maps due to the use of reference (static data). In addition, no changes at EU level for a 10 year time period is not very likely

The average and standard error of the rate of change for the different data sources show variability in the uncertainty for each ecosystem type (Figure 5.1). To calculate the average rate for each ecosystem type, information derived from the HILDA dataset was not included for different reasons: a) it is derived exclusively from modelled data, in contrast to the observed data from other source; b) it presents important mismatches in the land cover classification when compared to the other datasets. For instance, grasslands within HILDA also include wetlands and shrublands (Annex V); c) it presents large discrepancies in terms of LC changes compared to other data sources. The HILDA dataset shows a decrease of urban areas between 2000 and 2010 in contrast to the increase shown by CLC, LUCAS and the GHSL (Table 5.2). Similarly, the modelled forest extent within HILDA shows important increases between 2000 and 2010 however, whereas CLC and CCI-LC only show a modest increase and even the GFW indicates that there are important decreases for practically the same period.



(Bars represent standard error and numbers show the absolute value of the coefficient of variation (COV). HILDA data were not included in these averaged values)

Figure 5.1 – Average rates of change according to the available datasets per ecosystem type
(In percentage per decade)

The ecosystem type showing the largest standard error is the sparsely vegetated land. The large standard error in this land cover type is mainly due to differences between LUCAS data (with an estimated increase of 1.42% per year between 2009 and 2012, Table 5.2), in contrast to the decrease estimated by CLC. Since the standard error of the data must always be understood within the context of the mean of the data, we also calculated the coefficient of variation (COV = standard deviation/mean). COV is independent of the unit in which the measurement has been taken, becoming more suitable for comparison between datasets with widely different means. We found the largest COV for wetlands; however, this value should be interpreted with caution since the rate of changes in wetlands approaches zero, inflating the COV. After wetlands, woodland and forest, and sparsely vegetated land are the ecosystem types with the largest COV. In contrast, rivers and lakes followed by urban areas show the smallest COV.

This variability in trend of LC changes arising from the different LC maps may have important consequences on the uncertainty of the outcomes, when modelling changes in ES through time. This uncertainty will become especially important for those ES highly driven by the land cover types characterised by higher uncertainty. For instance, soil erosion control will give very different results depending on the LC data used since both forest and sparsely vegetated land are key determinants of this ES.

Uncertainty varies highly among the different ecosystem types, but also across the geographic space. Figure 5.2 shows the COV at country level, for each ecosystem type.

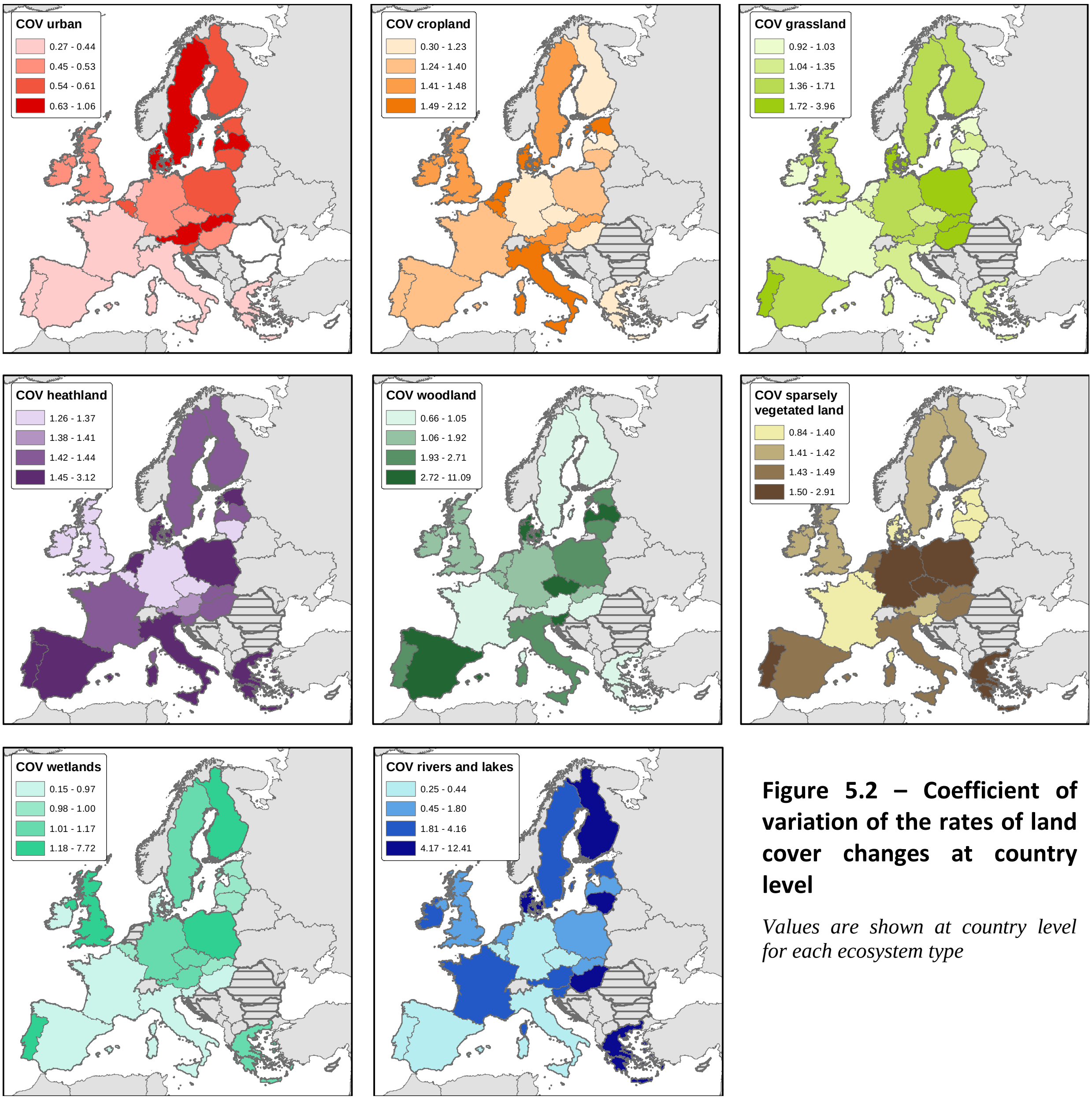


Figure 5.2 – Coefficient of variation of the rates of land cover changes at country level

Values are shown at country level for each ecosystem type

Colour palette showing darker colours indicate percentile ranges. Countries with line fill symbol were not included in the comparisons because of the lack of data for some of the LC datasets. Number of datasets included in the analysis varies among ecosystem types: urban 3; cropland 3; grassland 3; heathland 2; woodland 4; sparsely vegetated land 3; wetlands 2; rivers and lakes 3

When modelling different ES, higher uncertainty in the outcomes may be expected for those countries where the COV is large. For instance, if we model flood control using urban areas as target area for this service, we would find different results depending on the LC dataset used as model input, particularly in countries with large COV (i.e. Sweden, Denmark, Austria…).

5.1.1 Urban land

Urban areas are the land cover type showing the largest increase in relative terms in Europe (EU-23), with an average increase of about 8% (± 1.85 SE) in a decade (Figure 5.1). However, it is among the land cover types with the smaller COV at EU level, showing larger values in North-Eastern Europe (Figure 5.2). Figure 5.3 shows the urban extent for the different LC dataset and years. GHSL estimates the amount of urban areas to be about 120,000 km^2 higher than the LUCAS data. GHSL is the LC dataset showing the largest rate of increase in built-up areas between 1990 and 2014. We also included values for urban extent for CCI-LC for visual comparison; however, this LC was static in this map.

Even when the urban extent of GHSL and LUCAS are quite different (Figure 5.3), the rates of changes are fairly similar, with values of 12.31 and 8.22 % $decade^{-1}$ respectively.

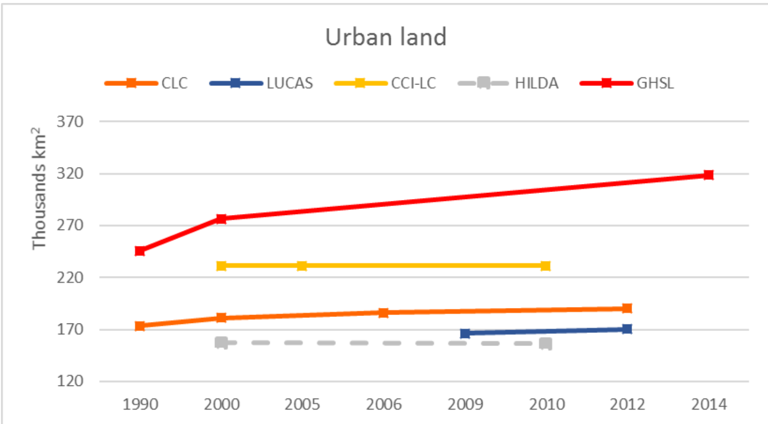


Figure 5.3 – Urban extent through time for the available LC datasets

(Values based on 23 countries)[9]

5.1.2 Cropland

Cropland is the ecosystem type showing the largest relative decrease in Europe (based on EU-23), with an average decrease of almost 1% (± 0.62 SE) in a decade (Figure 5.1). The COV at country level shows larger values in Italy, Belgium, the Netherlands and Estonia. In contrast, different LC datasets tend to converge in Germany, Czech Republic and Finland, among others (Figure 5.2). Figure 5.4 shows that the estimates on the extent are more similar between CLC and CCI-LC, but LUCAS delivered a much lower total extent for cropland. However, the rates of change for the longest available period suggest a slight increase of cropland based on CCI-LC (0.19 % per decade), but a decrease of cropland based on CLC and LUCAS, with values of -0.5% and -2.33 % per decade respectively (Table 5.2).

[9] Note that X-axis does not show consecutive years

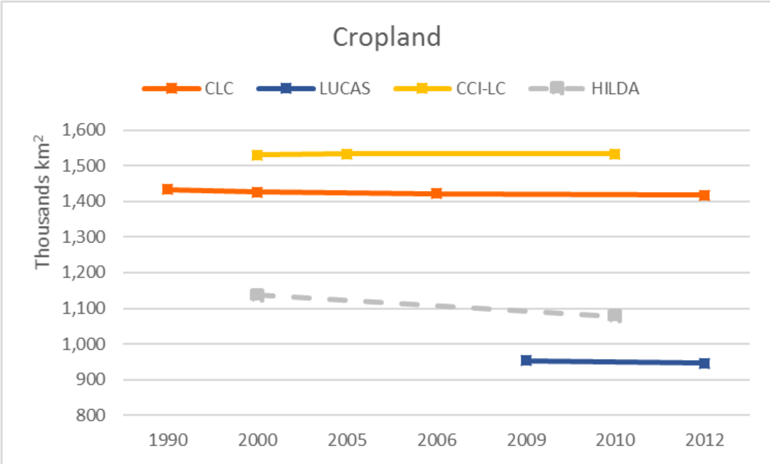


Figure 5.4 – Cropland extent through time for the available LC datasets
(Values based on 23 countries)

5.1.3 Grassland

The three LC datasets revealed an average decrease in the extent of grassland of about 0.5 % per decade (± 0.3 SE) (i.e. based on values for 23 countries, Figure 5.1). The spatial distribution of the COV suggests that uncertainty is especially large in countries such as Poland, Slovakia, Hungary and Portugal (Figure 5.2). The LUCAS data estimate the extent of grassland significantly larger than CLC and CCI-LC (Figure 5.5). However, the rates of change for the longest available period delivered a slight increase in grasslands based on CCI-LC, whereas CLC and LUCAS resulted in a decrease (Table 5.2).

Grassland, together with heathland and shrub, are the ecosystem types showing the largest ranges between the estimates of their extent, compared to the average extent. Between LUCAS and CCI-LC there is a difference of about 450,000 km^2, which is high relative to the average extent of this ecosystem (ca. 500,000 km^2). These large differences may be due to the different methods used, but possibly also to the broad definition of grassland. For instance, LUCAS includes grassland with sparse tree/shrub cover, grassland without tree/shrub cover but also spontaneously re-vegetated surfaces. In contrast, in CLC we consider as grasslands (MAES ecosystem type) natural grasslands and pastures (Annex V). The lack of standardized legends among LC dataset hinders a proper comparison.

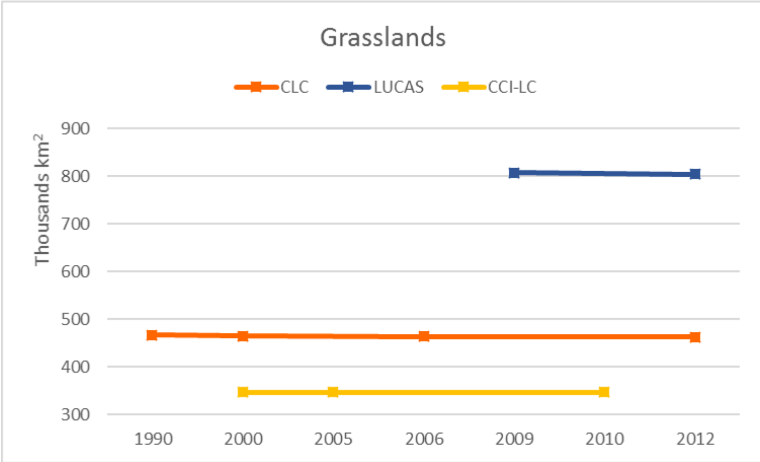


Figure 5.5 – Grassland extent through time for the available LC datasets

(Values based on 23 countries)

5.1.4 Heathland and shrub

Heathland and shrub ecosystems show, on average, a slight decrease in extent of 0.18 % (± 0.15 SE) per decade (Figure 5.1). This ecosystem type presents a COV larger than cropland and grassland, with larger values in Southern Europe, but also in Poland, The Netherlands and Denmark (Figure 5.2). The estimates from LUCAS are substantially larger than CLC and CCI-LC do (Figure 5.6). Similarly to grassland ecosystems, the rates of change for the longest available period show a slight increase in heathland according to CCI-LC, whereas CLC and LUCAS report a decrease (Table 5.2).

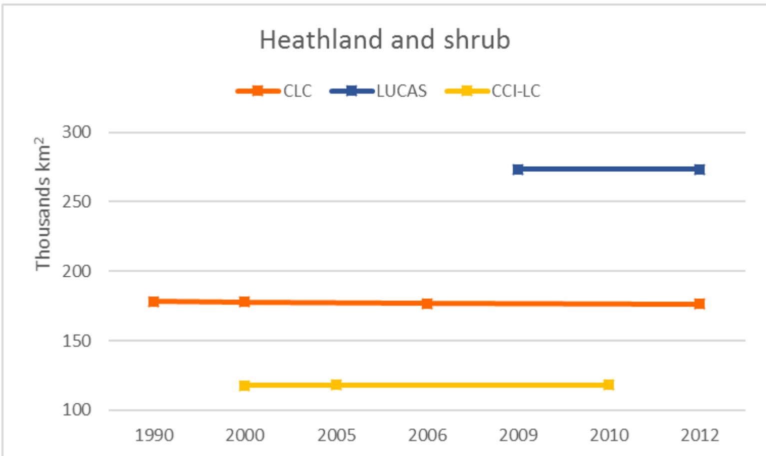


Figure 5.6 – Heathland and shrub extent through time for the available LC datasets

(Values based on 23 countries)

5.1.5 Woodland and forest

Woodland and forest show an average reduction in extent of 0.56 % (± 0.58 SE) per decade (Figure 5.1). It is the ecosystem type with the largest COV (excluding wetlands), presenting large uncertainty in the trend of changes in extent. CLC and LUCAS report an increase (together with HILDA), while CCI-LC and GFW show a reduction. The COV is significantly larger in Spain, Austria, Denmark, Latvia and Slovenia (Figure 5.2). Figure 5.7 shows forest extent for the different LC datasets and years, calling especial attention to the decrease shown by GFW. This decrease should be interpreted with caution because even when gains and losses are compared within the original work (Hansen *et al.*, 2013), the data user manual include a disclaimer discouraging the comparison of tree cover, loss, and gain data sets. Actually, the trends comparison suggests that the forest losses in the GFW are, to some extent, overestimated, since the decrease it shows is extremely strong and notably diverge from the trends shown by the other datasets.

Around 2009, differences are apparent in the forest extent of about 80,000 km^2 between LUCAS and GFW. However, these differences are not very substantial with respect to the average forest extent (ca. 1,400 thousands km^2). Thus, in relative terms, this is the ecosystem type where extent estimates are more similar among datasets in relation to its total extent.

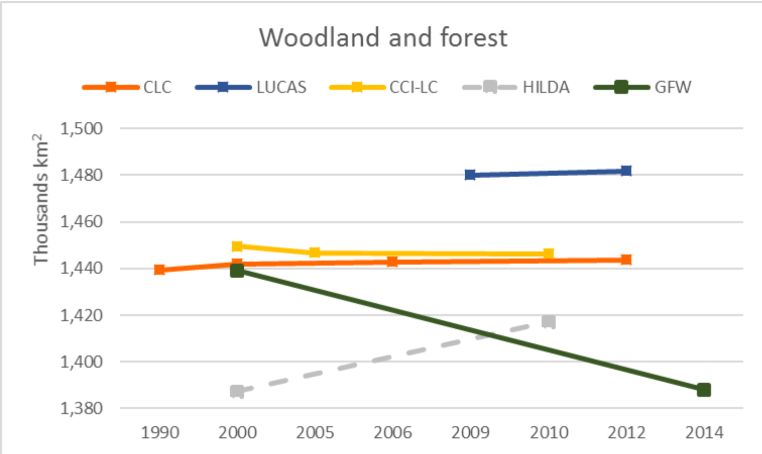


Figure 5.7 – Extent of woodland and forest through time for the available LC datasets
(Values based on 23 countries)

It is important to consider that forest definition may differ depending on the LC dataset used. For instance, forest in CLC is defined for canopy density about 30%, but (following MAES ecosystem type) we also included transitional woodland-shrub, with canopy density between 10 and 30% (Appendix V). In this way, the measure of the forest extent is directly comparable with the forest definition in LUCAS data, which defines forest for a canopy density above 10%. The forest definition in the CCI-LC uses different fractions of canopies depending on the location, so, it is difficult to identify the thresholds they adopted to distinguish forest from non-forest (see also Li et al. 2016).

5.1.6 Sparsely vegetated land

The average rate of changes in sparsely vegetated land shows the second largest relative change in extent (4.45 % per decade, ± 4.0 SE), after urban areas. The large standard error, but also the COV, confirms a large uncertainty in the estimates of change for sparsely vegetated land (Figure 5.1). Geographically, this uncertainty is larger in Greece, Portugal, Germany, Poland and Czech Republic (Figure 5.2).

The variability in the extent of sparsely vegetated land between CLC and CCI-LC is about 25,000 km^2. This variability is smaller than the average extent estimates for all LC dataset and all years, which is about 65,000 km^2 (Figure 5.8).

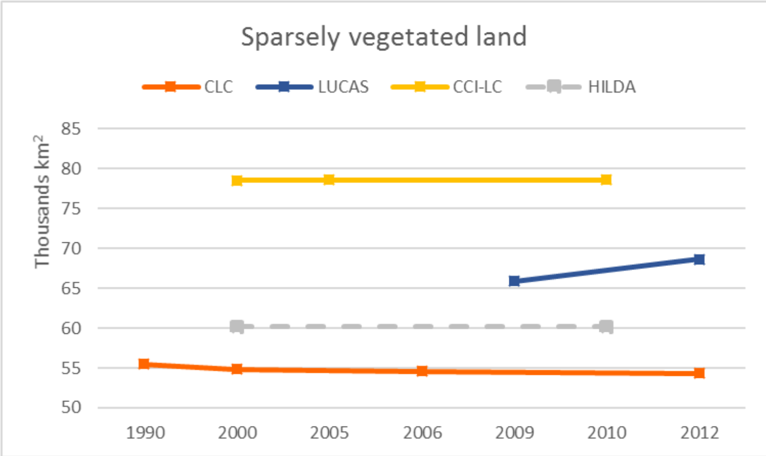


Figure 5.8 – Extent of sparsely vegetated land through time for the available LC datasets
(Values based on 23 countries)

5.1.7 Wetlands

Changes in wetland extent are only reported by CLC and LUCAS, and they show an average increase of 0.1% per decade, with a very large standard error (± 0.5 SE) (Figure 5.1). This large SE is due to the opposing trend of changes shown by both datasets (Table 5.2). Thus, from this assessment, is not clear if wetlands are increasing or decreasing at EU level. Uncertainty is particularly large in countries such as Portugal, Poland and Finland (Figure 5.2).

Figure 5.9 shows that wetland extents obtained from CLC and CCI-LC are really similar. However, CCI-LC does not report changes in wetland extent due to the use of a static reference layer.

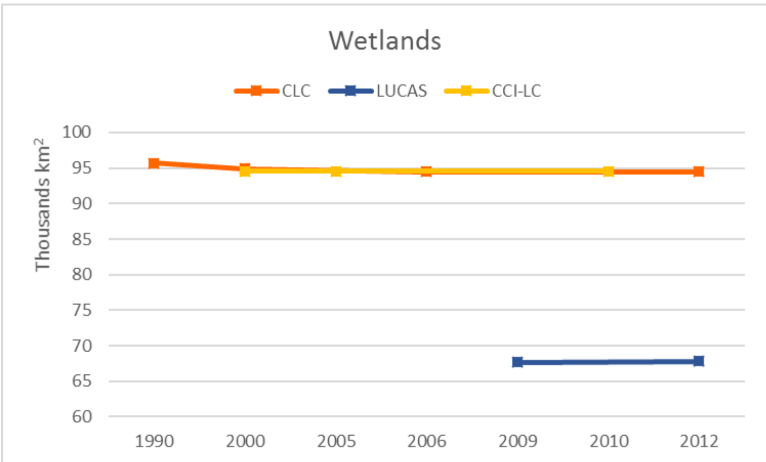


Figure 5.9 – Wetland extent through time for the available LC datasets
(Values based on 23 countries)

5.1.8 Rivers and lakes

River and lakes (including also the water layer of wetlands) represent the ecosystem type where uncertainty on changes in the extent is limited, as shown by the small standard error and COV. Rivers and lakes show an average increase of 1.05% (± 0.13 SE) per decade (Figure 5.1). The small uncertainty for this ecosystem type might be explained by the clear limits of this land cover (i.e. water vs. no water), that can be relatively easily distinguished by remote sensing imagery processing, but also very clear to be recognized in field observations (i.e. such as in LUCAS data). The limits between sparsely vegetated land, grassland and heathland and shrubland are more difficult to define, as stressed also in the grassland section, thus increasing the uncertainty for these land cover types.

All LC datasets report a positive trend of changes at EU level (Table 5.2), with no very different estimates in the extent (Figure 5.10). CLC and the GSWS show practically the same extent; although CCI-LC do not report changes because of the use of a static reference layer (included in the figure for visual comparisons).

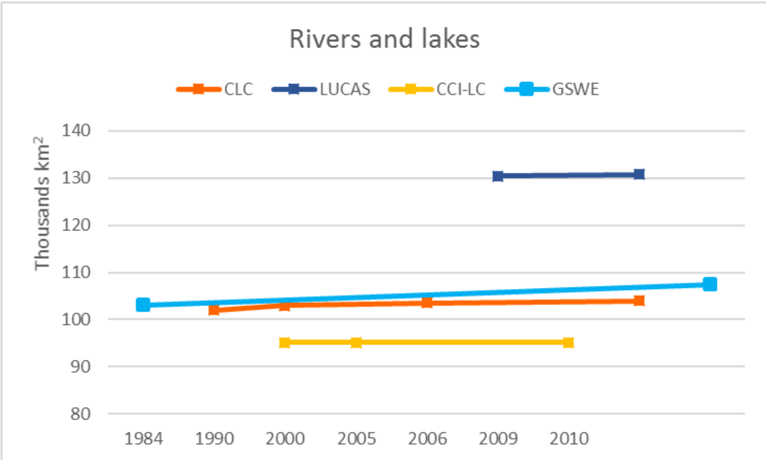


Figure 5.10 – Extent of rivers and lakes through time for the available LC datasets
(Values based on 23 countries)

5.1.9 Implications for ecosystem services accounting

The differences among the analysed datasets highlight one important source of uncertainty in the ecosystem services assessment and changes over time. As shown before, this uncertainty is especially important for forest, sparsely vegetated land and heathland, where COV's are larger. Therefore, the choice made on the use of the land cover/use datasets for natural capital accounts will largely determine the outcomes, which should be considered within the accounting framework. Ideally, model projections should be made using different sources of land cover. Unfortunately, GlobCover and Modis cannot be used for time series analysis.

For a more robust integration of uncertainty in land cover changes within the ecosystem services assessment, new land cover maps with EU coverage would be required. In this sense, Copernicus data (http://land.copernicus.eu/) constitute a promising source of data for ecosystem services accounting. However, since the release of data from Copernicus it is still in its initial stage, it lacks representative historical data to implement the accounting. Novel applications of Google Earth Engine to obtain updated information on land covers would be also useful, at least to validate data sets or model predictions.

5.2 Population: driving changes in the ecosystems and the demand

As mentioned before, population is a key driver of land use and land cover changes affecting the ES potential, but it is also very important to indicate the demand side of ecosystem services. Because ES are meant to contribute to the human well-being, population can be used to estimate the direct and indirect demand of households and economic sectors, respectively, and hence also to approximate or quantify the use of the ES and the benefits derived from them. Therefore, population changes are usually translated into changes in the amount of users and beneficiaries of the ES.

A comparison of the population data provided by the Global Human Settlement dataset and the Eurostat data at Nomenclature of Territorial Units for Statistics (NUTS) 0 (table [demo_pjan]) reveals few differences between the two datasets. Differences become slightly more important in 2015 (Figure 5.11). However, the trend of population increase is very similar between the two data sources, confirming that in the EU-28, population has increased, on average, by 6% between 1990 and 2015.

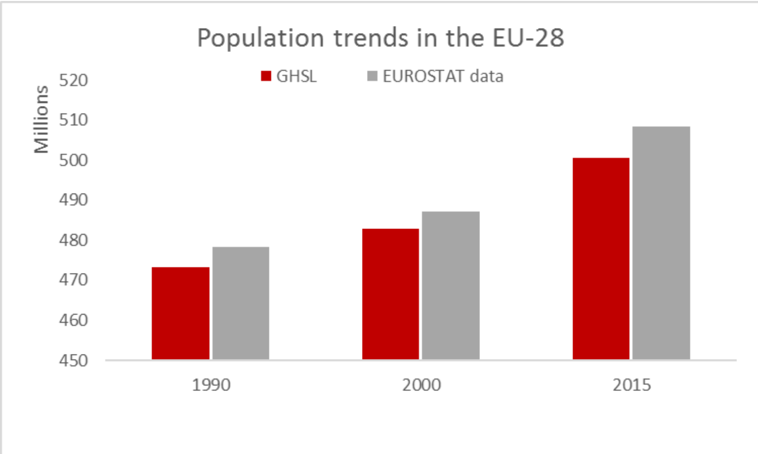
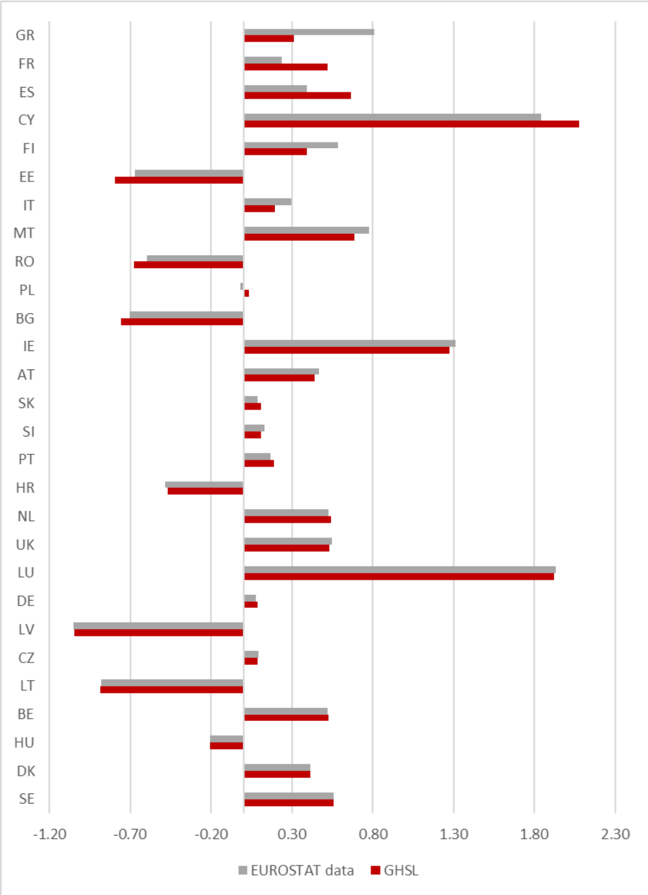


Figure 5.11 – Population in the EU-28 according to the Global Human Settlement dataset and Eurostat data

At country level, we can find some countries like Greece, France and Spain where the differences in the population changes between 1990 and 2015 are higher than in other countries (Figure 5.12). On the contrary, the level of uncertainty in changes estimated by the two data sources in Sweden, Denmark and Hungary is practically insignificant.

Figure 5.12 – Average rates of population change between 1990 and 2015 at country level

Data source: the Global Human Settlement Layer and the Eurostat data (values are in % per year)



6 Final remarks

Ecosystem services are the contributions of ecosystems to human well-being. Ecosystem accounting aims to measure these contributions in a consistent manner at different points in time. They allow us tracking the changes in ecosystems, biodiversity, ecosystem condition and ecosystem services. Ecosystem accounts can be used to measure how ecosystems contribute to the economy through the delivery of ecosystem services.

The System of Environmental Economic Accounts – Experimental Ecosystem Accounts (SEEA EEA) is the starting point and fundamental basis to build these ecosystem accounts. The SEEA EEA provides a set of Technical Recommendations to set up ecosystem accounts that aims to complement the System of National Accounts and the SEEA-Central Framework.

In terms of definitions, ecosystem services differ from the benefits in both their ecological meaning (degree of complexity) and accounting meaning (need to separate ecosystem services from the SNA goods & services).

Merging ecological and accounting perspectives remains a challenge, which requires on the one hand capturing the complexity of ecological processes in single numbers and, on the other hand, respecting the rigorous rules of accounting systems, which are based on economic principles. The possibility to expand core economic accounts with external satellite information opens the door to a common ground where ecology and economic perspectives can be harmonized in a consistent way.

This report presents a series of fact sheets that contain essential information to set up physical and monetary ecosystem services accounts, which align well with the SEEA EEA technical recommendations (SEEA EEA TR). They describe a conceptual framework and then report on a set of alternatives to proceed with their quantification. A closer inspection of these fact sheets suggests that the ecological dimension calls for a more harmonized integration with the economic perspective. Within the JRC, there are tools and knowledge basis to proceed consistently toward this harmonization.

The information reported in the SEEA EEA TR could thus benefit from additional sets of tables to complete the initial picture, in order to enable sustainability assessment and to track a causality nexus between human activities and ecosystem services. However, the interconnection between ecosystem extent and condition accounts with the ecosystem service accounts is still unsolved.

The pilot applications running at the JRC within the KIP INCA framework will address these issues by: (i) applying the supply and use tables as reported in the SEEA EEA TR and (ii) complementing these tables with additional information aimed at considering the questions raised in Section 3.2 according to the structure proposed in Annex IV.

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Annex I: Water Purification

General introduction

Excessive nitrogen loading is a leading cause of water pollution in Europe and globally which makes nitrogen a useful indicator substance for water quality (Sutton et al., 2011; Rockström et al. 2009). We define N retention as the process of temporary or permanent removal of nitrogen taking place in the river. This includes the processes of denitrification, burial in sediments, immobilization, and transformation or simply transport (Grizzetti et al., 2015). According to this definition, N retention varies with the characteristics of the stream and of the living organisms in the aquatic ecosystem (e.g. bacteria, algae, plants), and hence depends on the ecological functioning of the system. Previous studies show that N retention is affected by N concentration in streams. Mulholland et al. (2008) showed that the efficiency of biotic uptake and denitrification declines as N concentration increases and Cardinale (2011) concluded that biodiversity in aquatic ecosystems has a positive effect on nitrogen retention. At the same time, biodiversity is threatened by high nutrient loadings in freshwater and coastal waters.

In this Annex we describe how we estimate the water purification ecosystem service first in physical and then in monetary terms. Available applications of this method are:

- the time series for Europe 1985-2005 (La Notte et al., 2017);
- a scenario analysis to improve nutrient supply based on an optimal reuse of organic manure and the adjustment of minimized mineral inputs. (La Notte et al., 2012).

Method: biophysical assessment

Use: actual flow of nitrogen removal

We use the Geospatial Regression Equation for European Nutrient losses (GREEN) model (Grizzetti et al., 2005; 2008; 2012) to estimate the in-stream nitrogen retention in surface water, which is considered in this paper as the actual flow of service provision.

GREEN is a statistical model developed to estimate nitrogen (N) and phosphorus (P) flows to surface water in large river basins. The model is developed and used in European basins with different climatic and nutrient pressure conditions (Grizzetti et al., 2005) and is successfully applied to the whole Europe (Grizzetti et al., 2012; Bouraoui et al., 2009). The model contains a spatial description of nitrogen sources and physical characteristics influencing the nitrogen retention. The area of study is divided into a number of sub-catchments that are connected according to the river network structure. The sub-catchments constitute the spatial unit of analysis. In the application at European scale, a catchment database covering the entire European continent was developed based on the Arc Hydro model with an average sub-catchment size of 180 km2 (Bouraoui et al., 2009). For each sub-catchment the model considers the input of nutrient diffuse sources and point sources and estimates the nutrient fraction retained during the transport from land to surface water (basin retention) and the nutrient fraction retained in the river segment (river retention). In the case of nitrogen, diffuse sources include mineral fertilizers, manure applications, atmospheric deposition, crop fixation, and scattered dwellings, while point sources consist of industrial and waste water treatment discharges. In the model, the nitrogen retention is computed on annual basis and includes both permanent and temporal removal. Diffuse sources are reduced both by the processes occurring in the land (crop uptake, denitrification, and soil storage), and those occurring in the aquatic system (aquatic plant and microorganism uptake, sedimentation and denitrification), while point sources are considered to reach directly the surface waters and therefore are affected only by the river retention.

For each sub-catchment i the annual nitrogen load estimated at the sub-catchment outlet (Li, 103 kg N year-1) is expressed as following:

$$Li = (DSi \times [1 - BRi] + PSi + Ui) \times (1 - RRi) \qquad \text{(eq. 1)}$$

where DSi (103 kg N year-1) is the sum of nitrogen diffuse sources in each catchment i, PSi (103 kg N year-1) is the sum of nitrogen point sources in each catchment i, Ui (103 kg N year-1) is the nitrogen load received from upstream sub-catchments, and BRi and RRi (fraction, dimensionless) are the estimated nitrogen basin retention and river retention, respectively. In the model, BRi is estimated as a function of rainfall while RRi depends on the river length. For more details on model parameterisation and calibration see Grizzetti et al. (2012) and Bouraoui et al. (2009). Although simple in its structure the model GREEN is able to provide spatially distributed estimates of nitrogen river and basin retention at large scale.

The actual flow of service or in-stream nitrogen retention Nretained is simply derived from equation 1 as the share of nitrogen that not included in Li and equals:

$$Nretained = Li \times RRi \times (1 - RRi)\text{-}1 \qquad \text{(eq. 2)}$$

In natural systems, nitrogen retention is related to nitrogen input. The residence time of water is a key variable for in-stream nitrogen retention since it directly affects the processing time of nitrogen within an aquatic system. Longer residence times increase the proportion of nitrogen input that is retained and removed from the water. We use modelled nitrogen retention as indicator for the actual flow of the water purification service.

ES potential: sustainable flow of nitrogen removal

Our initial hypothesis to calculate a sustainable flow of in-stream nitrogen retention is that there is a threshold in the nitrogen concentration of surface water below which the removal of nitrogen by the different ecological processes is sustainable from an ecosystem point of view. A similar threshold exists for atmospheric nitrogen deposition on terrestrial ecosystems with suggested critical nitrogen loads between 5 and 25 kg ha^{-1} $year^{-1}$ (Bobbink et al 2010). Here we propose to use a tentative threshold concentration of 1 mg N l-1 (Maes et al., 2012). This threshold is based on eutrophication risk. A global synthesis of published literature on the ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems suggests that levels of total nitrogen lower than 0.5–1.0 mg l-1 could prevent aquatic ecosystems from developing acidification and eutrophication (Camargo and Alonso, 2006). For potential risk of eutrophication for European surface water related to nitrogen concentration see also Grizzetti et al. (2011). This threshold concentration serves as an example for the purpose of this paper and will change depending on the vulnerability of different aquatic ecosystems to nitrogen loading. For instance, it does not apply for ecosystems naturally rich in nitrogen such as estuaries where a higher threshold could be used or for catchments with very vulnerable lakes where a lower threshold should be used. Spatially explicit sustainable targets for thresholds of total nitrogen concentration in freshwater systems can be set based on the European Water Framework Directive requirements for good or high ecological status.

Using data on average river flow (m3 year-1) in combination with the critical nitrogen concentration (1 mg l-1), we can calculate the critical nitrogen loading (Lcrit, 103 kg N year-1) - the critical threshold below which no environmental damage is expected. Substituting the nitrogen loading Li with Lcrit in equation 1 and solving equation 2 for N retained we obtain:

Ncrit = Lcrit × RRi × (1 – RRi)-1 (eq. 3)

where Ncrit is the critical nitrogen removal by the river network (103 kg N year-1), assuming a critical loading Lcrit.

Next, we use the critical nitrogen load and the critical nitrogen removal function, which assumes that at or below the critical nitrogen load, the removal of nitrogen by the different ecological processes that take place in the ecosystem is sustainable and results in the optimal use of the ecosystem from an ecosystem services point of view. However, increases in nitrogen loading far above the critical loading will result in costs due to the degradation of most other ecosystem services. This hypothesis allows thus for the use of nitrogen from anthropogenic sources and the subsequent nitrogen inputs to river systems up to a level at which nitrogen concentrations reach a critical threshold. In the monetary valuation calculations nitrogen removal will be valued the most at critical nitrogen loads. The following equation is used to estimate the sustainable removal of nitrogen:

Nsustainable = Ncrit × exp (– 0.5 × [L – Lcrit]2 × [1.5 × Lcrit]-2) (eq. 4)

Where

Nsustainable: the sustainable removal of nitrogen (103 kg N year-1),

Ncrit: the critical removal of nitrogen (103 kg N year-1),

L: the nitrogen loading at the outlet of each catchment (103 kg N year-1), and

Lcrit: the critical loading of nitrogen at 1 mg N l-1 (103 kg N year-1).

Equation 4 gives the sustainable in-stream nitrogen retention, also referred to in our paper as sustainable flow. It is important to stress that the exponent factor in equation 4 is introduced in this study to account for trade-offs that arise between water purification and other ecosystem services in conditions where nitrogen loads and concentrations are unsustainable. Studies unlike this one which analyse multiple ecosystem services delivered by aquatic ecosystems can use simply use Ncrit as value for Nsustainable. without applying the exponent function.

Benefit

Benefits of the water purification service could be intended as non-SNA benefit and specifically clean water. An indicator could be calculated by considering the water account compiled for the SEEA CF.

In surface freshwater abstraction we can select those beneficiaries who withdraw water; not all of them but only those who need clean water (i.e. water supply companies but not the hydroelectric sector). Based on the GREEN outcomes we could calculate the reduction of N concentration (generated by water purification) per cubic meter of abstracted water. At the moment we do not have this indicator but this is a future development to be addressed in the next run of the GREEN model.

Method: translation in monetary terms

In line with SEEA EEA guidelines, we adopt an exchange value based technique, specifically: replacement cost. The rationale for choosing replacement cost is well known. By (partially) cleaning up discharges from human activities, aquatic ecosystems provide for free a valuable ecosystem service and thus avoid a degradation of the ecosystem that would impact on human health and living conditions. Since human activities will not stop, there will always be the need for this ecosystem service even after river bodies will not be able to provide it any longer. The operational hypothesis of our valuation exercise is that an artificial replacement would be required in order to maintain the water purification service, and replacement would entail a cost. Considering the relevant pollution sources (mainly agriculture and livestock activities together with already treated industrial and households' discharges), the best proxy we can use as replacement cost are constructed wetlands. Wastewater treatment plants would be inappropriate because: (i) they are not applicable to the primary sector (agriculture and livestock activities) and (ii) what is discharged by the secondary sector (industrial activities) and by households is already treated by wastewater treatment plants before reaching water bodies10. Constructed wetlands (CW) provide ecosystem functions similar to those delivered by aquatic ecosystems. Their construction cost refers to ecosystem engineering work, which is more objective than values obtained through stated preferences, with a survey questioning citizens on the value they would place on nitrogen retention. The rationale is that artificial wetlands are also able to retain N present in relatively low concentrations, as opposed to urban wastewater treatment plants that need high concentration of the pollutant for efficient removal. A review of the value attributed to nitrogen retention is available from a previous study (La Notte et al, 2012a) where it is clearly shown how the choice of replacement costs is very popular among environmental economists. Wastewater treatment plants are much more expensive than CW; moreover, in our valuation exercise (following subsection) we differentiate between typologies of CW in order not to overestimate the cost, in fact the more extensive typology of CW (Free Water Surface) is the less expensive solution. We thus use the cost of CWs as proxy for the valuation of nitrogen retention, which represents a proxy for water purification. Specifically, the amount of nitrogen that is retained and removed by rivers and lakes will be converted to a CW area equivalent, i.e. the total area (ha) of CW that is needed to result in the same nitrogen retention as the river network in each sub-catchment. Once we have this CW area equivalent, we calculate the costs of the corresponding typology of CWs based on cost data.

The typologies of CW are differentiated according to the types of pollutant sources (Kadlec and Wallace 2009).

Free Water Surface (FWS) CWs are densely vegetated basins that contain open water, floating vegetation and emergent plants. They basically need soil to support the emergent vegetation. The FW constructed wetlands reproduce closely the processes of natural wetlands, attracting a wide variety of wildlife, namely insects, mollusks, fish, amphibians, reptiles, birds and mammals (Kadlec and Wallace, 2009). FWS-CWs are the best choice for the treatment of nutrients from diffuse primary sector activities.

Horizontal subsurface Flow (HF) CWs consist of waterproofed beds planted with wetland vegetation (generally common reeds) and filled with gravel. The wastewater is fed by a simple inlet device and flows slowly in and around the root and rhizomes of the plant and through the porous medium

[10] In the model GREEN the discharges from wastewater treatment plants are treated as point sources.

under the surface of the bed in a more or less horizontal path until it reaches the outlet zone. HF-CWs represent the best choice for treating point sources.

Kadlec and Knight (1996)'s method for the sizing of CWs systems describes nitrogen removal with first-order plug-flow kinetics:

$$\ln\left(\frac{c_e - c^*}{c_i - c^*}\right) = \frac{-k}{q} \qquad q = \frac{365.Q}{A_s} \qquad \text{(eq. 5)}$$

$$A_s = \frac{365.Q}{k}\ln\left(\frac{c_i - c^*}{c_e - c^*}\right) \qquad \text{(eq. 6)}$$

where:

As : surface of the CWs (m2)

ce: outlet concentration (mg l-1)

ci: inlet concentration (mg l-1)

c*: background concentrations, for nitrate assumed at 0 mg l-1

k: areal constant of first order (m year-1); for nitrogen removal k is temperature dependent: K=K20·θ(T-20) (K20 takes values of 41.8 for HF and 30.6 for FWS; θ takes values 1.102 for HF and FWS, T is the temperature of the water in degree Celsius)

Q: hydraulic load (m year-1)

q: mean flow (m3 day-1)

The flow Q is separated in two different sub-flows: a first one containing only nitrogen from diffuse sources, which is calculated as the product of surface basin and annual precipitation (supposing a completely impervious basin); and a second one containing only nitrogen from point sources, whereby the point input sources (kg) were converted according to equation 6 to a flow value (m3 day-1) by using population data and by assuming person equivalents (a person equivalent corresponds to 12 g N day-1 and discharges 250 l drinking water per day).

We assumed that the nitrogen load removed by HF and FWS is proportional to the ratio between non-point and point sources discharging into the basin. In order to assess the ratio between ci and ce (equation 5) we perform the calculations in equations 7 and 8.

For diffuse sources:

$$\frac{c_i}{c_e} = \frac{(L_i + (DS_i \times (1 - BR_i))}{L_i + (DS_i \times (1 - BR_i)) - (\%N_{FWS} \times NR)} \qquad \text{(eq. 7)}$$

Where:

Li: Load at catchment inlet (103 kg year-1)

DSi: Diffuse sources at catchment (103 kg year-1)

BRi: Basin retention (dimensionless)

% N FWS: 1 - Percentage of point sources

NR: In-stream nitrogen retention (103 kg year-1)

For point sources:

$$\frac{c_i}{c_e} = \frac{(L_i + PS_i)}{L_i + PS_i - (\%N_{HW} * NR)}$$

(eq.8)

Where:

Li= Load at catchment inlet (103 kg year-1)

PSi= Point input sources to the river at catchment (103 kg year-1)

% NHF = Percentage of point sources

NR: In-stream nitrogen retention (103 kg year-1)

Once we have the CW area equivalent, we can calculate the costs of the corresponding typology of CWs. Total costs include direct construction costs, indirect construction costs and costs of labour and material.

To include economies of scale in construction costs, we implement the relationship between surface and construction costs presented by Kadlec and Wallace (2009), with a factor of 0.77 for the conversion US dollar to euro11.

FWS Cost (€) = 0.77×194×A 0.690 (eq. 9)

where A stands for area in ha and 0.03 ha < A < 10000 ha; and

HF Cost (€) = 0.77×652×A0.704 (eq. 10)

where A stands for area in ha and 0.005 ha < A < 20 ha.

Indirect costs (not including the cost of land acquisition) have been included as a standard percentage (30%) of construction costs12.

Labour cost values have been extracted from the Eurostat labour statistics, which reports costs from 1997 to 2009. For countries with missing data, we estimate approximate values based on those of adjacent countries with similar economic conditions. The costs of filling materials are obtained by a direct survey conducted among CW designers and builders in different European countries and by data available in the peer-reviewed literature.

To account for price differentials across countries, construction costs have been divided in three components: (1) a fixed component (including waterproofing, excavation, plants, concrete elements, piping, etc.); (2) labour costs; (3) filling materials costs.

For each country the total cost (€ m-2) is obtained as the sum of fixed costs, labour costs and filling material cost for HF and as sum of fixed costs and labour cost for FWS. On the ground of a series of

[11] The 0,77 was the exchange rate when our study was completed.

[12] Indirect costs usually include: Engineering and permitting activities, non-construction contractor costs, construction observation and start-up services and contingency and escalation: escalation is an allowance for inflation. Contingency is a percentage of the base cost to cover error in human judgment. Contingency allotments of 10-30% are typically used. The hypothesis of 30% is based on field experience reported by engineering companies that build CWs.

case studies examined, we assume an operating and maintenance (O&M) cost equal to 3850 € ha-1 for FWS and 7700 € ha-1 for HF.

The building value that we calculate refers to the whole building project. What we need in our valuation is an annual flow, we thus need to calculate it. For the estimation of the annual flow from the total building costs, we can use the standard equation:

$$a = \frac{Y * i * (1+i)^{LE}}{(1+1)^{LE} - 1} \qquad \text{(eq. 11)}$$

where:

a: yearly amount of building costs (euro)

Y: total building costs

i: discount rate (in our application set at 3%13)

LE: Life Expectancy of the CW (20 years).

We should take into account on one hand the economy of scale effect, and on the other hand the fact that different countries in Europe have different costs. The two aspects cannot be calculated together because the imposition of fake thresholds would unrealistically affect the final result. We thus calculate separately the economy of scale effect and the price difference effect. After few simulations were run (La Notte et al. 2012), the most reliable outcomes result from the combination that considers a 70-30 breakdown, i.e. 70% of the cost is based on an assessment of the price difference effect and 30% of the cost is based on the economies of scale model (equations 9-10).14

Limitations and data gaps

The biophysical model GREEN is based on a statistical approach, using regression analysis to build a statistical relation between retention and explanatory variables such as land cover, climate, and so on. The model does not include equations representing the physical functions of the ecosystem. For future applications, process-based models should be preferred in order to better assess the ecological functioning especially for regulating services. The limitation of GREEN itself is to consider only physical properties and not to include any biological element.

Another point highlighted by our application is the critical role played by the way in which the sustainability threshold is calculated and spatially differentiated according to physical conditions. The latter, in fact, causes the sustainable flow be very sensitive to changes in emissions. In our application, we considered one threshold without differentiating upstream catchments from downstream catchment. In future applications, this difference will have to be made.

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[13] The discount rate has been chosen according to the SEEA-CF guidelines reported in Annex A5.2 (UN. et al. 2014).

[14] A complete description of the cost-based approach is available in La Notte et al. (2012). A sensitivity analysis related to the model GREEN outcomes is reported in Grizzetti et al. (2012).

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Annex II: Crop pollination

General introduction

Insect pollination benefits more than 80% of crops grown in Europe (Williams, 1994), with an estimated value greater than 14 billion euro annually (Leonhardt et al., 2013). Hence, there is growing concern that observed declines in insect pollinators may impact on production and revenues from pollinator-dependent crops. Knowing the distribution of pollinators, therefore, is crucial to estimate their availability to pollinate crops. This information, in turn, can be used to ensure the maintenance of habitats that support insect pollinators, ultimately safeguarding the long-term provision of crop-pollination services.

This report aims to address the following needs:

1. Delineating where semi-natural and natural ecosystems have the potential to support insect pollinators (in other words, defining the environmental suitability to support insect pollinators);
2. Quantifying the distribution of pollinator-dependent crops;
3. Quantifying the availability of insect pollinators to pollinator-dependent crops;
4. Quantifying the crop-production dependent on insect-pollinators.

Within the frame of ecosystem services accounting, the four elements listed above represent, respectively:

1. Potential to support insect pollinators
2. Demand (for insect pollination, by pollinator-dependent crops)
3. Use (or availability of insect pollinators to pollinator-dependent crops; i.e. the pollination service)
4. Benefits (agricultural production resulting from the contribution of insect pollinators)

The following sections propose a method to estimate these four elements. This proposal builds upon the experience of JRC in developing indicators for pollination services, and expands this work to deliver outputs usable for the assessment, valuation and accounting of ecosystem services. Ecosystem services are defined as ecological processes that lead to a change in human well-being; in other words, ES represent the contribution of ecosystems to generate benefits; ES are flow while benefits are assets.

Through external satellite accounts, it is possible to integrate standard national economic accounts with information on the flow of ecosystem services and on the benefits they generate.

The outcomes of this work are expected to be relevant for policy makers and land managers. For instance, they can help identify areas that are vulnerable to mismatches between pollination potential and demand (e.g. potential pollinator deficits), which in turn can be the target of mitigation measures aiming at boosting suitability for wild pollinator, such as the creation of patches of pollinator-friendly habitats (e.g. wild flowers strips between crop fields).

Method

Potential to support insect pollinators

Ecosystem potential to support insect pollinators is quantified through the modelled environmental suitability. We make use of an Expert-based Model (EBM) build upon previous work undertaken by JRC staff, which has resulted in a map with a spatial resolution of 1 ha (100 x 100 m grid-cell). Like every modelling approach, the EBM has some strengths and weaknesses: for instance, it has the advantage of being able to account for the effect of detailed local information, such as the presence of wild flower edges between crop-fields, or other small patches of habitat suitable for pollinators. The EBM, however, may fail to reflect the environmental suitability for poorly known species, or to capture environmental characteristics that can modify the expected suitability (e.g. climatic differences) or, again, it may not be able to predict species richness. In this proposal, we also outline how we address some of these issues.

The EBM model provides a 'suitability' score between 0 and 1 for each grid-cell. The 'suitability' is often interpreted as the 'capacity of the environment to support insect pollinators', or the 'pollinator potential', for the purpose of our work. The suitability is based on experts' knowledge of the species ecology (see (Zulian et al., 2013) for the details of the model).

The original model by Zulian et al. (2013) was adapted to meet the requirements of the accounting, such as the need to rely on datasets regularly updated.

The main features considered to estimate the environmental suitability to support wild insect pollinators are land use and land cover (LULC) elements providing food resources and nesting sites. At this stage, the most suitable candidate are the CORINE data; in particular, the accounting layers made available from the EEA, which allow us to make comparisons over time.

In addition to these datasets, we also include the major roads from Tele Atlas, to identify areas that cannot provide floral resources or nesting sites to insect pollinators (suitability = 0 for road categories 0, 1 and 2).

The two maps quantifying the environmental suitability to provide food resources and nesting sites to pollinators are then averaged to obtain an overall suitability for each location (each pixel in the map). Thermal constraints on flight activity are known to limit the pollinating effectiveness of bees (Corbet et al., 1993). Hence, we use global irradiance and mean air temperature from the Agri4Cast gridded agro-meteorological data (http://agri4cast.jrc.ec.europa.eu/DataPortal/Index.aspx), to estimate a pollinator activity index, as described in Zulian et al. (2013). This index is used to revise the modelled suitability (the 'pollinator potential'), allowing us to account for climatic differences between LULC classes located in different geographical areas, which may affect the actual pollinator activity.

Lastly, we account for the evidence that pollinator richness and visitation rates show strong exponential declines with distance from (semi-)natural areas (Ricketts et al., 2008), with consequential decreases in the stability of pollination services (Garibaldi et al., 2011). Namely, we used the following distance decay function (Ricketts et al., 2008) to revise the pollinator potential:

$$Y_{ij} = exp^{(\alpha_i + \beta_i D_{ij})} + \varepsilon_{ij}$$

Where:

- Y_{ij} = observed pollination datum in the i^{th} study (Ricketts et al., 2008);
- D_{ij} =associated distance from the nearest natural habitat, in meters;

- α_i = study specific intercept (the agricultural score, in our case);
- β_i = rate of change (-0.00046 from Ricketts et al., 2008);
- ε_{ij} = fitted error term.

The pollinator potential computed for the whole of EU-28 mainland is extracted for a number of stratified random samples, with the strata reflecting the chosen level of aggregation. Additionally, if the outputs are reported for each Member State (MS), it might be useful to consider different types of strata, for instance administrative (e.g. NUTS2) as well as environmental (e.g. LULC classes, climatic zones etc.).

The number of random samples may be defined after establishing whether there is a threshold (and if so, which one) beyond which a plateau in the information gain is reached.

Ultimately, the model of pollination potential needs to provide estimates of areas with 'sufficient' suitability for insect pollinators for the chosen level of aggregation (in other words sufficient 'pollinator potential', as derived from the revised suitability). In absence of a definition of 'sufficient', it is recommended to consider different thresholds for pollinator potential (cut-off for 'sufficient') and (or) classes of pollinator potential (e.g. percentage of land in 'low', 'medium', 'high' pollinator suitability, defined using quartiles). An uncertainty analysis should be carried out to evaluate how ***different threshold choices*** affect the overall outcome of the pollination potential model. The results of the uncertainty analysis can be mapped out to accompany the map resulting from the model of the potential to support insect pollinators.

To account for changes over time, the model of pollination potential is recomputed when **updated input data** become available. We expect that changes within the model variables (e.g. LULC) affect the outcome of the model, in this case the potential to support insect pollinators.

Demand

Schulp et al. (2014) defined ***demand*** from the share of 1km^2 grid-cells occupied by nine crop groups benefitting from insect pollination. They adopted the levels of crop-pollinators dependencies (little, modest, great, essential) from Klein et al. (2007), to attribute to each crop group the area percentage, pertaining to each dependency level. They expressed the dependency levels as a percentage of yield-loss upon absence of pollinators, compared to the optimal situation, using mid-range values (i.e. 5%, 25%, 65%, and 95%). See the example in Table A.II.1.

Table A.II.1 – Area percentage of each crop group attributed to the categories of pollinator dependency at European scale (Schulp et al., 2014)

Crop group	Pollinator dependency level (% yield loss)			
	Little (5%)	Modest (25%)	Great (65%)	Essential (95%)
Citrus fruit	100%			
Fruits	0.1%	11%	77%	12%
Oil crops	100%			
Pulses	14%	82%		
Rapeseed		100%		
Soya		100%		
Sunflower		100%		
Tomato	100%			
Vegetables	10%	6%	6%	4%

Crop-shares in Schulp et al. (2014) refer to the year 2000 and they were created within the CAPRI-Dynaspat project (Common Agricultural Policy Regional Impact - The Dynamic and Spatial

Dimension) by downscaling administrative level statistics based on point observations (Kempen et al., 2005; Britz et al., 2011).

To meet the objectives set out in the introduction, updated figures are needed. It is proposed to derive updated crop shares from the proportion of LUCAS points for a particular crop or crop group, ***assuming that the same proportion holds true at the chosen level of aggregation*** (e.g. NUTS2 or national level, depending on data availability). The inferred crop extents must be verified using EUROSTAT aggregated data. The choice of crops (or crop groups) can be taken from previous work, such as Zulian et al. (2013).

Table A.II.2 shows the main elements contributing to quantify crop pollination demand.

Table A.II.2 – Main elements of the demand model and expected outcome

DEMAND	
Available data	Main characteristics
EUROSTAT LUCAS (Land Use and Coverage Area frame Survey). http://ec.europa.eu/eurostat/web/lucas/overview	• Every three years, from 2006; • Spatially explicit stratified samples across the MS (more than 270,000 points visited from March to October for 2015).
EUROSTAT aggregated data for extent of agricultural production. http://ec.europa.eu/eurostat/web/agriculture/data/database	• Crops statistics (area); • Annual data, presented in time series for each MS; • The period covered depends on each country's date of accession to the European Union. The earliest data are available from 1955 for cereals and from the early 1960's for fruits and vegetables.
Crop pollinator-dependency (Klein et al., 2007).	Dependencies are translated into percentages using mid-value [5%, 25%, 65%, 95%].
Objective	Expected outcome
Using LUCAS data to infer regional and national spatially explicit estimates of pollinator-dependent crop extents.	Extent of land with pollinator-dependent crops: • Maps: area percentage per km^2; • Tables: national and regional extents.

Use

The potential to support insect pollinators and the demand for insect pollinators by (pollinator-dependent) crops are used to quantify the ‘use’, which is defined as the extent of pollinator-dependent crops benefitting from insect pollination. Within the System of Environmental-Economic Accounting (SEEA), the contribution of the ecosystem to generate benefits is defined as the ecosystem service, which is a flow and must be quantified in relation to time. For the specific case presented here, therefore, ‘use’ represents the ‘pollination service’.

Practically, using LUCAS samples located in pollinator-dependent crop fields, pollination service is inferred by overlaying the information from the pollination potential and demand models. The results are then aggregated at the chosen level of administrative and/or environmental units, ***assuming that the relation between LUCAS points holds true for the chosen level of aggregation.*** For example, if 2% of LUCAS samples for crop A in a given MS have *x* pollination potential (or, for instance, ‘sufficient’ pollinator suitability), we assume that 2% of that MS’s land will also have *x* pollination potential. As stated above, it is recommended the use of different thresholds and/or classes to define pollinator presence, based on the potential to support insect pollinators. Table A.II.3 shows the main elements to quantify ‘use’, in other words, the expected pollination service.

Table A.II.3 – Main elements and expected outcome contributing to quantify 'use' ('pollination service')

USE	
Available data from the POTENTIAL and DEMAND	Main characteristics
• Maps and tables showing the extent of land supporting insect pollinators (' Pollination potential'); • Maps and tables showing extent of land with pollinator-dependent crops (Table A.II.2, 'Demand'); • LUCAS samples.	• Maps quantifying the information as percentages of the grid-cell size (e.g. % of 1-km^2), or as hectares (or km^2); • Tables quantifying the extent in hectares (or km^2), for the chosen levels of aggregation (i.e. administrative and/or environmental units).
Objective	Expected outcome
Deriving the pollination-service, defined as the insect-pollinator presence where demand exists.	Maps and tables quantifying the extent of pollinator-dependent crops benefitting from pollination.

Benefit

Benefits are tangible and intangible assets and their measure should differ from that of ecosystem services.

Many experimental studies are advancing our understanding of the effects of insect pollination on the crop production (seed set, shape, chemical composition, for instance) (Garratt et al., 2014; Klatt et al., 2014; Garibaldi et al., 2016). However, we do not have yet sufficient information to translate this knowledge into a crop-production function that can accurately reflect the contribution of insect pollinators to the harvested yield; this is particularly true when upscaling field-level observation to national and global estimates. Valuing pollination services to agriculture remains, therefore, an open challenge (Melathopoulos et al., 2015).

For this reason, any use of benefit figures should be done keeping in mind these limitations.

Here, we propose to link the information gathered from the three previous models to characterise agricultural production, for each chosen level of aggregation. Given the experimental nature of this work and the knowledge gaps, our estimates must necessarily be taken with caution.

Statistics on agricultural production are taken from EUROSTAT data on agricultural production (See Table A.II.2), in particular, the information listed within 'apro_acs_a' under 'Crop statistics (from 2000 onwards)' (http://ec.europa.eu/eurostat/web/agriculture/data/database).

EUROSTAT data report production in two different ways:

- Harvested quantities: 1000 tonnes. Production including on-holding losses and wastage, quantities consumed directly on the farm and marketed quantities, indicated in units of basic product weight;
- Yield: 100 kg/ha. The harvested production per area under cultivation.

These definitions are listed within the RAMON – Reference And Management Of Nomenclatures (http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL_GLOSSARY&StrNom=CODED2&StrLanguageCode=EN), and follow the Regulation (EC) No 543/2009 of the European Parliament and of the Council of 18 June 2009 'concerning crop statistics and repealing Council Regulations (EEC) No 837/90 and (EEC) No 959/93' (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:167:0001:0011:EN:PDF)

All these estimates need to be repeated over time and developed keeping in mind the availability of resources that are being released, based on the latest technologies both in terms of datasets (e.g. through Copernicus) and tools (e.g. openforis, Google Engine).

Limitations and data gaps

The main limitations of the proposed models are the lack of data on some of the relevant environmental pressures on pollinators, due to the scarcity of spatial information on these pressures. One of these pressures for which we only have partial information, for instance, are the pesticides. As mentioned before, other limitations arise from the main assumptions made in model in relation to the effects of insect pollination on the crop production.

Furthermore, the model used for the pollinators potential would significantly benefit from field observation gathered for different groups of pollinators and with a consistent spatial coverage for a given time period.

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Annex III: Nature-based local outdoor recreation

General introduction

Cultural ecosystem services (CES) combine elements from social and ecological concepts. They are nature's intangible benefits related to human perceptions, attitudes and beliefs. People obtain spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences from ecosystems. People's perceptions can differ significantly not only individually but also from one area and culture to another. Therefore, CES are not readily transferrable from one place to other environments (Kopperoinen et al. 2017).

Public, nature-based, outdoor recreational activities include a wide variety of practices ranging from walking, jogging or running in the closest green urban area or at the river/lake/sea shore, bike riding in nature after work, picnicking, observing flora and fauna, organizing a daily trip to enjoy the surrounding beauty of the landscape, among a myriad of other possibilities. These activities play an important role in human well-being and health. While tourism is an occasional activity, local outdoor recreation affects the daily life of people.

Following the general template, for the account of cultural ecosystem services, we characterize the main elements to quantify nature-based recreation services in terms of Potential supply (potential availability of opportunities); Flow (proximity of the opportunities); Use (proportion of population that have access to the opportunities).

Method

The ESTIMAP model for recreation (Zulian et al. 2013; Paracchini et al. 2014) is based on "Advanced multiple layers LookUp Tables" (Advanced LUT). Advanced LUT assign ES values to land units based on cross tabulation and spatial composition derived from the overlay of different thematic maps. ES values (scores) for each input are derived from literature and from an expert-based approach (Schröter et al. 2014).

The original configuration of the model has been slightly modified to deliver the outcomes needed for the account.

Figure A.III.1 presents the new configuration that consists of three sections: 1) The Recreation Potential (RP); 2) the Service Flow; 3) The use of or demand for service.

ES potential of outdoor recreation

The Recreation Potential Map (RP Map) estimates the potential capacity of ecosystems to support nature-based recreation activities. It depends on the biophysical structures and functions that play a role at ecosystem level. At European scale, we derive the RP Map from the combination of four main components:

1. Suitability of land to support recreation (Figure A.III.1-1.1);
    a. land use types contribute differently to the provision of recreation opportunities [very low or close to 0 in industrial or high urbanised areas or potentially very high in semi-natural areas]
2. Presence and quality of water (Figure A.III.1-1.2);
    a. the presence of water represents a key element for nature based leisure and recreation practices (Jennings 2007; Ghermandi 2015). As proxies for this

component, we consider sea coastal and inland elements. The first group is represented by: geomorphology of coast, water clarity, proximity to sea coast and presence of marine protected areas (see Liquete et al. 2016 for further details). The second group is represented by: proximity to lakes and riparian areas and bathing water quality points.

3. Inland natural elements (Figure A.III.1-1.3);
    a. this component includes other features that play a role in the provision of nature-based opportunities, such as the presence of natural protected areas; the presence of semi-natural vegetation and the presence of other natural features related to vegetation or land form. Natural protected areas are scored according to the IUNC management categories for Protected areas[15], see the matrix of management objectives in Eagles et al. 2002, pp. 11, table 2.2.
4. Urban green infrastructures (Figure A.III.1-1.4);
    a. public urban green areas are fundamental point of reference for urban dwelling. We consider in this component all public urban areas within the functional urban areas boundaries in Europe.
5. Elements that decrease the recreation potential
    a. Presence of busy roads

Service Flow

Especially on a daily basis, recreation opportunities have to be easily reached. The service flow is expressed by the Recreation Opportunity Spectrum (ROS) Map which depends on the RP Map and the proximity map.

The proximity map depends on the presence of infrastructures to access and profit from the potential opportunities, such as:

- paths and trails and leisure and tourism infrastructures (e.g. pic-nic tables; birds or wild life hides), (Figure A.III.2-2.1);
- local road network and residential buildings (Figure A.III.2-202).

Demand

The demand for service is expressed by the share (percentage) of local population that have access to areas with high density of opportunities.

Limitations and data gaps

At European scale one of the most important limitation is availability of data on:

- leisure and recreation related infrastructures (especially local trails and paths). For the time being, we refer to Open Street map data set for all these information while being aware that this is not an official source.
- Actual use data related to daily recreation activity

[15] http://www.iucn.org/about/work/programmes/gpap_home/gpap_quality/gpap_pacategories/

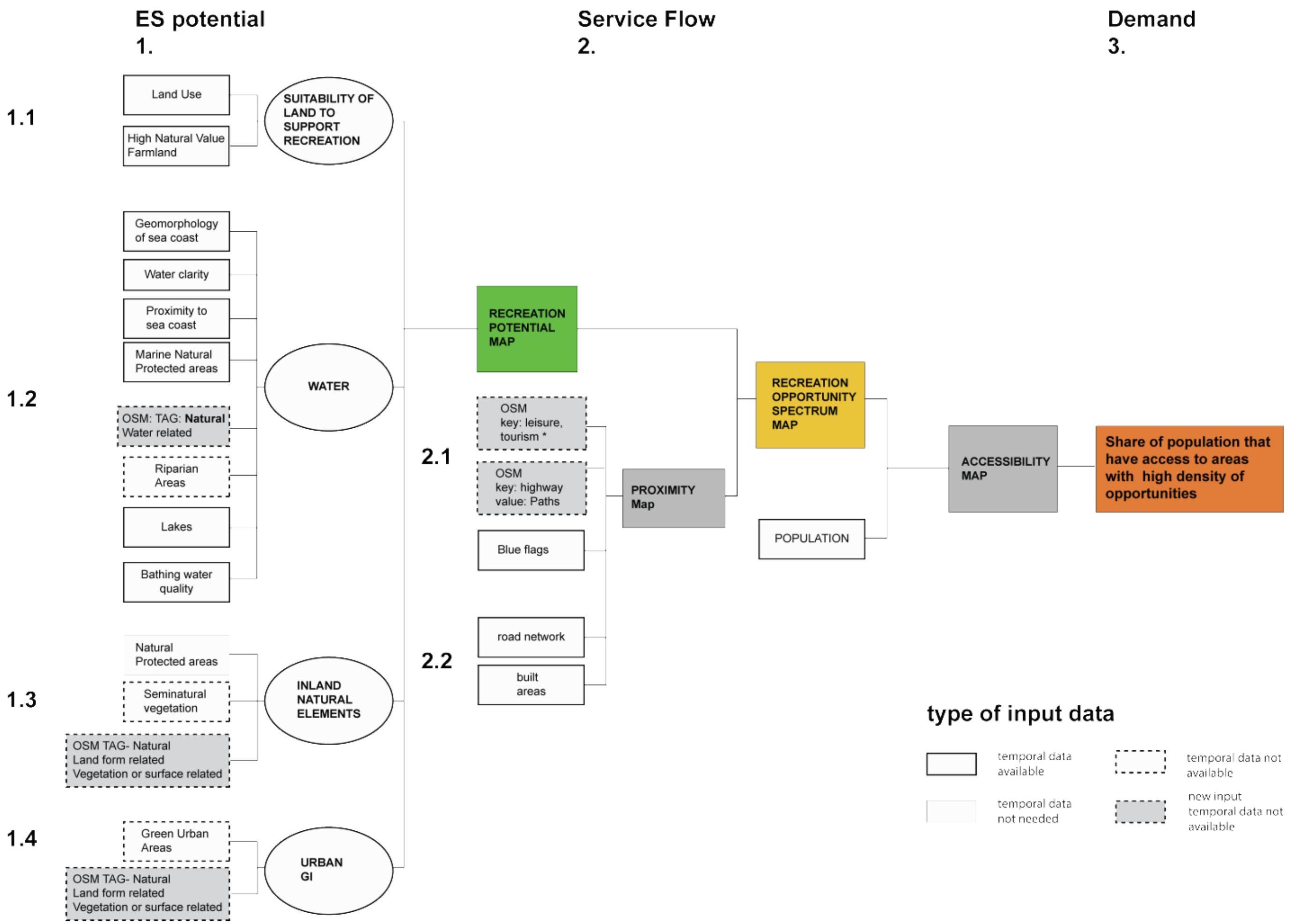

Figure A.III.1 – New model configuration. When needed, temporal data will be used as they become availabl

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Annex IV: Report structure for each ecosystem service

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SEEA EEA ecosystem service accounts

1- Actual flow in physical terms

   Presentation of tables' structure; description of the biophysical model used; reporting of the full table for a selected year

2- Actual flow in monetary terms

   Description of the valuation technique(s) used; reporting of the full table for a selected year

3- Trends of actual flow in physical and monetary terms

   Reporting of time series in graphs and tables and analysis of the trends

SEEA EEA complementary accounts

4- Potential or sustainable flow tables in physical and monetary terms

   Presentation of tables' meaning; description of changes in the biophysical model used; description of changes in valuation technique [if any]; reporting of the full table for a selected yeas

5- Trends of potential or sustainable flows in physical and monetary terms

   Reporting of graphs and tables and analysis of the outcomes

6- Capacity account in physical and monetary terms

   Presentation of the table's structure; reporting of the full tables for a selected year

7- Trends of Capacity in physical and monetary terms

   Reporting of graphs and tables and analysis of the outcomes

8- Synergies and trade-offs with the flows and capacity of other ecosystem services

   Description of specific examples when available otherwise reporting standard text to acknowledge this important issue

9- Benefits generated by the ecosystem service

   Presentation of tables with a clear separation between the ecosystem service section and the benefit section, link to related data sets such as emissions by economic actors

Annex V: Look-up tables for different land cover data

Look-up table of land cover classes according to the MAES ecosystem types

MAES ecosystem	CORINE Land Cover	HILDA	LUCAS
Urban	Continuous urban fabric	Settlement	Artificial
Urban	Discontinuous urban fabric	Settlement	Artificial
Urban	Industrial or commercial units	Settlement	Artificial
Urban	Road and rail networks and associated land	Settlement	Artificial
Urban	Port areas	Settlement	Artificial
Urban	Airports	Settlement	Artificial
Urban	Mineral extraction sites	Settlement	Artificial
Urban	Dump sites	Settlement	Artificial
Urban	Construction sites	Settlement	Artificial
Urban	Green urban areas	Settlement	Artificial
Urban	Sport and leisure facilities	Settlement	Artificial
Cropland	Non-irrigated arable land	Cropland	Cropland
Cropland	Permanently irrigated land	Cropland	Cropland
Cropland	Rice fields	Cropland	Cropland
Cropland	Vineyards	Cropland	Cropland
Cropland	Fruit trees and berry plantations	Cropland	Cropland
Cropland	Olive groves	Cropland	Cropland
Cropland	Annual crops associated with permanent crops	Cropland	Cropland
Cropland	Complex cultivation patterns	Cropland	Cropland
Cropland	Land principally occupied by agriculture, with significant areas of natural vegetation	Cropland	Cropland
Cropland	Agro-forestry areas	Cropland	Cropland
Grassland	Natural grasslands	Grassland	Grassland

Look-up table of land cover classes according to the MAES ecosystem types

MAES ecosystem	CORINE Land Cover	HILDA	LUCAS
Grassland	Pastures	Grassland	Grassland
Heathland and shrub	Moors and heathland	Grassland	Shrubland
Heathland and shrub	Sclerophyllous vegetation	Grassland	Shrubland
Woodland and forest	Broad-leaved forest	Forest	Woodland
Woodland and forest	Coniferous forest	Forest	Woodland
Woodland and forest	Mixed forest	Forest	Woodland
Woodland and forest	Transitional woodland-shrub	Forest	Woodland
Sparsely vegetated land	Beaches, dunes, sands	Other Land	Bare land and lichens/moss
Sparsely vegetated land	Bare rocks	Other Land	Bare land and lichens/moss
Sparsely vegetated land	Sparsely vegetated areas	Other Land	Bare land and lichens/moss
Sparsely vegetated land	Burnt areas	Other Land	Bare land and lichens/moss
Sparsely vegetated land	Glaciers and perpetual snow	Other Land	Bare land and lichens/moss
Wetland	Inland marshes	Grassland	Wetlands
Wetland	Peat bogs	Grassland	Wetlands
Rivers and lakes	Water courses	Water	Water areas
Rivers and lakes	Water bodies	Water	Water areas

Look-up table of land cover classes according to the MAES ecosystem types

MAES ecosystem	CCI-LC
Urban	Urban areas
Cropland	Cropland, rainfed
Cropland	Herbaceous cover
Cropland	Tree or shrub cover
Cropland	Cropland, irrigated or post-flooding
Cropland	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous)
Grassland	Grassland
Heathland and shrub	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)
Heathland and shrub	Shrubland
Heathland and shrub	Evergreen shrubland
Heathland and shrub	Deciduous shrubland
Woodland and forest	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%)
Woodland and forest	Tree cover, broadleaved, evergreen, closed to open (>15%)
Woodland and forest	Tree cover, broadleaved, deciduous, closed to open (>15%)
Woodland and forest	Tree cover, broadleaved, deciduous, closed (>40%)
Woodland and forest	Tree cover, broadleaved, deciduous, open (15-40%)
Woodland and forest	Tree cover, needleleaved, evergreen, closed to open (>15%)
Woodland and forest	Tree cover, needleleaved, evergreen, closed (>40%)
Woodland and forest	Tree cover, needleleaved, evergreen, open (15-40%)
Woodland and forest	Tree cover, needleleaved, deciduous, closed to open (>15%)
Woodland and forest	Tree cover, needleleaved, deciduous, closed (>40%)
Woodland and forest	Tree cover, needleleaved, deciduous, open (15-40%)
Woodland and forest	Tree cover, mixed leaf type (broadleaved and needleleaved)
Woodland and forest	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)
Sparsely vegetated land	Lichens and mosses
Sparsely vegetated land	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)
Sparsely vegetated land	Sparse shrub (<15%)
Sparsely vegetated land	Sparse herbaceous cover (<15%)
Sparsely vegetated land	Permanent snow and ice
Sparsely vegetated land	Bare areas
Sparsely vegetated land	Consolidated bare areas
Sparsely vegetated land	Unconsolidated bare areas
Wetland	Tree cover, flooded, fresh or brakish water
Wetland	Tree cover, flooded, saline water
Wetland	Shrub or herbaceous cover, flooded, fresh/saline/brakish water
Rivers and lakes	Water bodies

Glossary of terms

Actual flow: ecosystem service flow that generates the benefit. Amount of the ecosystem service which is effectively used by the users/enabling actors ('actually used service' in the MAES report, European Commission 2013).

Beneficiaries: economic activities (according to the Statistical classification of economic activities in the European Community (NACE)) and households (possibly including also 'Global' for climate regulation) that obtain a benefit by the service-derived good (economic products and non-tangible products). A person or group whose well-being is changed in a positive way by (in this case) an ecosystem service (Burkhard and Maes 2017).

Benefit: positive change in wellbeing from the fulfilment of needs and wants (TEEB, 2010). The direct and indirect outputs from ecosystems that have been turned into goods or experiences that are no longer functionally connected to the systems from which they were derived. Benefits are things that can be valued either in monetary or social terms (OpenNESS Glossary, 2016).

Demand: the need for specific ecosystem services by society, particular stakeholder groups or individuals. It depends on several factors such as culturally-dependent desires and needs, availability of alternatives, or means to fulfil these needs. It also covers preferences for specific attributes of a service and relates to risk awareness (Burkhard and Maes 2017). Since ecosystem service and benefit are different according to the Cascade model, for some ecosystem services there is a clear separation between the **demand for the service** and **demand for the benefit**. For instance, for air purification, the demand for the service is given by the amount of pollutants that need to be removed from the atmosphere (directly modifying the actual flow of the service), while the demand for the benefit (i.e. clean air) is determined by the population requiring clean air.

Drivers of change: any natural or human-induced factor that directly or indirectly causes a change in an ecosystem. A direct driver of change unequivocally influences ecosystem processes and can therefore be identified and measured to differing degrees of accuracy; an indirect driver of change operates by altering the level or rate of change of one or more direct drivers (MA, 2005).

Ecological asset: ecological assets are the stocks of potential services, which the ecosystem, conditioned by structure and processes, might provide. In economic terms, these represent the 'wealth' of the ecosystem (OpenNESS Glossary, 2016).

Economic units: an economic unit—referred to as an institutional unit in national accounting—is an economic entity that is capable, in its own right, of owning assets, incurring liabilities, and engaging in economic activities and in transactions with other entities. Institutional units may be either households, or legal or social entities that are recognized independently of the people that own or control them. Groupings of institutional units that are similar in their purposes, objectives and behaviours are called institutional sectors. Following the SNA, five types of institutional sector are recognized: households, non-financial corporations, financial corporations (in the SEEA, financial and non-financial corporations are usually assigned to a single category: corporations), general government and non-profit institutions serving households (UN, 2014). In ecosystem service accounts economic unit are the users, enabling actors and/or beneficiaries of the ecosystem services.

Economic valuation: the process of expressing a value for a particular good or service in a certain context (e.g., of decision-making) in monetary terms (TEEB, 2010). In this report, economic valuation refers to the translation of biophysical model outcomes into monetary units.

Ecosystem accounting: the process of organising information about natural capital stocks and ecosystem service flows, so that the contributions that ecosystems make to human well-being can be understood by decision-makers and any changes tracked over time. Accounts can be organised in either physical or monetary terms (OpenNESS Glossary, 2016).

Ecosystem capacity: ecosystem capacity refers to the ability of a given ecosystem (or ecosystem asset) to generate a specific (set of) ecosystem service(s) in a sustainable way for the future (modified from UN, 2014).

Ecosystem condition: the physical, chemical and biological condition of an ecosystem at a particular point in time. The capacity of an ecosystem to yield services, relative to its potential capacity (MA, 2005). For the purpose of MAES, ecosystem condition is, however, usually used as a synonym for 'ecosystem state' (European Commission, 2013).

Ecosystem service potential: this describes the natural contributions to ES generation. It measures the amount of ES that can be provided or used in a sustainable way in a certain region. This potential should be assessed over a sufficiently long period of time.

Ecosystem service: the direct and indirect contributions of ecosystems to human wellbeing (TEEB, 2010).

Ecosystem units: conceptually, for accounting purposes, each area representing a different type of ecosystem is considered to represent an ecosystem asset. Each of these individual areas is considered an ecosystem unit (UN, 2014)

Enabling actors: (only for sink related services) economic activities and/or households directly modifying the actual flow of the service by the increase of pollutants in the environment.

Land cover: refers to the observed physical and biological cover of the Earth's surface and includes natural vegetation and abiotic (non-living) surfaces (UN, 2014). In this report, land cover was taken as a proxy of ecosystems.

Sink-related services: those services that remove, dilute, retain, or/and capture chemical substances from the ecosystem (water and air purification, global climate regulation).

Sustainable flow: service flow (yearly amount of the service) that can be delivered by the ecosystem without degrading the ecosystem, and therefore guaranteeing the long-term maintenance of ecosystem capacity.

Unmet demand: the need for specific ecosystem service by society that is not fully satisfied.

Users: actors (economic units and households) using and modifying the ecosystem service flow. An increase of users is usually related to an increase in the actual flow. Note however, that for sink-related services, the actors modifying the actual flow are the enabling actors (see enabling actors).

Valuation: the process whereby people express the importance or preference they have for the service or benefits that ecosystems provides in monetary terms (OpenNESS Glossary, 2016).

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List of abbreviations and definitions

(Alphabetic order)

- Climate Change Initiative-Land Cover (CCI-LC)
- Coefficient of variation (COV)
- Common International Classification for the Ecosystem Services (CICES)
- CORINE Land Cover (CLC)
- Ecosystem services (ES)
- Global Forest Watch (GFW)
- Global Human Settlement Layer (GHSL)
- Global Surface Water Explorer (GSWE)
- HIstoric Land Dynamics Assessment (HILDA)
- Knowledge innovation project on an integrated system for natural capital and ecosystem services Accounting (KIP INCA)
- Land cover (LC)
- Land Use and Coverage Area frame Survey (LUCAS)
- Mapping and Assessment of Ecosystems and Services (MAES)
- Natural capital accounting (NCA)
- System of Environmental-Economic Accounting Central Framework (SEEA CF)
- System of Environmental-Economic Accounting Experimental Ecosystem Accounting Technical Recommendations (SEEA EEA TR)
- System of national accounts (SNA)
- United Nations System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA EEA)

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KJ-NA-28681-EN-N

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Publications Office

doi:10.2760/214137

ISBN 978-92-79-70517-5