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Ecosystem Services Accounting – Part III
Pilot accounts for habitat and species maintenance, on-site soil retention and water purification

*Report on the Knowledge Innovation Project on an Integrated system for Natural Capital Accounting in the EU (**KIP INCA**)*

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Abstract

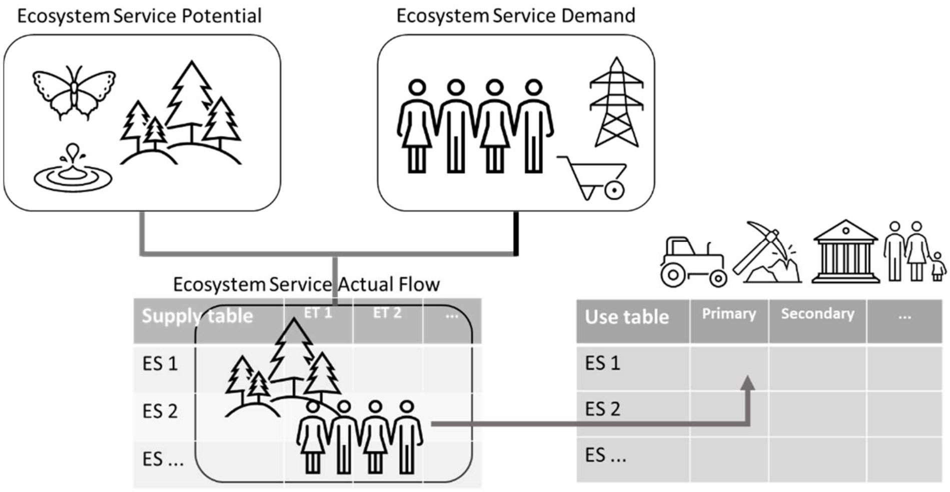
The purpose of ecosystem services accounting is to quantify the main contributions of ecosystems to society and the economy and to report these contributions in accounting tables that are compatible with the structures and practices used in traditional economic accounting. In 2015, the European Commission launched the Integrated system for Natural Capital Accounting (INCA) project to produce concrete applications for the European Union, compliant with the international standard of the system of environmental economic accounting experimental ecosystem accounting. In this report, we assess, value and account for three new ecosystem services: habitat and species maintenance, on-site soil retention, and water purification. We also review and build on existing ecosystem services accounts, such as crop and timber provision, carbon sequestration and crop pollination. Finally, based on the nine ecosystem services accounts compiled for the EU, we look at the readily available INCA indicators, which can support policy analysis and contribute to international reference frameworks such as the post-2020 global biodiversity framework and the sustainable development goals.

Ecosystem services accounting: Part III in a nutshell

The purpose of ecosystem services (ES) accounting is to quantify the main contributions of ecosystems to society and the economy and to report these contributions in accounting tables that are compatible with the structures and practices used in traditional economic accounting. **In 2015, the European Commission launched the Integrated system for Natural Capital Accounting (INCA) project** to produce, (i) at European Union level, ecosystem accounting pilot applications and, (ii) in an international context, a test case for the system of environmental economic accounting (SEEA) experimental ecosystem accounting (EEA).

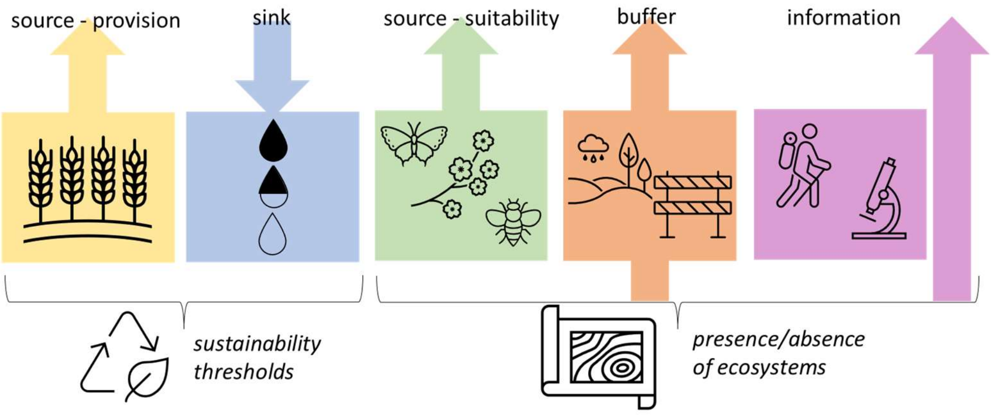
The INCA phase II (2016–2020) applications regarding ES accounts have enabled a continuum of learning by doing each time new ESs are assessed and valued. Thanks to previous applications (Part I and Part II reports), we were able to establish a model in which the **ES flow is determined by the interaction between an ecosystem component and a socioeconomic component** (Figure 1). This interaction can explain whether ES flows and changes in flows are the result of sustainable or unsustainable practices.

Figure 1. Conceptual scheme underpinning the measurement of Ecosystem Services actual flow



We were also able to distinguish **different groups of ESs** (Figure 2): the **ESs that can be overused** if their annual use goes beyond their sustainability thresholds (e.g. the regeneration of natural resources for the ESs characterised by regeneration rates, such as timber provision, and the emission of pollution for the ESs characterised by absorption rates, such as water purification) and the ESs that are provided only if the ES potential to deliver the services is high enough and located where they are demanded (otherwise the **ES demand will remain unsatisfied**). In this report, we add further applications and further findings from both (i) a **methodological point of view** and (ii) **results** obtained from computation.

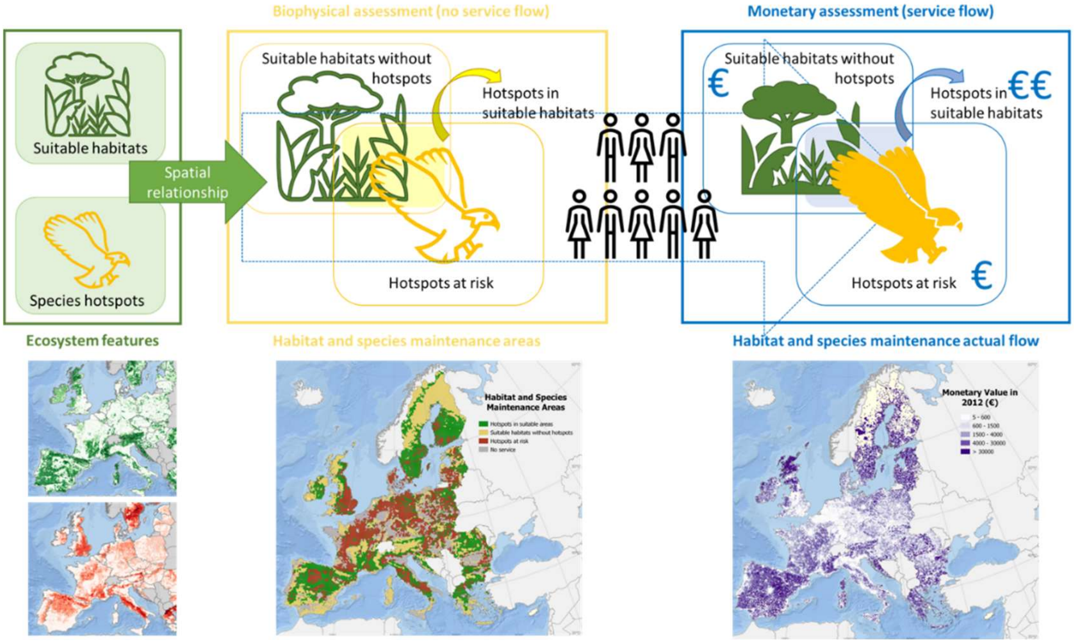
Figure 2. Groups of Ecosystem Services by ecosystem and economy mismatch



The first ES assessed in this report is habitat and species maintenance. From a methodological point of view, the development of the account for this service presents a number of novelties.

- People value habitats and species not because they want to ‘use’ them, but because, thanks to their existence, the planet as we know it can be maintained for present and future generations (existence value).
- In contrast to other ESs in the INCA project, the biophysical assessment of habitat and species maintenance does not quantify on its own the ES actual flow. However, the presence of certain ecosystem features is necessary to generate the ES actual flow that is valued only in monetary terms (Figure 3).
- **This ES** behaves like ecological public goods and services since it **addresses an overarching environmental target: biodiversity loss**. **ES demand goes beyond national boundaries**; thus, this transaction is allocated to ‘global society’.
- Assessing both ES actual flow and ES missed flow (i.e. what could be achieved but is not because of poor territorial management) can help to set reference policy targets for measuring ecological improvements or degradation.
- Metrics concerning ecosystem condition are directly linked to the calculation of this ES actual flow.

Figure 3. From ecosystem features to monetary assessment (EUR/km^2) for habitat and species maintenance



Results concerning habitat and species maintenance show the following.

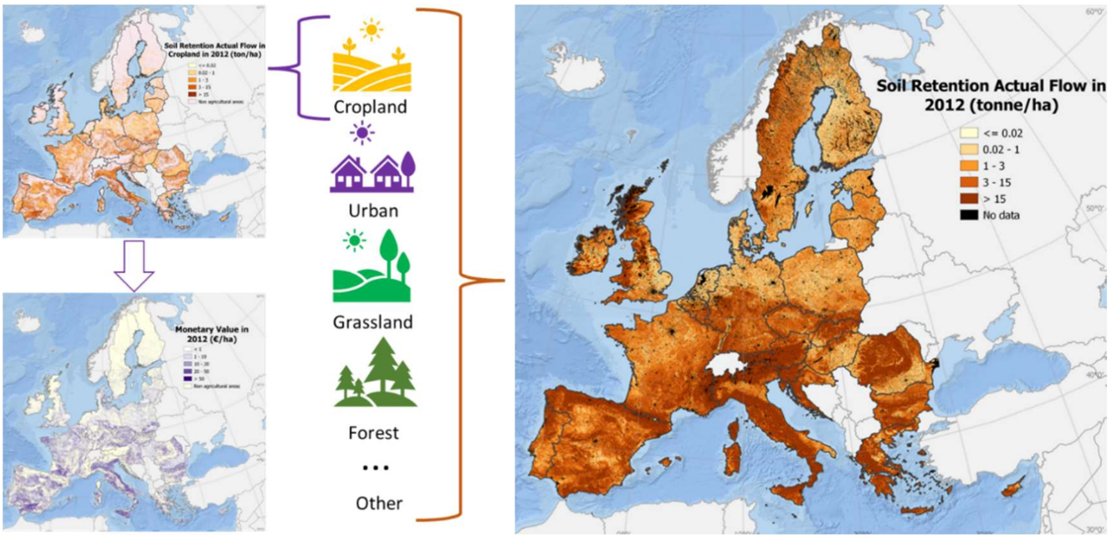
- **Habitat and species maintenance provided a yearly flow of EUR 32.5 billion** (EUR per capita) in 2012, mostly from cropland (44 %), followed by woodland and forest (35 %).
- **Habitat and species maintenance missed flow was about EUR 56 billion in 2012.** This assessment implies that there is significant room to restore ecosystems to improve ecological conditions and enhance biodiversity.
- From 2000 to 2012, a negative change (– 1.1 %) in the extent of hotspots in suitable habitats (over 9 000 km^2) can be explained by the increase in imperviousness (+ 2.91 %). The overall decrease in hotspots in suitable habitats is larger than the decrease in suitable habitats (– 0.36 %), which means this decrease has taken place especially in areas with species hotspots.
- From 2000 to 2012, in absolute terms (total euro), we record an increase in the ES actual flow (+ 3.14 %). This is largely due to an increase in the human population living in service-providing areas. In relative terms (euro per km^2), we record a decrease in the ES actual flow (– 0.82 %), which

demonstrates that there is room to improve the implementation of policies to improve ecosystem conditions.

The second ES assessed is on-site soil retention. From a **methodological point of view**, the development of the account for this service highlights the following.

- Although the main ecological role of soil retention is to support soil conditions for all ecosystem types (**intra-ecosystem flow**), it also has economic importance: to enhance the fertility of cropland for agricultural production (**transaction from one ecosystem type to one economic unit**). This is the ES flow that is valued in monetary terms and accounted in official supply and use tables (SUTs) (Figure 4).
- To avoid double counting with crop provision, the role of soil in crop production is disentangled from the ecosystem contribution ratio, as calculated in the previous approach.
- Metrics concerning ecosystem condition are directly linked to the calculation of this ES actual flow.

Figure 4. Ecosystem types providing soil retention, and its accounting



Results concerning on-site soil retention show the following.

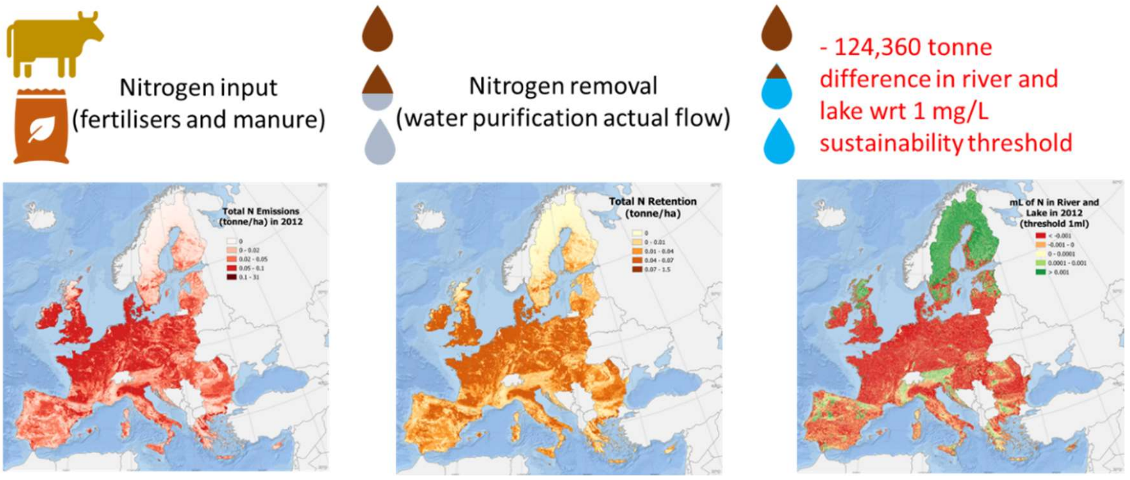
- **Ecosystems provided a soil retention service with a value of EUR 11.5 billion in 2012.** This represents the ecological contribution to agricultural production, but in terms of overall soil retention it captures only 15 % of the total amount of soil retained since most of the ecological contribution consists of intra-ecosystem flows;
- About 7 270 million tonnes of soil was retained by ecosystems in 2012. Retained soil covers about 88 % of the total ES demand; the remaining 12 % is eroded.
- **Soil retention potential improved by 2.4 % between 2000 and 2012.** Arable land is the ecosystem type showing the most important changes, as a result of the positive effects of conservation measures.

The third ES assessed is water purification. From a **methodological point of view**, the development of the account for this service illustrates the following.

- ES demand is identified as the main driver of change, which in this case is related to polluters: the ‘work’ of ecosystems in removing pollutants enables polluters to undertake their activities within a certain limit imposed by law. The existence of a regulatory framework provides the conceptual context to justify the allocation of sink ESs to polluters (Figure 5).

- As pollutants increase, ES demand may be higher than the ecosystem absorption rate. In this respect, ES actual flow does not provide a measurement of **ES overuse**; that **requires the setting of a sustainability threshold**.
- The role of basin retention is separated from the role of river and lake retention and thus does not constitute double counting.

Figure 5. From nitrogen input to ES actual flow and ES overuse in rivers and lakes



Results concerning water purification show the following.

- **The value of water purification was about EUR 55 billion in 2012.** 65 % of nitrogen retention takes place in cropland, but we need to consider that about two thirds of the overall basin retention is crop uptake, which does not constitute pollution.
- Nitrogen input decreased by about 2 % from 2006 to 2012 across the EU-28[1], where the water purification flow saw, in physical terms, a similar decrease: from 20.6 million tonnes/year to 20.1 million tonnes/year.
- Sustainability analysis is required to assess not only the ES actual flow, but also the ES overuse. For river and lake retention in the EU-26 (EU-28 minus Finland and Sweden), when using a sustainability threshold of 2 mg/l (corresponding to a good ecological status), we record an ES overuse of 22 % with respect to actual flow; when using a sustainability threshold of 1 mg/l (corresponding to a high ecological status), we record an ES overuse of 52 % with respect to actual flow.

This report also reviews and builds on the previously assessed ESs to ensure that the best available knowledge and data are provided. Once all ESs were consistently aggregated, the EU SUTs using the common monetary unit were produced (Table 1). A number of indicators can be directly calculated from official and complementary accounting tables; in this report, we considered only **descriptive analysis indicators**. For example, in the supply table (part (a)) we can see that the ecosystem type 'woodland and forest' provided about 51 % of the total ES yearly monetary flow in 2012. 'Timber provision' accounted for only 21 % of the value of services generated by **woodland and forest**, and this supports the important role of this ecosystem type, which **goes far beyond its conventional categorisation of 'supplying wood'**. In the use table (part (b)), we see that the agricultural sector used 31.2 % of the total ES provided in 2012, with households using 31.6 %. This confirms that **agriculture is one of the main activities through which a territory is actively managed** and the importance of society as a user of ESs. However, the INCA project enables **processed indicators** (non-parametric estimates) and **processed variables** (parametric estimates) to be calculated to serve a large variety of users and uses. The INCA project can contribute to the **post-2020 global biodiversity framework**

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[1] Please note that the KIP INCA project started at a time when the United Kingdom was still an EU Member State

and to the **sustainable development goals** with indicators that are already available; other indicators will be made available in the near future.

Table 1. Supply (a) and use (b) tables for the EU-28, 2012

(a)

	Ecosystem type										
	Urban	Cropland	Grassland	Woodland and forest		Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/ intertidal area	**Total**
				Available for wood supply	Other						
(million EUR)											
Crop provision		11 407									11 407
Timber provision				22 714							22 714
Crop pollination		4 517									4 517
Soil retention		11 512									11 512
Carbon sequestration	—	—	—	9 189		—	—	—	NA	NA	9 189
Flood control	89	1 015	3 129	11 388		333	357	1	NA	NA	16 312
Water purification	1 105	31 041	4 128	15 374		330	312	170	3 114	NA	55 576
Habitat and species maintenance ([a])	NA	5 516	985	20 416		1 689	1 176	369	2 363	NA	32 515
Nature-based recreation	77	4 073	7 482	30 723		2 296	3 097	1 351	1 015	279	50 393
Total value	1 272	69 081	15 724	109 805		4 649	4 941	1 891	6 493	279	214 134
EUR/km^2	6 026	42 972	31 014	69 051		47 525	27 361	32 202	59 586	14 531	48 877
% ecosystem type	0.6 %	32.39 %	7.3 %	51.3 %		2.2 %	2.3 %	0.9 %	3.0 %	0.1 %	

([a]) Welfare value is reported for this ES.

(b)

	Economic units					
	Primary sector		Secondary and tertiary sectors	Households	Global society	**Total**
	Agriculture	Forestry				
(million EUR)						
Crop provision	11 407					11 407
Timber provision		22 714				22 714
Crop pollination	4 517					4 517
Soil retention	11 512					11 512
Carbon sequestration					9 189	9 189
Flood control	799		3 786	11 726		16 312
Water purification	38 615		11 307	5 653		55 576
Habitat and species maintenance ([a])					32 515	32 515
Nature-based recreation				50 393		50 393
Total value	66 851	22 714	15 093	67 773	41 704	214 314
% economic units	31.2 %	10.6 %	7.0 %	31.6 %	19.5 %	100 %

([a]) Welfare value is reported for this ES.

1. Introduction

Ecosystems contribute essential services to the economy and society. These include the provision of food, filtration of air and water, climate regulation, and protection against extreme weather events such as heatwaves and flooding. The flows of these ecosystem services (ESs) can be quantified through ecosystem accounting. Ecosystem accounts quantify the main contributions of ecosystems to society and the economy and report these contributions in accounting tables that are compatible with the structures and practices used in traditional economic accounting. The goal of ecosystem accounting is to provide policymakers and decision-makers with critical information on the various contributions (i.e. ESs) that ecosystem assets make to the economy and society, so that these assets can be governed in a safe and sustainable way.

In Europe, the Integrated system for Natural Capital Accounting (INCA) project was launched in 2015 to produce, (i) at European Union level, ecosystem accounting pilot applications, and, (ii) in an international context, a test case for the system of environmental economic accounting (SEEA) experimental ecosystem accounting (EEA) (UN et al., 2014). The results and findings of the INCA project not only confirmed that the creation of a wide range of ecosystem accounts is feasible and useful (Vysna et al., 2021), but also provided feedback for the revised version of the UN handbook on SEEA ecosystem accounting (EA) (UN et al., 2021), completed and adopted in March 2021.

There are two fundamental principles in the INCA project and ecosystem accounting. First, the accounts need to be as realistic as possible (the content of the cells should reflect the real contributions of the various ecosystems through various pathways (services) as much as possible). Second, the accounts need to maintain a structure and logic that is compatible with basic accounting principles and simple enough to be useful for the end users. There seems to be a trade-off between these two principles, and in order to find the optimal compromise it is important that the most relevant and meaningful reporting items (ecosystem types, economic units, ESs) are selected; realistic methods and reliable data are used to assess ecosystems and their services.

All these points are relevant, and there are several long-standing historical challenges in creating accounts that are both broad (encompassing many services over large areas and a long time scale) and consistent (in terms of their implementation details). The INCA phase II (2016–2020) applications on ES accounts enable continuous learning each time a new ES is assessed and valued. Thanks to the previous applications (Vallecillo et al., 2018, 2019a), in the attempt to address these points we were able to develop a conceptual basis, as follows.

- There is a structure underpinning ES flows that is reported in supply and use tables. There is an ES potential (ES P) that becomes an ES actual flow only when it interacts with an ES demand (ES D). Their interaction may generate matches (i.e. actual flow) or mismatches.
- When it comes to sustainability, not all ESs are the same. For some ESs there is a regeneration rate (e.g. timber provision) or an absorption rate (e.g. water purification) that can be exceeded when ES D is too high. In this case, the mismatch between ES P and ES D generates an ES overuse. For other ESs, the only thing that matters is the presence/absence of ecosystems where there is ES D (e.g. crop pollination, flood control and nature-based recreation). In this case, the mismatch between ES P and ES D generates an ES unmet demand.

We were also able to acknowledge the existence of different approaches to estimating the required ecosystem data.

- Biophysical assessments can be ‘fast tracked’ when based on currently available data sets (e.g. crop and timber provision and carbon sequestration) or when based on biophysical modelling when there are no raw data that can be collected, in which case they have to be estimated based on the best available ecological knowledge (crop pollination, flood control, nature-based recreation).
- Monetary valuation can be as simple as multiplying price and quantity (e.g. crop and timber provision, crop pollination and carbon sequestration), or may require economic models that, by employing more sophisticated techniques, link to critical variables of biophysical models to consistently translate outcomes in monetary terms (e.g. flood control and nature-based recreation).

However, there are still a number of challenges that need to be addressed. There are major issues that the international community of ecosystem accountants will soon be addressing, considering the exponentially growing interest and number of applications in this field. Some of these major issues are as follows.

- Is it possible to establish a linkage between ecosystem condition accounts and supply and use tables? This would in fact establish the overall accounting cause–effect relationships between ecosystem and socioeconomic spheres.
- How can ecosystems be dealt with when they act like ecological public goods and services? What are the accounting implications? This specifically concerns overarching environmental targets such as climate change and biodiversity loss.
- What should practitioners do to address specific methodological issues that are currently unsolved, such as the treatment of intermediate ESs and the allocation of pollution removal services? It is in fact difficult to consistently work on ES accounting without an approach that is comprehensive enough to also tackle these issues.
- How can ES accounts be used? The answer concerns both building independent indicators and linking to international references such as the post-2020 global biodiversity framework and the sustainable development goals.

In this report, we attempt to address all these new challenges by assessing and valuing three additional ESs: habitat and species maintenance (Chapter 3), soil retention (Chapter 4) and water purification (Chapter 5).

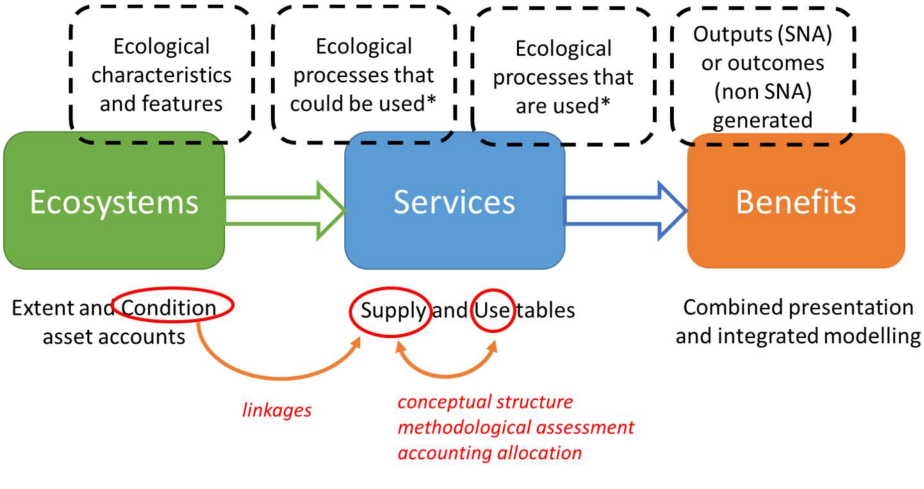
Being a learning by doing process, the more we learn the more we can improve previous assessments and provide more reliable accounts (Chapter 6). We can also start thinking about how to use the ES accounts, for example by proposing a set of indicators (Chapter 7).

In the conclusion (Chapter 8), we emphasise the usefulness of the INCA applications in addressing a number of policy questions, while solving some conceptual and methodological issues.

2. New insights in the accounting framework of INCA

This fourth INCA report by the Joint Research Centre illustrates the assessment and valuation of three ESs: habitat and species maintenance, soil retention and water purification. The examination of these ESs provides new insights on some critical issues concerning ES accounting. These critical issues run across the whole accounting logic chain: from the linkage between ecosystem condition and services, to the allocation of services to users, and the nature of users themselves, as illustrated in Figure 2.1.

Figure 2.1. Critical issues (red text) addressed throughout the accounting logic chain



* «use» here is to be intended in a broad context, i.e. what can be part of people utility (even if non effectively used)

SNA: system of national accounts.

Considering that SEEA EA dedicates specific accounting modules to ecosystem condition (asset accounts) and services (supply and use tables), it is worthwhile exploring whether and how there are direct linkages and connections between the two modules in our current application. The first section of this chapter addresses the underpinning theory and concrete examples of how a change in ecosystem condition indicators can directly affect ES flow.

When moving towards the first arrow in Figure 2.1, the identification of an ecological flow as a service implies that there is a user. The nature of such users matters structurally and methodologically.

The identification of the 'users' who enjoy the contribution from an ES is also a key element in ES accounts, but these users can be ambiguous in some cases. Although most users can be assigned to specific locations, within exclusive national borders, some ESs cannot be allocated to such concrete users. This difference matters, as the type of user affects the design of the conceptual scheme underpinning the assessment of the ES actual flow. The second section of this chapter addresses, through the examples of habitat and species maintenance and carbon sequestration, cases when the user is 'domestic' compared with cases when the user is identified as 'global society'.

The way that ES D is identified and eventually modelled affects the methodological assessment of the service in terms of its expected outcomes and accounting allocation, as illustrated by the third section of this chapter, which deals with the following.

1. The example of the soil retention service shows the case in which the assessment of the ES D takes place at ecosystem level, and actually only one part of this flow directly contributes to economic sectors.
2. In the case of negative externalities, sink services are 'initiated' (and thus also demanded) by economic sectors and/or households that act as polluters. The example of water purification shows the case in which the polluter, as the driver of the service flow, is identified as the user.

It is not only the nature of users that matters, but also the nature of ESs and specifically the way they are assessed. The fourth section of this chapter assesses the difference between intermediate and final services, by identifying two specific risks of double counting. By using soil retention and water purification services as examples, an attempt is made to illustrate that no ES is intermediate by default; rather, this depends on how the ESs (i.e. the contributions of ecosystems to society) are defined and assessed/modelled.

All these issues are conceptually presented in this chapter and empirically illustrated in the following chapters, which are each dedicated to a specific ES, providing all the methodological details and numerical results. The specificities of the ESs also need to be taken into consideration in the context of the overall SUT aggregation (see Chapter 7).

2.1. From ecosystems to economy and society: linkage between ecosystem condition asset accounts and ecosystem service supply and use tables

ESs represent the flow that connects ecosystems to people. The ecological side and the socioeconomic side are closely linked, even when a quick and direct connection is not evident initially. The ESs assessed and valued in this report provide an opportunity to make visible some apparently hidden connections and point out how important it is to 'keep together' the accounts concerning ecosystem condition and ESs. Refreshing the conceptual guidance underpinning the general approach can facilitate the illustration of the rationale used throughout the concrete applications.

In the Convention on Biological Diversity, ecosystems are defined as a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit. All elements with regard to ecosystem composition, structure and function are interdependent and maintain the life-support system of the planet upon which humans depend (Keith et al., 2020).

This holistic perspective of ecosystems contrasts with the individual flows of ESs. Introduced by Haines-Young and Potschin (2012) and applied on a large scale in a variety of applications (Potschin et al., 2018), the cascade model links natural systems to elements of human well-being: from ecological structures and processes generated by ecosystems, to the services and benefits eventually derived by humans. Complexity is added as a critical element when considering the vertical and horizontal hierarchical organisation of ecosystems: more emphasis can be attributed to the correct functioning of the complex system, which, in turn, generates individual ESs and, in turn, their associated benefits for humans (La Notte et al., 2017a). From the representation of the cascade model (Figure 2.2(b)), it is possible to visualise how the function box involves a higher degree of complexity than the service box: the former acts at ecosystem level whereas the latter acts at individual flow level.

Different kinds of values apply throughout the cascade model: what defines the 'value' can be the purpose and the worldview perspective. When considering the purpose, the meaning of 'value' may range from intrinsic to instrumental; when considering the worldview perspective, it may have an anthropocentric view or ecocentric view to illustrate the perspective or worldview of the analysis (Tuner et al., 2003). Purpose and worldview have been combined by Keith et al. (2020) into a two-dimensional space (Figure 2.2(a)).

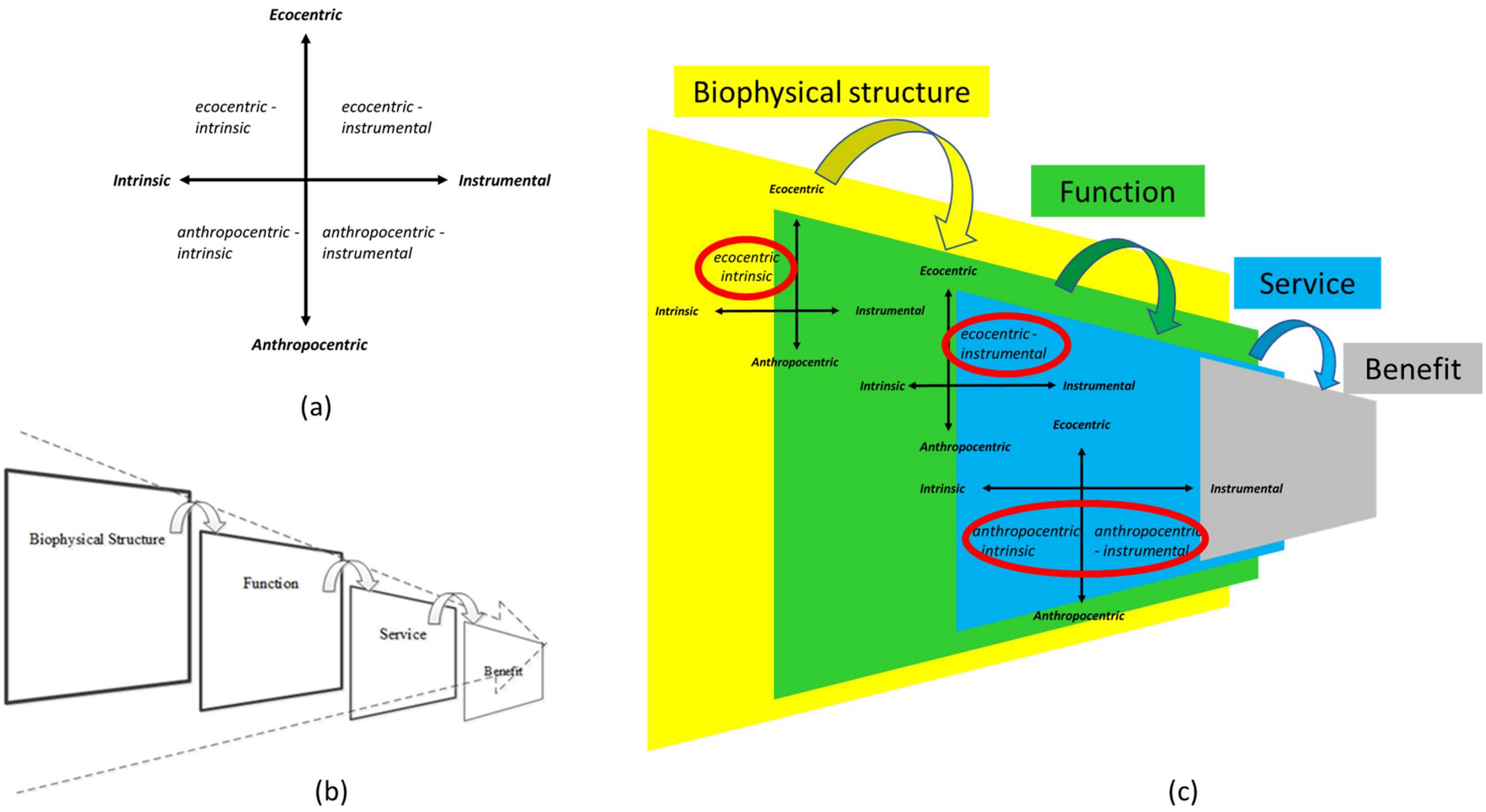
The value framework in two dimensions is explained in Keith et al. (2020) as follows.

- The ecocentric–intrinsic category represents the ongoing functioning of the ecosystem; it works at the ecological level without reference to humans.
- The ecocentric–instrumental category refers to intra- and inter-ecosystem flows supporting the provision of ESs. This category reflects dependencies among ecosystem types, but it does not represent a transaction to the economy and society.
- The anthropocentric–intrinsic category includes actions for environmental protection meant for the collective good and the benefit of future generations. This category embeds the attribution of human values in ESs that probably flow to society.
- The anthropocentric–instrumental category concerns the provision of ES flows to the economy and society.

In summary, an ecocentric view characterises environmental conservation policies, whereas an anthropocentric view has human beings at the centre. Combining the cascade model with the value two-dimensional space (Figure 2.2 (c)) can facilitate:

- an understanding of how the ecocentric perspective can play a role in the delivery of ESs;
- an understanding of how all anthropocentric values (not only instrumental but also intrinsic) should be considered final services for human beings.

Figure 2.2. The value framework (c), combining the two-dimensional values (a) with the telescopic cascade model (b)



Source: (a) Adapted from Keith et al. (2020) and (b) adapted from La Notte et al. (2017a).

To gain this understanding, it is necessary to find out:

- where and how the linkage between ecosystem condition and ESs takes place in order to track how an ecocentric perspective is (through services) relevant to human needs;
- where and how anthropocentric values enter as final ESs into the economy as 'instrumental' and into society as both 'instrumental' and 'intrinsic'.

The clear identification of these views and purposes is important to understand what can directly enter the socioeconomic dimension (through the ES SUTs) and that what does not directly enter the socioeconomic dimension still plays an important role in it. This information can be registered in the ecosystem condition accounts.

One accounting module that is used in the SEEA EA framework is ecosystem condition, defined as the quality of an ecosystem measured in terms of its abiotic and biotic characteristics (UN et al., 2014, 2021; UN, 2019). Ecosystem condition aims to measure the biophysical properties that underpin services and underlie the integrity (sustainability, resilience) of the whole ecosystem (Keith et al., 2020), thus providing the most relevant pieces of information on the physical, chemical and biological characteristics of the ecosystem assets.

The condition of an ecosystem needs to be evaluated through quantitative indicators describing its characteristics that are based on a good scientific understanding of system behaviour. These characteristics encompass all perspectives taken to describe the long-term 'average behaviour' of an ecosystem, using well-defined quantitative metrics (variables and indicators). The selection of these metrics is implemented in three stages (Keith et al., 2020).

- In the first stage, relevant ecosystem characteristics have to be identified and data – in the form of variables – for each characteristic have to be quantified.
- In the second stage, a reference condition has to be determined for each variable (with upper and lower reference levels) to develop a condition indicator.
- In the third stage, condition indicators are normalised and aggregated to compute condition indices.

A simple typology of ecosystem condition characteristics is described by Czúcz et al. (2021) (Table 2.1), where selection criteria are discussed). The focus in assessing condition is on characteristics that describe the quality or state of the ecosystem using the time scales of an accounting period. For consistency with the SEEA EA accounting framework, ecosystem condition characteristics assessed include recurrent interactions within and between ecosystem assets ([2]), as well as recurrent interactions between ecosystem assets and human society. Some ecosystem characteristics are relatively stable by nature (e.g. soil type and topography), whereas others are more dynamic and can change as a result of not only natural processes but also human activities (e.g. water quality and species abundance).

Table 2.1. Ecosystem characteristics typology

Groups	Classes	Examples
Abiotic ecosystem characteristics	Physical state	Soil structure, impervious surface, water availability
	Chemical state	Soil nutrient concentration, air pollution concentration, water quality
Biotic ecosystem characteristics	Compositional state	Species richness, genetic diversity, presence of threatened species
	Structural state	Vegetation density, habitat structure, food chain and trophic levels
	Functional state	Productivity and decomposition processes, community age
Landscape-level characteristics	Landscape and seascape at coarse scale	Connectivity, fragmentation, ecosystem type mosaics

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([2]) Interaction is intended to 'make space' for functional characteristics in the framework (such as the intensity/frequency of a disturbance), which otherwise would be problematic because state is often characterised using flow-like quantities.

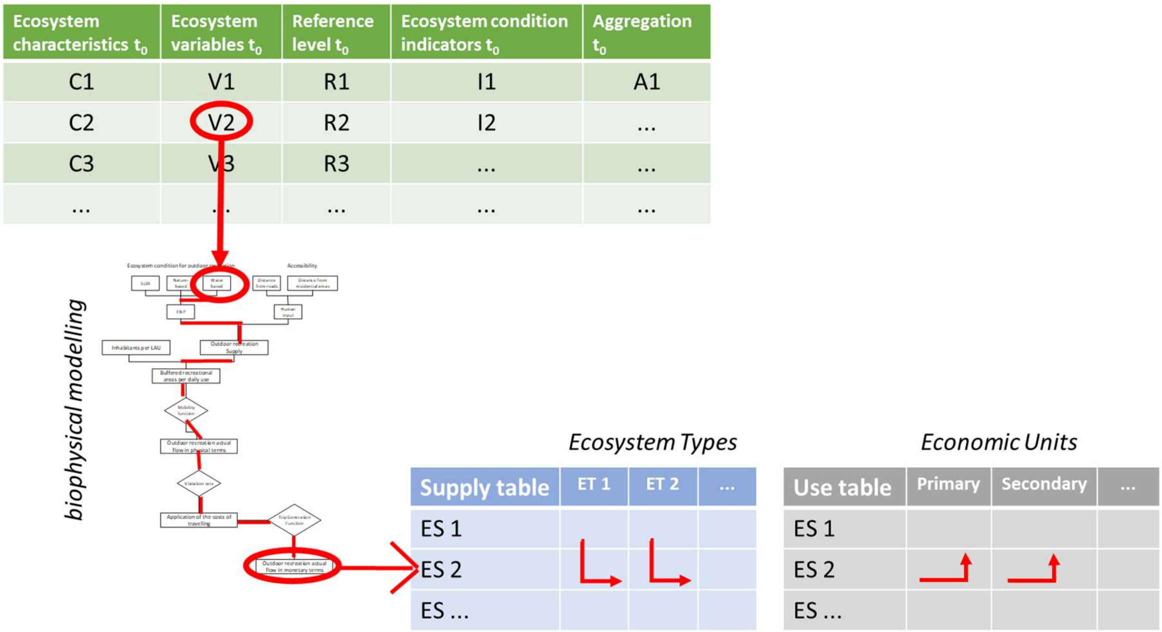
The SEEA ecosystem condition typology provides a harmonised reporting structure for SEEA EA ecosystem condition accounts. For each ecosystem type and SEEA ecosystem condition typology class, at least one variable is expected to be selected using a transparent process (Czúcz et al., 2021).

One important aspect of ecosystem condition accounts is that the variables selected should measure the state of the ecosystem, rather than the flows. This creates important considerations for the concrete definition and modelling of ES variables, too. For example, in the case of water purification, the main driver of change in the modelling of the actual flow for this ES is nitrogen emissions in river catchments. This is a flow, and thus does not meet the criteria to be selected as a condition variable. However, a variable such as nitrogen concentration in the same river catchment is a suitable variable for measuring ecosystem condition, which is determined by the nitrogen emissions.

The biotic ecosystem characteristics group includes features that are typically associated with ecosystems and biodiversity, which are subdivided according to composition, structure and function. Compositional state considers species data: their presence, abundance and diversity at a given location and time. Structural state considers properties of the whole ecosystem or its main biotic compartments (aggregated as mass, density, etc.). Functional state considers chemical and physical interactions between the ecosystem compartments in the form of summary statistics (such as frequency and intensity). For example, in the case of on-site soil retention, the assessment of ES P is based on the revised universal soil loss equation (RUSLE), which includes both soil properties (abiotic elements), such as soil texture and soil structure (which affect soil erodibility), and biotic elements such as vegetation cover.

The group of landscape-level characteristics can include landscape metrics describing the integrity of landscapes at ‘local’ landscape scales, through, for example, diversity, connectivity or fragmentation.

Figure 2.3. Direct linkages between ecosystem condition indicators and Ecosystem Services flows



Ecosystem characteristics t_0	Ecosystem variables t_0	Reference level t_0	Ecosystem condition indicators t_0	Aggregation t_0
C1	V1	R1	I1	A1
C2	V2	R2	I2	…
C3	V3	R3	…	…
…	…	…	…	…

Ecosystem Types

Supply table	ET 1	ET 2	…
ES 1			
ES 2			
ES …			

Economic Units

Use table	Primary	Secondary	…
ES 1			
ES 2			
ES …			

V_1, V_2 and V_3 are biophysical variables describing the condition of ecosystems. In the condition accounts, these variables are further processed into indicators (I_1, I_2, etc.) using reference levels (R_1, R_2, etc.), and then possibly also aggregated into indices (A_1). On the other hand, some of these variables (e.g. V_2) may also feed into the models used for the calculation of ES flows in the SUTs. A good selection process for the ecosystem condition variables maximises the interlinkages between the condition accounts and the ES SUTs through the underlying models. Figure 2.3 visualises how to establish a direct connection between condition asset accounts and ES SUTs. The linkage is not likely to occur at the condition indicator or aggregation stages (although this is possible), but rather occurs at the ecosystem characteristic and eventually variable stage (i.e. when variables (and/or input data for variables) are identified and selected). A careful selection of ecosystem condition variables can ensure that the selected variables will be relevant in terms of ESs (Czúcz et al., 2021).

Drivers of change can be natural or human (3). Both natural processes (e.g. natural regeneration) and human activities (e.g. environmental restoration actions) can improve ecosystem condition characteristics, which can, in turn, exert a positive impact on ES flows allocated to economic sectors and society (linkage). However, a growth in human pressures (e.g. pollutant emissions), for example, can decrease ecosystem condition characteristics and increase the overuse of ESs, eventually leading to ecosystem degradation.

2.2. Conceptual scheme: domestic users versus global society

SUTs report ES actual flow, which represents the transaction between ecosystem type and economic units. SEEA EA (UN, 2021) does not specify how to undertake the measurement of ES actual flow. Most applications used to date (Hein et al., 2020; La Notte et al., 2021) have in fact used different techniques and indicators, depending, in most cases, on what is currently available. In the INCA project, the calculation of ES actual flow is based on a coherent structure that considers ES actual flow as determined by the interaction between the ES P and the ES D (La Notte et al., 2019). ES P is the ecosystem's ability to generate services, irrespective of the demand. When ES P and ES D match, their interaction generates the ES actual flow that is reported in the official SUTs. When there is no match between ES P and ES D, there could be ES unused potential (where ES P > ES D) and ES unmet demand (where ES P < ES D). This information is complementary to the official SUTs, and its spatial mapping can provide relevant information for those policies oriented towards territorial planning, such as land management and ecosystem restoration.

An analysis/acknowledgement of the interactions between ES P and ES D is not at variance with the accounting notion of ES transactions, but it can help to explain the nature of this transaction, which can provide useful information for society. A clear distinction between ES P and ES D may help to clarify the relationship between condition and service, because condition almost always affects potentials, and very rarely affects demand. The comparison of ES P and ES D, furthermore, can reveal sustainable or unsustainable practices. In fact, mismatches between ES P and ES D can reveal that increasing ES actual flow (when considering time series) may result from greater human pressure rather than the enhancement of ecosystems (Vallecillo et al., 2019). This kind of information, currently reported as complementary from an accounting perspective, may be very relevant from a policy perspective.

In this report, we explore an additional aspect that can be relevant from a policy perspective: there are ES flows that can be allocated to specific users in specific countries, but there are also ES flows that cannot be allocated in this way because their allocation targets overarching environmental issues that go beyond national boundaries. Those services where ES D can be linked to a specific territory may be defined as 'domestic ESs': users of these services will be economic sectors and households, whose presence can be mapped within each country. The conceptual structure behind the quantification of ES actual flow describes perfectly these domestic ESs (Figure 2.4).

Nevertheless, there are some ESs whose users are not represented by a specific sector in a specific country. These particular ESs represent a sort of public good for the global population and its survival on the planet. Global public goods are extensively mentioned in the recent Dasgupta review (Dasgupta, 2021). Specifically, the reduction in damages caused by climate change and biodiversity loss is connected to the production of public goods (4), and 'global public goods' are acknowledged in the form of certain regulating and maintenance services. The examples reported for global public goods are the world's rainforests and oceans and, in turn, the services they provide to the whole planet. It is clearly stated that if we are to preserve them, the global community should be prepared to pay, and their management requires transnational institutions.

In the use tables, we name this specific category of users 'global society'. Including global society in use tables is a unique feature of the INCA project compared with SEEA EA, in which this kind of flow is attributed to 'government'. However, using the economic unit 'government' as an ES user comes with two major drawbacks in this case: (i) it does not reflect the entire society, because it remains a sector with its own costs, expenses and management practices; and (ii) it maintains its own national boundaries. For these reasons, the use of 'global society' was preferred in the INCA project.

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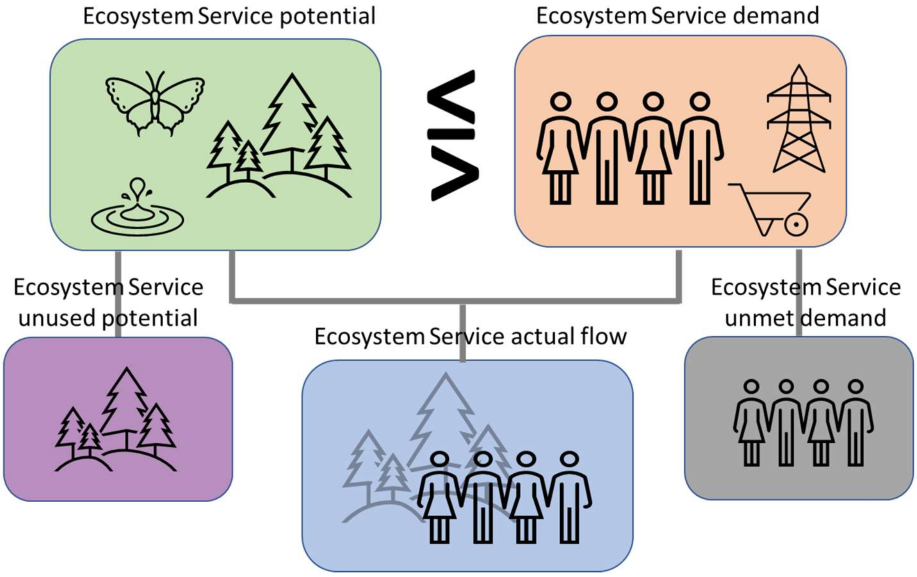
(3) It is important to keep in mind that most characteristics do not have a 'default' directionality (i.e. they simply change, but you cannot normally say if the change is positive or negative). However, for ecosystem condition characteristics there is an expectation that they should have a clear and consensual directionality (Czúcz et al., 2021).

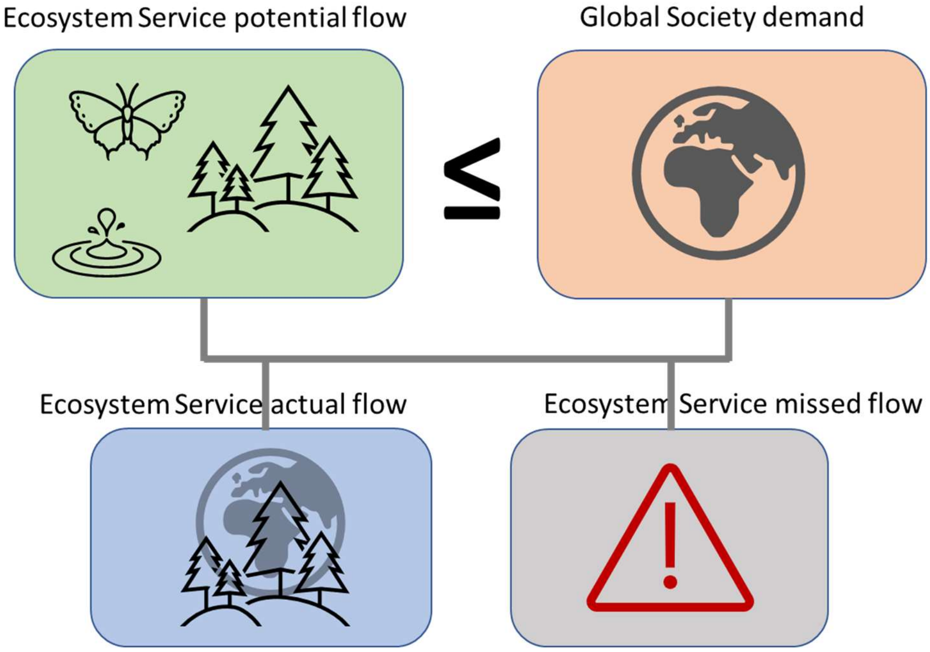
(4) In economics, a good is defined as 'public' (in contrast to 'private') when it is neither rivalrous (i.e. the access to a public good by any one group of people has no effect on the quantity available to others) nor excludable (i.e. when no one can be excluded from access to the good).

Figure 2.4. Conceptual schematic of domestic Ecosystem Services (visual simplification)



One important property of ESs that are global public goods is that they do not require any conscious and active 'harvest efforts' to exert their benefits. Therefore, all of ES P will instantly be 'utilised' and there is no need to model, assess or map ES D, as is done for other ESs. Nevertheless, it is still meaningful to compare the actual flow with an 'adjusted' version of the potential flow, which is calculated as the potential value of the ES assuming sustainable management and a stable good condition of the ecosystem (Figure 2.5). The difference between this (adjusted) potential flow and the actual flow is a 'missed flow' that does not reach global society. Such missed flows have an important message for global policy, so we provide two examples to illustrate how they are generated.

Figure 2.5. Conceptual schematic of global Ecosystem Services (visual simplification)



The first example concerns carbon sequestration (see Chapter 6). This refers directly to climate change mitigation, which is a global issue affecting the whole planet. Among the several international initiatives that directly address climate change, the Intergovernmental Panel on Climate Change is the UN body created to provide policymakers with regular scientific assessments on the implications and potential future risks of climate change, as well as adaptation and mitigation options. In the case of carbon sequestration, the ES P flow is the net carbon removal by ecosystems, especially (but not exclusively) the net removals by ‘woodland and forest’. However, ecosystems also generate net emissions. Before considering carbon removal as an ES actual flow to global society, emissions (which largely depend on how ecosystems are managed) have to be quantified and their levels will lower the net carbon removal. The actual flow is therefore quantified as the net balance between removals and emissions (net carbon sequestration). Carbon emissions are the ‘obstacle’ to accounting all net carbon removal as ES actual flow; they can be reported as the ES missed flow. If emissions are greater than removals, then ecosystems are not contributing to the mitigation of CO_2 in the atmosphere (i.e. there is no benefit to global society). The message for policymakers is to promote policies able to reduce ecosystem emissions, and thus eliminate (as much as possible) the obstacle to full carbon removal actual flow.

The second example concerns habitat and species maintenance (see Chapter 3). This service refers directly to the issue of biodiversity loss, whose impacts (although local) affect the whole planet. Among the several international initiatives that directly address biodiversity loss, the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES) is considered here. This is an independent intergovernmental body established by states and whose secretariat is held by the United Nations environment programme. Like the Intergovernmental Panel on Climate Change, the purpose of the IPBES is to strengthen the science–policy interface, specifically with regard to conservation and the sustainable use of biodiversity, long-term human well-being, and sustainable development. In the case of habitat and species maintenance, the ES potentially available flow (available only in monetary terms) is the value attributed to habitats and species. The value is higher where both are present in good ecological condition. However, this is not the case everywhere: the ES missed flow will be recorded where habitats are not in good ecological condition, but contain species hotspots. The message for policymakers is to encourage policies able to ensure the presence and quality of habitats able to support the existence of species through, for example, restoration actions and appropriate land use planning. Considering the current situation, in some areas there are suitable habitats but no species, or there are species but no suitable habitats. This lack of (respectively) species and habitats determines the deficit in what is the highest monetary flow currently obtainable. This deficit can be interpreted as the missed ES monetary flow: people would be willing to pay more if ecological features were there, but this is not the case.

Table 2.2 summarises some methodological features that can be used to distinguish ESs directed at domestic users from ESs directed at global society.

Table 2.2. Synthesis of key differences between domestic users and global society

	Domestic users	**Global society**
Mapping	Users can be spatially mapped Unmet demand can be spatially mapped	Users cannot be mapped Missed ES flow can be spatially mapped
Ecosystem type: geographical locations	Ecosystem type locations where there is ES unmet demand differ from ecosystem type locations where there is ES actual flow	Ecosystem type locations where there are ES P and actual and missed flows are the same
Use and values	Real markets; use (direct and indirect), bequest and option values	‘Artificial’ or hypothetical markets; non-use values
Policy scope	National interest to drive national policies; losing these ESs is a loss for the people living in those countries	Global initiatives to drive national policies; losing these ESs is a loss for all (the planet, global society)
Definitions	ES P / ES potential flow, ES D, ES actual flow, ES unmet demand, ES overuse	(Adjusted) ES potential flow, global society demand, ES actual flow, ES missed flow

As previously mentioned, demand for global services cannot be mapped. On the other hand, what can be mapped is the actual ES flow and the missed flow, which can provide policy-relevant maps for territorial planners.

In the case of domestic ESs, the location where the actual flow is measured can never overlap with the location of overuse / unmet demand because of the nature of the ESs. For example, (i) in response to the question 'Do residents live close to a green area?', 'yes' indicates areas of met demand and 'no' indicates areas of unmet demand); and (ii) in response to the question 'Is wood felling below the regeneration rate?', 'yes' indicates areas of met demand and 'no' indicates areas of overuse. In the case of global ESs, ES actual flow and ES missed flow are located in the same place; their sum will measure the (adjusted) ES potential flow.

In the case of domestic ESs, the delivery of ES flows directly affects real markets (e.g. agriculture and forestry) and physical users (e.g. farmers and households) geographically located in a country. Any policy affecting domestic ESs will have a national scope to reach a national goal. In the case of global ESs, 'artificial' markets (such as the carbon market) or hypothetical markets (such as those set to assess stated preferences) need to be created to generate a type of impact that can be measured. Any policy affecting global ESs may have a national scope but will reach an international target, because the underpinning rationale is that any change in these services will affect all rather than a single country, a single population or a single sector.

Although the overall framework does not change (ES P and ES D), the underlying terminology and definitions may need some refinement. Through Figures 2.4 and 2.5 and Table 2.2, we make an initial proposal that we expect to further develop as long as the continuous learning by doing enriches this evolving field of applied research.

2.3. Methodological approach: ecosystem service demand by ecosystems and enabling actors as users

In the case of domestic ESs, Figure 2.4 shows that ES D is usually represented by economic sectors and households, in line with the general industrial classification of economic activities within the European Union and the structure of the use table. However, there may be ESs that require additional considerations for the identification of ES D and the allocation of the ES actual flow in the use table. These considerations include:

- an option for ecosystems to also be listed as 'users' of ESs (in addition to socioeconomic sectors) – once the assessment of the ES actual flow is undertaken, it can then be allocated to the sectors in the general industrial classification of economic activities within the European Union that use it;
- an option for 'enabling actors' to also be identified as users of sink-type services (instead of the 'downstream beneficiaries' that would otherwise have had to suffer the harms of the pollution).

Both cases, although consistent with the overall framework, are groundbreaking with regard to the neoclassical economic perspective, which considers (i) 'supporting' (and thus intermediate) ESs as those for which there is a demand by ecosystems, and (ii) the 'downstream beneficiaries' as the only possible users.

2.3.1. Ecological demand as an interacting actor: methodological approach

When considering domestic ESs, the actual flow represents the transaction that takes place between ecosystem types and economic sectors and households, and is reported in official SUTs. As demonstrated in Vallecillo et al. (2019), ES D is often represented by economic sectors, households, derived infrastructures, etc., which can be considered the socioeconomic demand for the ESs. Human users can in fact be economic sectors (such as pollinator-dependent crops (i.e. the agricultural sector)) or households (residents who have the opportunity to enjoy nature-based recreation).

However, ecosystems also need ESs to maintain their condition and, although this is often neglected, ecosystems can be identified as users of ESs. This can be defined as the ecosystem demand for ESs. This typically applies when the ES actual flow contributes to the maintenance or enhancement of the ecosystem condition, which is a prerequisite for the provision of other ESs to society (for human use). The example provided in this report to illustrate the importance of the ecological demand is soil retention.

In the case of soil retention, the need for ecosystems to reduce erosion (on site) and maintain their soil properties exists only where there is the threat of erosion caused by rain (according to the specific model used in Chapter 4); in this case, there is an ES D by ecosystems. The ES P – the ability of vegetation to reduce erosion rates – becomes a service only where it is needed. The interaction between ES P and ES D generates as ES actual flow the soil retained by ecosystems (expressed in tonnes/ha). Although the soil retention service is provided by many ecosystem types, it plays different roles from an accounting perspective.

- It is 'anthropocentric–instrumental' (see Figure 2.2) in cropland because it keeps (and releases) nutrients in cultivated fields, and thus represents a transaction to the agricultural sector.
- It is 'ecocentric–instrumental' (see Figure 2.2) in other ecosystem types because it behaves as an intra-ecosystem flow and supports ecosystem condition.

Full details of the modelling and results are provided in Chapter 4.

2.3.2. Polluters as interacting actors: accounting allocation

Ecosystems may act as sinks to store, immobilise or absorb matter. The emission of pollutants is the major driver of change for the 'sink' ESs (La Notte et al., 2019). The first accounting implication is that two types of users can be distinguished: those carrying out economic activities that pollute 'upstream' and the 'downstream' beneficiaries of cleaned flows. Traditionally, assessments allocated sink ESs to the downstream beneficiaries. However, we support the allocation of sink ESs to the polluters, who are the enabling actors of the service: without them the service would not exist. This allocation is also more consistent with the 'polluter pays' principle: it is eventually the polluter whose costs are 'avoided' through the intervention of the ecosystems (the polluter does not need to compensate for the losses of the downstream economic units). The water purification ES (see Chapter 5) provides an example illustrating this case.

With regard to water purification, previous analysis (La Notte and Marques, 2017) demonstrates how polluters as enabling actors determine to what extent this ES is being used (the more pollutant emitted to the environment, the higher the need for the ecosystem to clean it up). Is this 'cleaning' needed? The existence of regulations that impose limits on the emission of pollutants (e.g. the 1991 EU nitrates directive) demonstrates that the answer is positive.

The fact that a regulation exists on this issue formally acknowledges that the degradation caused by pollution is a problem that needs to be monitored and controlled. In turn, the 'work' of ecosystems in removing and storing pollutants plays a role in this respect. In fact, ecosystems enable polluters to undertake the activities that cause the emission of pollutants, respecting the limitations imposed by law. From this perspective, the users of sink services are polluters because they are 'enabled' to a certain extent to pollute. The existence of such regulatory frameworks also provides a conceptual justification for the allocation of the sink ESs to polluters. However, the specifications of each individual law, directive, etc. should not be a constraint from an assessment perspective, which depends on the features of the ecological process.

The case of water purification (see Chapter 5) shows that the flow of this service in the use table is allocated to the agricultural sector. The ES flow that is computed in the official SUTs is the actual flow, as required by SUTs. Accounting for sink ES actual flow requires another implication to be considered. In fact, the actual flow (considered on its own) risks being misleading. Using the example of water purification, too much nitrogen (actual flow) can degrade the condition of the ecosystems that absorb it, which is not good from a sustainability perspective (La Notte and Dalmazzone, 2018). By setting one (or more) sustainability threshold(s), it is possible to measure to what extent the ecosystem is providing the service beyond its natural capacity, which is considered in terms of overuse (as shown in Chapter 5 of this report). From an accounting format perspective, overuse is part of the complementary information reported together with SUTs.

In summary, sink services show a number of peculiarities, such as the identification of the ES D (polluters) and the need to compute the ES overuse. In this respect, sink services differ from other ESs and need to be addressed carefully in order to avoid misleading messages. Full details of the modelling and results are provided in Chapter 5.

2.4. Methodological approach: intermediate and final ecosystem services

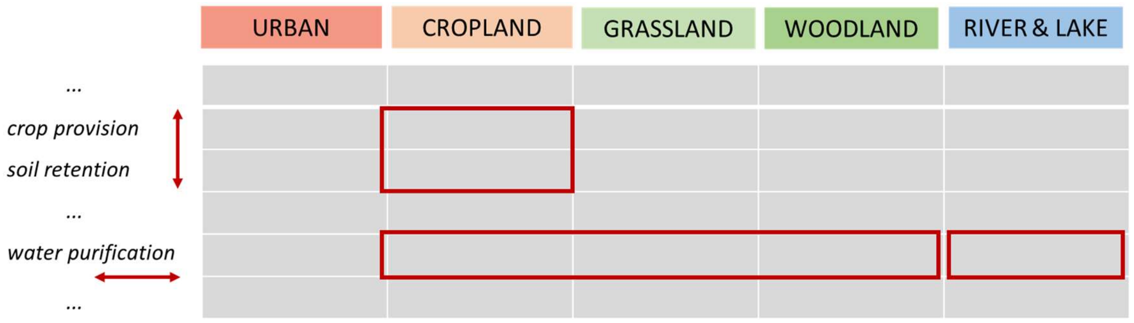
Final ESs are defined in SEEA EA as follows: 'those ecosystem services in which the user of the service is an economic unit – i.e., business, government or household. Thus, every flow of a final ecosystem service represents a transaction between an ecosystem asset (as a producing unit) and an economic unit' (UN et al., 2021, Chapter 6, Section 6.2.5). According to this definition, ecosystems provide a service when the service flow is transacted from ecosystem types (in the supply table) to socioeconomic users (in the use table).

SEEA EA also describes intermediate services as 'those ecosystem services in which the user of the ecosystem services is an ecosystem asset and where there is a connection to the supply of final ecosystem services' (UN et al., 2021, Chapter 6, Section 6.2.5). We would like to further explore the issue concerning intermediate services by considering those cases in which double counting may occur. Two ESs presented in this report explicitly address the issue of intermediate services.

- The case of soil retention addresses whether and how there may be a problem of double counting with reagrd to crop provision (i.e. whether soil retention should be considered intermediate because it supports crop provision). We consider such cases of an ES supporting another ES as having a 'vertical' risk of double counting (i.e. two services assessed as one).
- The case of water purification addresses whether there may be a problem of double counting in reporting the different roles of different ecosystem types in delivering a service. We consider this flow from one ecosystem type to another ecosystem type as having a 'horizontal' risk of double counting.

A simplified representation is provided in Figure 2.6.

Figure 2.6. Vertical and horizontal risk of double counting in the supply table



From the perspective of SEEA EA, the 'vertical' case questions the classification of ESs as intermediate or final, but still supports the central idea that ESs involve transactions and hence must involve two units – a supplier and a user. For final ESs, the two units are ecosystem type and economic unit.

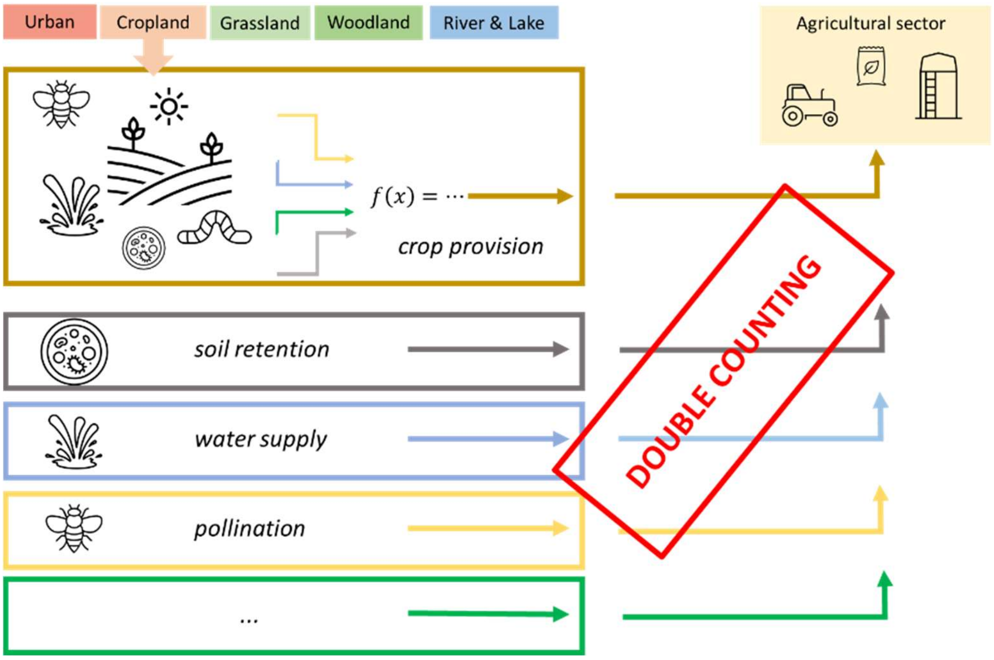
The 'horizontal' case aims to structure the analysis when it comes to identifying what is part of the final service. In Warnell et al. (2020), basin retention (areas of purifying land cover) is in fact considered a condition rather than a service.

2.4.1. Accounting for indirect services: the 'vertical' case

The assessment of crop provision, as an ecosystem contribution, may include many factors such as nutrients, water, pollination (depending on crops) and sunlight. The assessment of soil retention (see Chapter 4) takes into account the value of soil retained as a function of its fertility (more fertile soil has a higher value) and structure. Soil fertility is, in turn, an ecosystem input for agricultural yield. There may be methodologies for assessing crop provision that already include the role of soil. For example, agricultural production functions probably include soil fertility together with water and solar energy. In previous INCA assessments of crop provision (see Chapter 3 in Vallecillo et al., 2019), the adopted approach based on the emergy ratio included the role of soil in crop production. The examples of agricultural production functions and the emergy-based approach show that there is a risk of double counting (Figure 2.7).

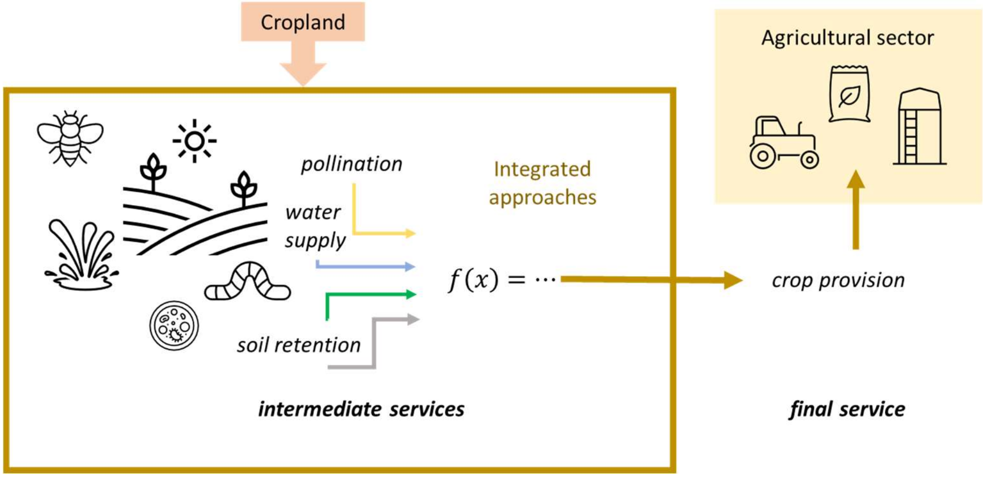
When aggregating on-site soil retention with crop provision, there is thus a need to unbundle the role of soil. There are several ways to avoid double counting. One option is to adopt an integrated approach in which ESs such as soil retention and water supply remain intermediate and are not considered explicitly as standalone ESs.

Figure 2.7. Crop provision example of the risk of double counting



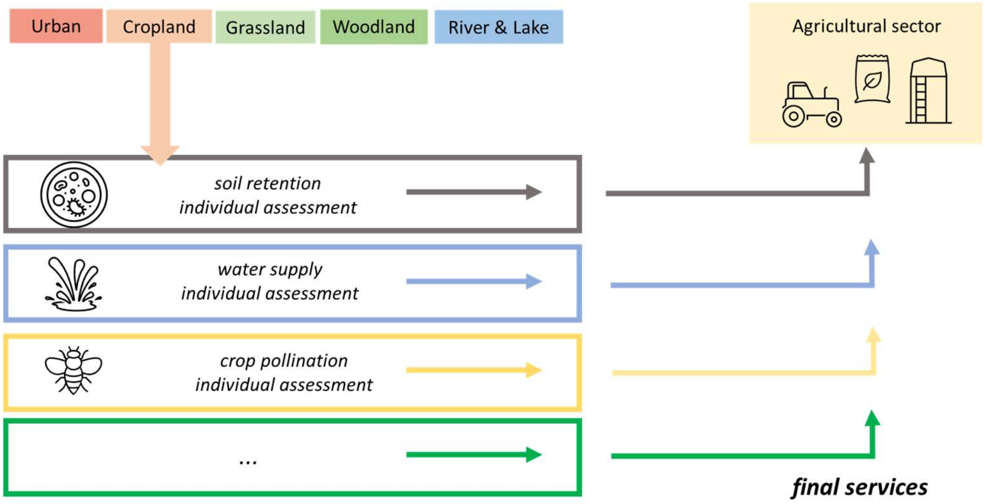
Examples of comprehensive approaches are the (in part already mentioned) agricultural production function, emergy-based approach and input–output analysis (Figure 2.8). In this case, intermediate ESs are considered only through crop provision (embedded in it), which might result in information that is too aggregated for decision-makers and makes it difficult to allocate the ecosystem contributions to the flow to the ecosystem types that contributed the most to it.

Figure 2.8. Crop provision assessment based on a comprehensive approach



A second and more demanding approach would require identifying and assessing each individual service by using a variety of techniques ranging from complex biophysical models, such as for pollination and soil retention, to environmental statistics and accounts, such as for water supply (Figure 2.9). In this case, no comprehensive approach is used. This approach is more demanding in terms of data needs and modelling, but it ensures a better, more realistic assessment of ESs. On the one hand, crop provision is not recorded as a standalone ES, because the ESs that nature provides through crops are allocated to all the services that make crop provision possible. On the other hand, it is difficult to obtain the information needed to quantify and record all possible flows (one by one) in the accounting tables. Furthermore, ecological systems are very complex, and the contributions of different processes may not be helpful, so the (re)allocation of ES flows is not straightforward, even if all the data are available. The most suitable solution would be a combination of the two approaches, which has the potential to give an unbiased representation of the various ecosystem contributions.

Figure 2.9. Crop provision assessment based on the assessment of each individual ES contributing to agricultural production



Therefore, a third option is to use both approaches, making sure that there is no double counting (Figure 2.10). In this case, the assessment of individual ES flows becomes pivotal and the application of comprehensive approaches helps to cover residual aspects that are otherwise not assessed.

Figure 2.10. Crop provision assessment based on a mixed comprehensive approach and ES modelling

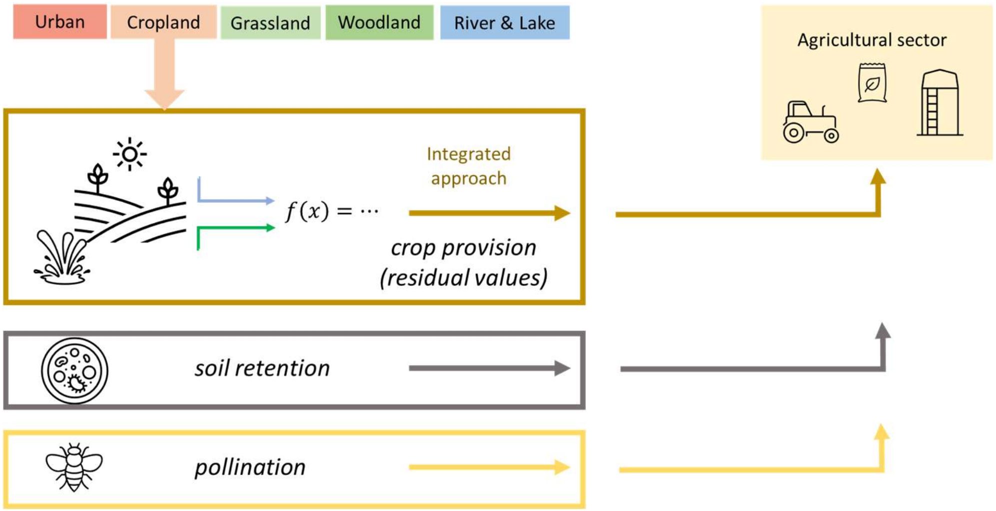
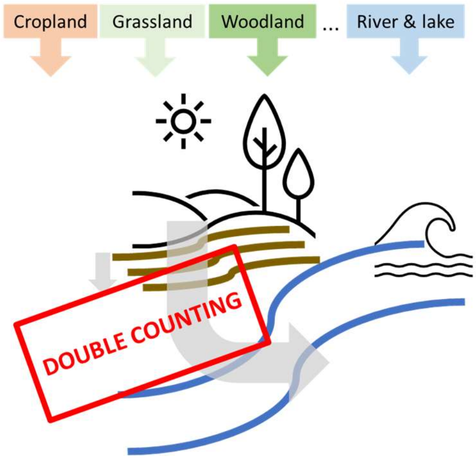


Figure 2.10 shows that, in this third approach, the contributions of the ES assessed individually are removed from the crop provision ES and double counting is avoided. In the INCA project, we apply this third approach: Chapter 4 details how the on-site soil retention service is assessed, Chapter 6 explains how the risk of double counting regarding soil provision is avoided and in Chapter 7 all ES flows are consistently aggregated.

2.4.2. Accounting for indirect services: the ‘horizontal’ case

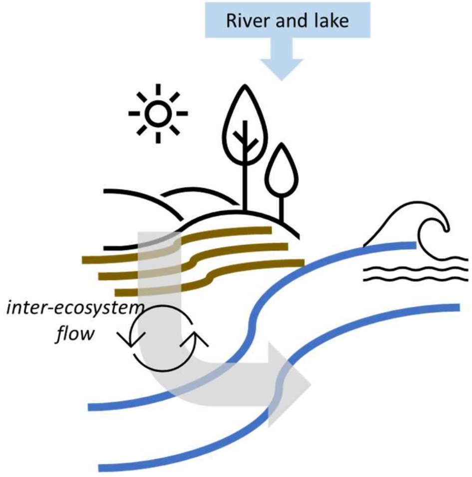
The assessment of water purification (see Chapter 5) provides the opportunity to explore another case of possible double counting. Here, we specifically refer to a service that flows from one ecosystem type to another ecosystem type. In the SEEA EA conceptualisation, this flow is defined as an ‘inter-ecosystem flow’, and this kind of flow risks being counted twice. In the case of water purification, there are two stages of retaining pollutants: basin retention (the retention of excess nutrients and pollutants in the soil and deeper layers of the lithosphere) and river and lake retention (the retention of excess nutrients and pollutants in surface waters). Basins play an important role and their role risks them being counted twice if aggregating two assessments that first consider basin retention only and then, when assessing river and lake retention, include basin retention again (i.e. (basin retention + (basin and river and lake retention))). This is illustrated in Figure 2.11.

Figure 2.11. Water purification example of the risk of double counting



In fact, biophysical models able to assess pollutant removal by integrating all the elements (basin, river, etc.) could be used. In this case, the final result includes the role that different ecosystem types have played, and there is no need to add a separate role for each of them. The role of basins remains intermediate (inter-ecosystem flow) (Figure 2.12).

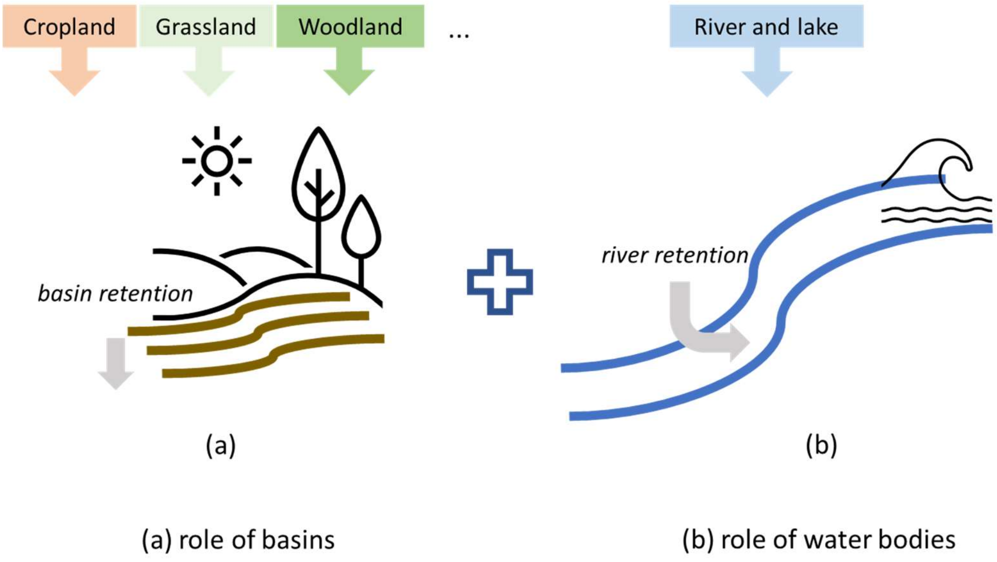
Figure 2.12. Water purification assessment including the role of both basins and water bodies



Other biophysical models may assess the role of ecosystem types separately: in this case each step in the retention process needs to be reported and valued separately, but in a consistent way (Figure 2.13). In fact, to consider only the ecosystem type ultimately involved in the service provision (in this case, river and lake retention) would seriously underestimate the value of the whole service. When comparing the pilot application on water purification, which considers only river and lake retention (La Notte et al., 2017b), with the assessment reported in Chapter 5, we found a difference in value of about 78 %. Moreover, this approach completely disregards the role and the contributions of upstream ecosystems.

The case of water purification is detailed in Chapter 5, where the role of basins and rivers is carefully explained with regard to both their physical assessment and their monetary valuation.

Figure 2.13. Water purification assessment that allows separate assessments of the role of (a) basins and (b) water bodies



2.5. Conclusions

Figure 2.1 shows (in red) the main issues addressed in this chapter and returned to throughout the report. These issues were raised while concretely working on the assessment and valuation of three ESs: habitat and species maintenance, on-site soil retention, and water purification. While always being compliant with the basic rules set out in SEEA EA guidelines (UN, 2021), in some cases INCA applications propose further developments in both conceptual and methodological terms.

First, identifying characteristics consistently between measurement of condition and measurement of ESs is logical and important. On the one hand, the existence of this linkage does not imply that practitioners need to measure condition first in order to measure ESs. On the other hand, clearly tracking the **causality nexus between condition variables and input data in ES assessments can make the overall accounting system more consistent**, with each module connected to the others rather than having independent modules running in parallel. However, there is still discussion on this issue.

Second, when dealing with overarching environmental targets such as climate change and biodiversity loss, the ES transaction is not domestic but rather global. ESs such as carbon sequestration and habitat and species maintenance will need to be structured differently from other ESs because their users cannot be geographically located. On this matter, INCA proposes 'global society' as an additional economic unit in the use table. This is different from SEEA EA, which allocates these ES flows to 'government'. **Global ecological public goods in ecosystem accounting will need to be discussed**; what we propose here is one contribution to the unavoidable debate on this issue.

Third, methodological developments concern the following.

- With regard to the identification of the users, the **modelling assessment may require ecosystems to be categorised as ES D** to measure ES actual flows, as happens for soil retention. Although this seems to conflict with the principle of the final transaction between ecosystem type and economic units, the modelling outcome is perfectly in line with what needs to be recorded.
- With regard to the allocation to users, **sink services directly depend on polluters' actions**. This issue, although greatly debated, has not been directly addressed in official ecosystem accounting guidelines. We propose an approach here for how to proceed in cases of absorption rates being exceeded; however, the role of polluters is still very controversial and at the moment there is no agreement on how to deal with this issue.
- **No ESs can be defined as intermediate by default**. This definition depends on the assessment technique that is used. The risk of double counting can occur in different ways. Here, we identified two

cases, which we named ‘vertical’ and ‘horizontal’, by following the structure of the ecosystem type supply table.

Concepts and methods will need to be further developed and improved alongside the increase in ecosystem accounting applications. Thanks to the basic guidelines provided by SEEA EA, we have a common ground to refer to; however, this field is very complex, and more time and more concrete experiences will be required before reaching a final, comprehensive set of recommendations.

Key messages

- Understanding the relationship between the condition of ecosystems and the supply of ESs requires an understanding of (i) how ecosystems can directly enter the socioeconomic dimension (ES SUTs) and (ii) why, even when not directly entering the socioeconomic dimension, ecosystems still play an important role in it (condition asset accounts).
- When it comes to ecological public goods, ES D is represented by global society. The interaction between ES potential flow and global society can generate ES actual flow and ES missed flow. These measurements can help to set reference policy targets for measuring ecological improvements or degradation with respect to overarching environmental issues such as climate change and biodiversity loss.
- The identification and allocation of ES flow can present some peculiarities, such as in the case of on-site soil retention (identification of ecosystems as ES D) and water purification (allocation to polluting sectors rather than downstream beneficiaries).
- On-site soil retention is not an intermediate ES when disentangled from crop provision.
- Basin retention is not an intermediate ES when assessed separately from river and lake retention.

3. Habitat and species maintenance

Habitat and species maintenance as an ES is defined here as the presence of suitable ecological conditions (usually habitats) and of species that people value. This definition is modified from the Common International Classification of Ecosystem Services (CICES) version 5.1 (Section 2.2.2.3 'Maintaining nursery populations and habitats'), which refers to species that people use or enjoy. However, if habitats and species are 'used', this would correspond to an intermediate service contributing to a provisioning service. For instance, maintenance of wild species such as wild boar would contribute to the provision of meat (provisioning service). If habitats and species are 'enjoyed', this would contribute to the delivery of a cultural ES. For instance, the presence of natural attractions (habitats and/or presence of species) would contribute to the provision of nature-based recreation. However, in this chapter we go beyond this use (as further explained in Section 3.1), focusing on the existence values of habitats and species.

We now consider other ES classification systems. In IPBES, the equivalent service is **habitat creation and maintenance**, defined as the 'formation and continued production, by ecosystems or organisms within them, of … nesting, feeding, and mating sites for birds and mammals, resting and overwintering areas for migratory mammals, birds and butterflies, nurseries for juvenile stages of fish' (IPBES, 2017). According to the National Ecosystem Services Classification System, this flow would be coded as follows: 2 (non-use), 21 (existence), 2101 (appreciated and valued by humans for existence reasons, without direct use or contact) (US EPA, 2015).

Ultimately, in this study, in line with the definition provided, we consider habitat and species maintenance as a final ES. people value habitats and species not because they want to 'use' them, either directly or indirectly (use values), either now or in the future (option and bequest values); they value habitats and species simply for their existence, because thanks to these ecosystems we can maintain the planet as we know it and in a way that we are accustomed to, for present and future generations (existence value). In this sense, society is willing to pay for the maintenance of suitable habitats and the maintenance of species.

Existence values (also called non-use values) are an integral part of the total economic value, which is the standard economic approach to valuing ecosystems in cost–benefit-analysis. They are completely accepted as economic values. The essential basis of the total economic value is that everything that has a positive effect on our preference function is a good or service that can be valued in monetary terms.

The existence of international biodiversity targets (Aichi targets (5)) and European policies to protect habitats and species, such as the EU birds and habitats directives, confirms the importance of this ES for global society, showing a real and direct societal demand for species maintenance as an ES. The EU birds and habitats directives are a direct policy response to the rising concern of people across Europe about the loss of their biodiversity (6). In this sense, there is a real societal demand for the maintenance of habitats and species related to human preferences and values (Wolff, Schulp and Verburg, 2015), since they contribute to the generation of benefits to society by preserving natural heritage and safeguarding intrinsic human values (Burkhard et al., 2012). Therefore, habitat and species maintenance should be considered a final ES (Lennon et al., 2004), rather than an intermediate service, as stated in other studies (e.g. Orme et al., 2005).

To approach such a complex service, its meaning needs to first be further clarified (Section 3.1) before proceeding with the assessment. In contrast to other ESs, the biophysical assessment of habitat and species maintenance does not quantify on its own the use or actual flow required for accounting (Section 3.2). However, the assessment of certain ES features is necessary to quantify the actual service flow, which takes place only in monetary terms (Sections 3.3 and 3.4). The results are provided in Section 3.5 and discussed in Section 3.6; Section 3.6. also presents the limitations of the assessment and proposals for further developments.

3.1. Habitat and species maintenance as a 'final' and 'maintenance' ecosystem service

The reference list of ESs proposed in SEEA EA (Table 6.3 in UN et al., 2021) includes (i) 'Nursery population and habitat maintenance services', defined as the ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy, and (ii) 'Ecosystem and species appreciation', which concerns the well-being that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use.

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(5) https://www.cbd.int/sp/targets/

(6) https://ec.europa.eu/environment/nature/info/pubs/docs/brochures/nat2000/en.pdf

The former is an intermediate service and may input to several different final ESs, including biomass provision and recreation-related services. This is classified as a 'regulating and maintenance service'. The latter is classified as 'flow related to non-use values' and does not belong to any specific CICES class; for this reason, we have slightly modified the CICES definition and filled in this gap for non-use values. Therefore, habitat and species maintenance as reported in this application is not an intermediate service and is classified as a 'maintenance' service. The rationale behind this choice is now explained.

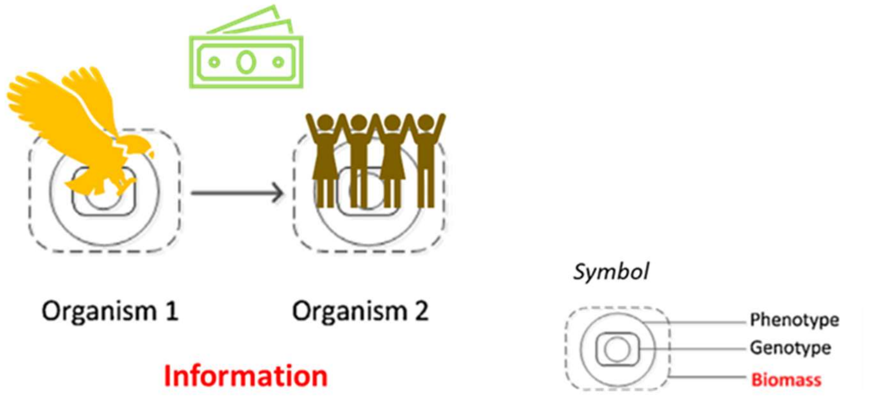
Habitat and species maintenance is considered to be a final service because people include the existence of habitats and species in their utility function, and they are willing to pay for it and for their maintenance. However, the fact that the value is attributed by people may generate a misunderstanding about the meaning of this service: is it a maintenance or a cultural service? To address this issue, we need to recall the three fundamental notions proposed by Jørgensen (2012) as the basis of ecological systems.

- Biomass is biological material derived from living or dead organisms. The quality aspect of biomass is also relevant (e.g. based on protein synthesis and evolution).
- Information is passed between two (or more) organisms when a receiver organism is able to capture and process an exchange from a sender organism. This is a unidirectional causal effect exchange. Organisms can exchange material and energy but also information (Dusenbery, 1992). The process of acquiring information involves a mechanistic phase of information capture by a receptor and a functional phase of information decodification. 'Knowledge' can be defined as the ability to recognise and process that information (Guilford and Dawkins, 1991).
- Interaction occurs in a network in which components have an effect upon one another. There is a multidirectional relationship between and among biotic and abiotic components. Interactions may result in emergent properties that, in a system, cannot be predicted or explained by the sum of the components alone (Odum, 1977; Edson et al., 1981).

When we deal with cultural services, as defined in CICES and the economics of ecosystems and biodiversity (TEEB) (2010), the system category is 'information' because people as the receiver organism receive from nature flows without interacting in the generation of those flows. For example, with regard to nature-based recreation, we enjoy being in a natural environment; with regard to mimicking nature, we collect input from nature to develop science and technology. We capture flows; we do not produce flows.

When people are willing to pay to visit a place where there are specific animals (use value) or to make sure that such a place will not be destroyed because in the future they or their children may wish to see those specific animals (option and bequest values), this is a cultural service. The use, option and bequest values are associated with 'visiting' and 'seeing' individual organisms.

Figure 3.1. Cultural services and the 'information' system category

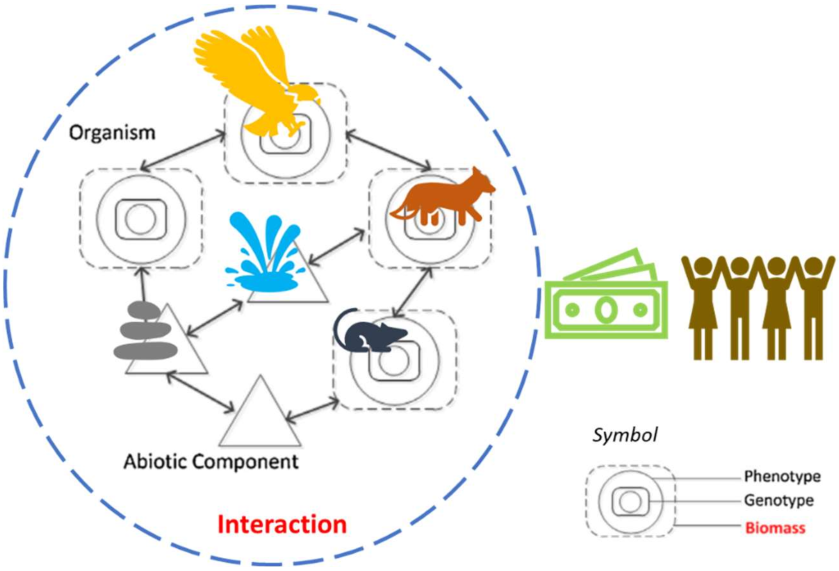


Source: Adapted from La Notte et al. (2017a)

When we deal with maintenance services, in CICES and TEEB the system category is 'interaction', because it is about an ecological process in which biotic and abiotic elements work together to generate a flow. In some cases, people or economic sectors can be users of this flow (e.g. pollination or pest control); in other cases, people may be willing to pay for the ES even if they are non-users (e.g. habitat and species maintenance).

In some cases, people are willing to pay to make sure that a mechanism (whatever its nature) keeps working to guarantee survival; for example, the food chain is necessary for ecological systems not to collapse. In this case, people are willing to pay for an interaction process (maintenance of ecological processes), not for an individual organism.

Figure 3.2. Maintenance services and the 'interaction' system ecology category



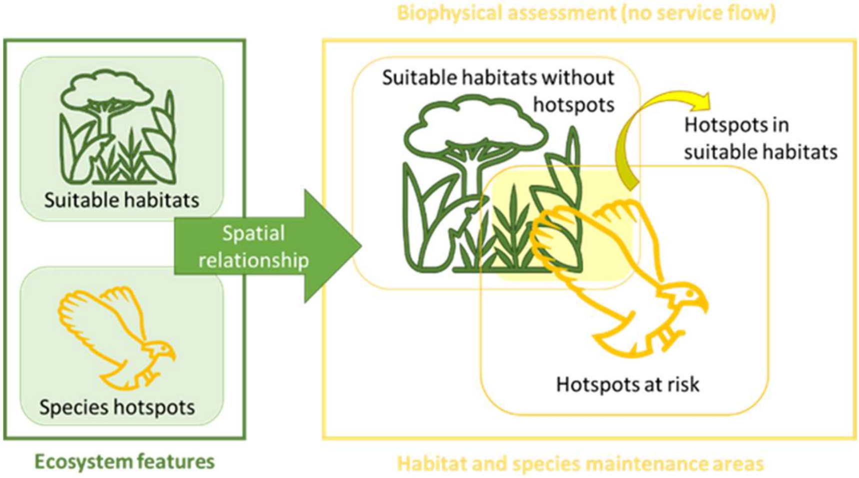
Source: Adapted from La Notte et al. (2017a)

Habitat and species maintenance as assessed in this application is a maintenance service, not a cultural service, because people are willing to pay for the maintenance of habitats and species (keeping the food chain working), as opposed to visiting and seeing species (for cultural or scientific purposes).

3.2. Biophysical assessment

The biophysical assessment for this ES includes the mapping of suitable ecological conditions (or suitable habitats) required to support species populations and mapping of the presence of species, considered in terms of species hotspots (Figure 3.3). The spatial relationship between these ecosystem features is used to identify different types of habitat and species maintenance areas (service areas). The service areas will ultimately be considered for the quantification of the actual flow in monetary terms (Figure 3.3).

Figure 3.3. Schematic representation of the biophysical assessment underpinning habitat and species maintenance



3.2.1. Mapping of suitable habitats

Habitat loss and degradation are identified as the main drivers of regional population extinction and biodiversity decline (Heinrichs, Bender and Schumaker, 2016). In this sense, we have developed an indicator of habitat suitability to support species populations, integrating information about the quality and quantity of different ecosystem types, since both parameters are important drivers of biodiversity (ten Brink, 2000). The habitat suitability indicator is calculated by multiplying the ecological condition, to account for habitat degradation, by the relative ecosystem extent, as a proxy for habitat loss:

$$Habitat\ suitability\ =\ \sum_{k=1}^{n} ecological\ condition\ \times\ relative\ extent \qquad \text{(Equation 3.1)}$$

where k corresponds to different ecosystem types, allowing the calculation of the indicator in areas where different ecosystem types coexist.

The habitat suitability indicator has been developed to identify, above a certain threshold, the presence of suitable habitats for supporting species populations, where both habitats and species have a higher likelihood of continuing to survive either in the present day or in the future. The identification of suitable habitats includes the following steps, which are described in the following subsections:

- modelling ecological condition:
    - selection of predictor variables,
    - logistic regression model;
- mapping habitat suitability to support species populations;
- delineation of suitable habitats.

3.2.1.1. Modelling ecological condition

To model the ecological condition of ecosystems, we used as input data habitat conservation status as reported under Article 17 of the habitats directive (7). We used the conclusion of the 'structure and function' parameter since it is more related to the ecosystem condition than the overall conclusion of the assessment. Article 17 data contain a subset of spatially explicit information on polygons delineating the habitat distribution and its conservation status. Article 17 data present large biases in reporting between countries (Maes, 2013), making necessary the development of spatial models to guarantee comparability of the output at EU level, but also to map ecological condition at the finer spatial resolution (from large polygons reported in Article 17 to 10 km grid cells) required for ecosystem accounting. The modelling of ecological condition is based on the method developed by Maes (2013). Maes presents a statistical model using the spatial polygons of the habitat assessment reported under Article 17 and a subset of environmental pressures and drivers of ecological condition found within each polygon.

The modelling of ecological condition was based on Article 17 spatial data for 2007–2012 (8), which reported conditions as 'favourable', 'unfavourable-inadequate' or 'unfavourable-bad'; data were available for all condition indicators used as predictor variables in the model (a total of 2 500 polygons). We used a selected subset of indicators used in the EU-wide assessment of ecosystem condition as predictor variables (Maes et al., 2020). Indicators were selected when they were available at least at 25 × 25 km^2 resolution and for at least 2 years (preferably for 2000 and 2012) to enable projections to be made over time. The condition indicators included in this study are tropospheric ozone in forest ecosystems, exceedances of critical loads for acidification and eutrophication, dry matter productivity in forest and in agricultural areas, imperviousness, high natural value farmland in agro-ecosystems, mineral fertiliser nitrogen input into the soil, total drought severity and naturalness (land mosaic). We also included other ancillary indicators that might also be relevant as drivers of ecological condition: small woody features in agro-ecosystems, fraction of green vegetation cover, Shannon's land cover diversity index, ecosystem type and share of arable and agricultural land (see 'Selection of predictor variables' below and Annex MA1).

The main innovations integrated in this study compared with Maes (2013) are as follows.

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(7) https://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

(8) Spatial data for 2007–2012 are missing for Croatia.

- We used the conclusion of the assessment for the ‘structure and function’ parameter instead of the overall conclusion of the assessment.
- We used reported data for 2007–2012 for the calibration of the modelling, whereas Maes (2013) used data for 2001–2006.
- Conclusions for unfavourable-inadequate and unfavourable-bad conditions were merged into one category: ‘unfavourable’. This enables logistic regressions for favourable versus unfavourable ecological conditions to be built.

Selection of predictor variables

Mean values of predictor variables were calculated within the spatial polygons from data reported under Article 17 of the habitats directive. Only for those variables related to land cover extent (Shannon’s land cover diversity index, and share of arable and agricultural land) were values calculated based on the land cover extent in each polygon. In this way, we gathered data on conservation status and predictor variables within the spatial polygons of Article 17 data.

We undertook bivariate correlation analysis between the indicators used as predictor variables to avoid collinearity problems in the modelling. Of the initial list of 16 indicators (see Annex MA1), three presented large correlations (Pearson correlation coefficient > 0.8) with other indicators and therefore were discarded from the analysis (see Annex MA2).

For the remaining 12 continuous indicators, we applied the non-parametric Wilcoxon test to analyse differences between favourable and unfavourable assessments (see Annex MA3). Variables were selected only when showing significant differences between favourable and unfavourable assessments aligned with ecological expectations. For instance, pressure indicators, such as mineral nitrogen in the soil, were expected to present greater values under unfavourable conditions than under favourable conditions to be selected for the model. In contrast, proxies of good condition, such as high natural value farmland, are expected to be greater under favourable conditions than under unfavourable conditions (see Annex MA3). The following indicators were discarded because the differences between favourable and unfavourable ecological conditions were the opposite to those expected: total drought severity, small woody features, ozone in forest ecosystems and vegetation cover.

Therefore, based on these previous analyses, eight continuous variables were used to build the full logistic regression (see Annex MA1): share of arable land, acidification, eutrophication, imperviousness, mineral soil nitrogen levels, high natural value farmland, dry matter productivity in forest ecosystems and Shannon’s land cover diversity index. Moreover, we included a categorical variable available in the spatial polygons of Article 17 data that groups every habitat assessment into one of the Mapping and Assessment of Ecosystems and their Services (MAES) ecosystem types. This enabled us to distinguish ecological condition by ecosystem type as a function of the regression intercept, accounting for differences in ecological condition among and within ecosystem types, to better model ecological condition of ecosystems.

Logistic regression model

A logistic regression model was built to estimate the probability of an ecosystem condition being reported as favourable as opposed to unfavourable. A backward stepwise regression was used to build a simplified model that best explains the data. It begins with a full (saturated) model, with all nine variables, and at each step non-significant variables are gradually eliminated from the regression model. The best final model is described in the following equation:

$$prob(condition = FV|UN) = f(ecosystem\,type + IMP + HNV + minN) \quad \text{(Equation 3.2)}$$

where *FV* and *UN* are favourable and unfavourable ecosystem conditions, respectively, reported in the habitat assessment; *ecosystem type* is a categorical variable that refers to the six terrestrial MAES ecosystem types (Maes et al., 2013), corresponding to the habitats reported in Article 17 of the habitats directive: grassland, heathland and shrubland, woodland and forest, sparsely vegetated land, wetland, and rivers and lakes; *IMP* is imperviousness; *HNV* is the high natural value of farmland; and *minN* corresponds to the mineral nitrogen in the soil, as a proxy for agriculture intensity (Table 3.1).

Table 3.1. Input data used to account for habitat and species maintenance

Input data		**Spatial resolution**	**Years included**	**Source**
Suitable habitats				
Modelling ecological condition				
Dependent variable	Structure and function assessment (spatial data reported under Article 17 of the habitats directive)	Spatial polygons in Article 17 data	Reported data for 2007–2012	https://data.europa.eu/data/datasets/article-17-database-habitats-directive-92-43-eec-1?locale=en
Independent variables	Ecosystem type	Spatial polygons in Article 17 data	Reported data for 2007–2012	https://data.europa.eu/data/datasets/article-17-database-habitats-directive-92-43-eec-1?locale=en
	Mineral nitrogen in the soil	10 × 10 km^2	2000 and 2012	Leip et al. (2016)
	Imperviousness	1 × 1 km^2	2006 ([a]) and 2012	https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/status-maps
	High natural value farmland in agro-ecosystems (accounting versions)	100 × 100 m^2	2000 and 2012	https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/4b3a3319-4db3-4a33-b18d-2ba55b3fe2ce; https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/82feb669-ebb9-4601-8a84-9e1fe0ae2e2c
Mapping habitat suitability to support species populations				
Spatial unit of reference	Reference grid for the European Environment Agency	10 × 10 km^2	Not applicable	https://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2
Ecosystem map (extent)	Accounting layers of the coordination of information on the environment in Europe (Corine) land cover inventory (version 18.5) (unpublished data)	100 × 100 m^2	2000 and 2012	New version available at https://data.europa.eu/euodp/data/dataset/corine-land-cover-accounting-layers
Species hotspots				
Hotspots of bird species richness	Based on distribution models of the *European Breeding Bird Atlas 2*	10 × 10 km^2	2013 and 2017	https://www.ebba2.info/
Monetary value				
Human population	Global human settlement layer	1 × 1 km^2	2000 and 2015	http://ghsl.jrc.ec.europa.eu/ghs_pop.php
Choice experiment study	Willingness to pay for habitat suitability and species hotspots	Willingness to pay per person per year	Data collected in 2019	La Notte et al. (2021b)

([a]) Since data for 2000 were not available, data for 2006 were used to assess changes over time.

The parameters in Equation 3.2 are shown in Table 3.2. Ecosystem types are sorted from more vulnerable (wetland and grassland) to those with a higher probability of being in a favourable ecological condition, such as sparsely vegetated land. For continuous variables, pressures on ecosystems appear to be negative, therefore decreasing the probability of a habitat being in a favourable condition, whereas high natural value farmland, which has a positive value, has an increased probability of being in a favourable condition.

Assessment of model accuracy was measured by applying a 100-fold cross-validation. The model accuracy of the 100 alternative models run was 0.71 (with a standard deviation of 0.074), which shows that the model is reasonable, although not very good. This point is discussed further in the limitations section (Section 3.7). A confusion matrix for the correct and incorrect predictions of favourable and unfavourable ecosystem conditions is provided in Annex MA3.

Table 3.2. Parameters of the logistic regression model for ecological condition

Variables		Coefficient	Standard error	z-score	p-value
Ecosystem type	Wetland	– 1.166	0.201	– 5.800	< 0.001
	Grassland	– 0.930	0.172	– 5.398	< 0.001
	Woodland forest	– 0.847	0.168	– 5.036	< 0.001
	Rivers and lakes	– 0.490	0.178	– 2.749	< 0.01
	Heathland and shrubland	– 0.135	0.184	– 0.730	0.465
	Sparsely vegetated land	0.524	0.177	2.960	< 0.01
Imperviousness		– 0.131	0.030	– 4.379	< 0.001
High natural value farmland		1.023	0.002	5.509	< 0.001
Mineral nitrogen in soil		– 0.011	0.186	– 4.326	< 0.001

3.2.1.2. Mapping habitat suitability to support species populations

The mapping of habitat suitability to support species populations involved two steps:

- projection of the logistic regression to a reference grid of 10 × 10 km^2;
- integration of ecosystem extent.

Projection of the logistic regression

Equation 3.2 was used to make projections on a reference grid of 10 × 10 km^2 (Table 3.2), where mean values of the predictor variables (imperviousness, high natural value of farmland and mineral nitrogen in the soil) were calculated. The variable 'ecosystem type' is categorical and therefore it is not available for grid cells of 10 × 10 km^2, since different ecosystem types coexist within each grid cell. Therefore, the model was applied six different times, once for each ecosystem type, assuming that within each grid cell only one ecosystem type was present, with the coefficients of the remaining ecosystem types set to zero. In this way, we obtained a map for each ecosystem type, showing the probability of each ecosystem being in a favourable ecological condition.

Integration of ecosystem extent

The probability of an ecosystem being in a favourable ecological condition was initially estimated without taking into account the extent of the ecosystem within each grid cell of 10 × 10 km^2. Therefore, the ecological condition estimated for each ecosystem type was multiplied by the relative extent of the ecosystem per grid cell, providing a habitat suitability indicator for each ecosystem type. Then, an aggregated indicator of habitat suitability per grid cell was calculated by applying Equation 3.1.

3.2.1.3. Delineation of suitable habitats

Habitat suitability derived from Equation 3.1 was then used to delineate, above a certain threshold for each ecosystem type, suitable habitats. The threshold was consistent with Article 17 of the habitats directive data, and was set by looking at the prevalence of favourable assessments in relation to the total number of assessments (9). For instance, in the case of wetland, only 58 of the total 278 habitat assessments were reported as favourable, meaning that 21 % of the polygons for wetland used in the logistic regression were reported as favourable (Table 3.3). Therefore, we used this same percentage to select the grid cells at a spatial resolution of 10 × 10 km^2 with the largest habitat suitability and considered them in terms of suitable habitats.

Model projections and the derived habitat suitability indicator allow the delineation of suitable habitats for the six ecosystem types reported in Article 17 (grassland, shrubland, forest, sparsely vegetated land, wetland and

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(9) Considering favourable and unfavourable assessments (unknown assessments were not considered).

rivers). However, the data used do not provide information on the ecosystem condition for cropland, which is an important knowledge gap. This ecosystem type is especially relevant in the EU in terms of extent, covering about 35 % of the whole EU extent, but also in terms of biodiversity. It is clearly in this ecosystem type where species conservation (or maintenance) appears as a trade-off with crop production (Godfray, 2011). Therefore, cropland cannot be left out of this assessment.

Table 3.3. Prevalence of favourable assessments in the data reported for each ecosystem type

Ecosystem type	Reported as favourable	Total reported	Prevalence
Grassland	134	546	25 %
Shrubland	130	308	42 %
Forest	179	650	28 %
Sparsely vegetated land	209	372	56 %
Wetland	58	278	21 %
Rivers	113	346	33 %
All ecosystems	823	2 500	33 %

To compensate for this knowledge gap, we considered cropland similarly to grassland, given that both are agro-ecosystems. Although this is an extremely strong assumption, it allows us to map habitat suitability similarly to that for other ecosystem types. Moreover, the model applied implicitly includes two variables related to agriculture: mineral nitrogen and high natural value farmland. Therefore, if they are important drivers of the ecological condition for habitats reported under Article 17 of the habitats directive, we can assume that they are also relevant in determining cropland condition. We applied the same equation as that used for grassland (see Equation 3.2 and Table 3.2) to the grid cells where cropland was present to obtain the probability of cropland being in a favourable ecological condition at a spatial resolution of 10 × 10 km^2. In contrast to grassland, delineation of suitable habitats was based only on the ecological condition, by applying the same prevalence percentage as for grassland (25 %), and not on the habitat suitability indicator, in which ecosystem extent also plays a role. The dominance of cropland in terms of extent in many grid cells means that it would outperform the values for ecological condition, biasing the outcome to cropland-dominated grid cells, with perhaps very low values for ecological condition and of which there are almost no data reported under Article 17 on natural ecosystems. Therefore, the selection of suitable habitats for cropland was based on the selection of 25 % of the grid cells with the most favourable ecological condition. Only after suitable habitats were identified was habitat suitability for cropland calculated, by multiplying the ecological condition of the suitable habitat by its relative extent (see Equation 3.1). Given the important data gap for cropland, by applying this alternative method we guarantee that suitable habitats for cropland will have the most favourable ecological condition to support species populations.

Since delineation of suitable habitats is based on different thresholds depending on the ecosystem type (including now also cropland), aggregation of the habitat suitability indicator for 10 × 10 km^2 grid cells (see Equation 3.1) was applied only for the suitable habitats identified for each ecosystem type. This was also required because the habitat suitability indicator for cropland was meaningful only once the suitable habitats had been identified (as justified in the paragraph above).

3.2.2. Mapping species hotspots

As previously described, a second ecosystem feature of habitat and species maintenance is the presence of species hotspots (Figure 3.3), identified in this study as bird species richness hotspots (Table 3.1). Bird species richness has been found to be positively correlated with life satisfaction at EU level (Methorst et al., 2021). Moreover, areas with high species richness are frequently considered to be important locations for the protection of overall biodiversity (Fleishman, Noss and Noon, 2006) and it is in these areas where people will be more willing to pay for the maintenance of a larger number of species (Martínez-Jauregui et al., 2021).

We focused on birds because they are a key component of vertebrate biodiversity, are at the top of the food chain, and are considered good indicators of the general state of biodiversity as a whole (Sekercioglu, 2006). When they start disappearing, it means that something is wrong with our environment and that we need to take action. Birds are also an intricate component of ecosystems, which are necessary for our own survival (10).

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(10) https://ec.europa.eu/environment/nature/legislation/birdsdirective/docs/why_take_care_of_birds.pdf

Moreover, birds are a well-known group of species and a detailed data set of species occurrence across Europe is available. The *European Breeding Bird Atlas 2* (EBBA2) provides the most detailed data available on species distribution at European level. Although EBBA2 provides occurrence data from across Europe at a spatial resolution of 50 × 50 km^2, this spatial resolution is too coarse for the purpose of this study. EBBA2 has also developed species distribution models for 219 native species at a resolution of 10 × 10 km^2 based on field observation data for 2013–2017. Species distribution maps of these 219 species were overlaid to calculate overall species richness.

Species richness was the biodiversity indicator used to delineate species hotspots because it is the most common and simplest measure of diversity, easy to communicate and frequently used in the literature (Lamb et al., 2009). This makes species richness the most suitable indicator for use at EU level, where biodiversity data are relatively scarce (Maes et al., 2020). However, it is important to bear in mind that species richness covers only one component of biodiversity (number of species) and its spatial pattern is predominantly dominated by species with large distribution ranges (common species), whereas rare species with narrow ranges are less represented (Lennon et al., 2004; Pearman and Weber, 2007).

Spatial patterns of species richness at continental scale are driven in general terms by water and energy availability (e.g. heat and food) (Hawkins et al., 2003). However, these drivers are weaker for European birds than for other taxa (Whittaker et al., 2007), and the marked positive gradient of bird species richness from west to east suggests that biogeographical factors are more relevant than south–north gradients of water and energy availability. As a result, the biogeographical biases in the patterns of bird species richness hamper the comparison of species richness across different locations in EU territory. For this reason, identification of species richness hotspots in different locations was based on values of species richness relative to a reference value. There are multiple appropriate reference values with which comparisons can be made (see the UN SEEA EA). In this case, we opted to use mean species richness by country and biogeographical region as reference values. By using these reference values, the role of global drivers of species richness is counterbalanced, allowing better comparability between different locations. Using different reference values by country and biogeographical region is aligned with Article 17 of the habitats directive reporting, in which habitat assessment results are provided by country and biogeographical region.

A given location (10 × 10 km^2 grid cell) was selected as a hotspot when its species richness was equal to or larger than the average richness of the country and biogeographical region to which the given location belonged (see Annex MA5). With this approach, we guaranteed that species richness hotspots were well represented in all EU Member States, as well as ensuring the representativeness of hotspots within each biogeographical region of the country. Therefore, species maintenance in this assessment targets areas with the largest number of overall bird species (11) at a spatial resolution of 10 × 10 km^2 in each country and biogeographical region.

Delineation of species hotspots was carried out in collaboration with biodiversity experts involved in EBBA2. Alternative methods to delineate species richness hotspots were also considered, such as the separate identification of hotspots for birds with preferences for different ecosystem types (e.g. farmland birds). However, from all preliminary tests carried out, the approach presented in this report was considered the most suitable from the accounting point of view, being more comprehensive in terms of the overall intrinsic value of biodiversity. Further details of the method applied to identify biodiversity hotspots are provided in Herrando et al. (2020).

3.2.3. Habitat and species maintenance areas

Similarly to studies analysing the spatial relationship between species hotspots and biodiversity threats (e.g. Aukema et al., 2017), we combined the ecosystem feature maps of suitable habitats and species hotspots to identify different types of habitat and species maintenance areas (Figure 3.3). Based on the cross-tabulation in Table 3.4, we identified the following service areas.

1. **Hotspots in suitable habitats.** This corresponds to the optimal situation in which both habitats and species achieve optimal values. The conservation of these areas should be prioritised.
2. **Suitable habitats without hotspots.** In these areas, habitats present suitable conditions to support species populations in general terms, and should also be considered for conservation and maintenance. Although they do not present hotspots of overall bird species richness as considered in this study, they

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(11) Note that patterns of species richness largely depend on the spatial resolution at which it is assessed

might be relevant for other groups of target species, such as threatened species (see, for instance, Orme et al., 2005), or for other taxa (McKerrow et al., 2018).

3. **Hotspots at risk.** The maintenance of these species hotspots may be compromised in the future. They are considered at risk of population decline because habitats are not good enough to support their populations in the long term and this may lead to a situation of 'extinction debt' if ecological condition (and/or extent) is not restored.
4. **No service.** We considered these areas not to be service providers, since they do not present the hotspots targeted in this study, nor suitable habitats. Restoration in these areas to enhance habitat suitability would be required to support species populations.

Table 3.4. Identification of habitat and species maintenance areas

Cross-tabulation service areas		Habitat suitability	
		Suitable habitats	No suitable habitats
Species hotspots	Hotspots present	1. Hotspots in suitable habitats	3. Hotspots at risk
	No hotspots	2. Suitable habitats without hotspots	4. No service

The biophysical modelling of habitat suitability was run for two different points in time – 2000 and 2012 – to assess changes over this period. Species hotspots were considered fixed over time due to the lack of data (see Table 3.1).

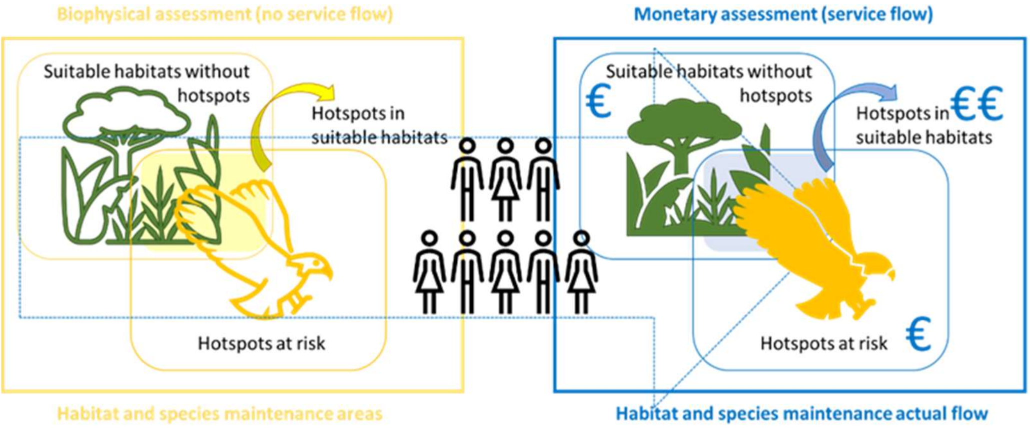
3.3. Monetary assessment

As explained in the introduction (see Chapter 1), habitat and species maintenance has a non-use value. As a non-use service, it is 'intrinsic' rather than 'instrumental' (see Chapter 2, Section 2.1). Measuring the presence of habitats suitable for supporting species and the presence of species hotspots is key for this ES. However, this measurement on its own (i) does not represent a real service because it cannot be accounted as a flow, and (ii) remains within an ecocentric perspective since humans do not play any role at all. It is through the appreciation of people for the existence of habitats and species that this service (i) enters into their utility function and thus (ii) can be measured as a monetary flow (as the value of habitat and species maintenance). Thus, differently from other ESs, the actual flow of habitat and species maintenance can be expressed only in monetary terms. However, without the biophysical assessment of suitable habitats and species hotspots, it would not be possible to link the monetary assessment to the current physical status of ecosystems and monitor changes over time.

There is a vast literature underpinning the valuation of the kind of services that include the protection of the natural environment to support suitable ecological conditions necessary for sustaining populations of species. Primarily, humans benefit from species diversity indirectly, but there is evidence that they value biodiversity and are prepared to pay for it (e.g. Morse-Jones et al., 2012). King et al. (2021) examine the concept of biodiversity from different perspectives and conclude that biodiversity is both a condition for other ESs and an independent service in itself (Turner et al., 2003; Mace, Norris and Fitter, 2012). In this application, we focus on biodiversity as an asset that provides a habitat and species maintenance service to secure ecological functioning of systems as a form of insurance value (Elmqvist et al., 2003). Little is known about this aspect of the value of biodiversity in Europe.

The methodological approach used in our application was a stated preference survey in which respondents were asked to make choices about the provision of the goods/services of interest, revealing through their choices their preferences for habitat and species maintenance policies. Specifically, through an ad hoc choice experiment (La Notte et al., 2021b) it was possible to separate the willingness to pay (WTP) for the different types of service areas described in the previous section, including an additional premium when both (habitats and species) are present (Figure 3.4).

Figure 3.4. Habitat and species maintenance: from the biophysical assessment to the monetary flow



The survey underpinning the choice experiment study contained questions about policies oriented towards habitat and species maintenance. The central features of these policies are (i) the level of biodiversity, in terms of species richness, whose presence guarantees the ecological food chain, and (ii) sustainable agricultural practices, in terms of habitat quality. In fact, agricultural practices, and specifically the use of chemicals, were acknowledged (12) as the primary source of pressure for habitat maintenance. Moreover, two of the three drivers of the modelled ecological condition were related to agriculture (see Equation 3.2 and Table 3.2).

The choice experiment questionnaire was designed to ask people (in a way that they can understand) how much they are willing to pay, with respect to the features modelled in biophysical terms, for the following.

- **Habitats in good ecological condition.** The way people generally perceive this feature is through more sustainable agricultural policies. In this understanding, agricultural policies are the main activities related to the management of territories.
- **Species hotspots.** Almost everybody is familiar with the concept of the ecological food chain, whose importance is perceived as key for present and future survival.

The monetary value attributed to the different types of service areas is the WTP expressed by the respondents (Figure 3.4). Table 3.5 shows selected results extracted from the choice experiment undertaken in the four countries that were initially surveyed (La Notte et al., 2021b).

Table 3.5. Welfare values for service areas (EUR/ha/year) (13)

	Suitable habitats with species hotspots	Suitable habitats without hotspots	Hotspots at risk
Czechia	0.51	0.31	0.14
Germany	1.40	0.66	0.31
Ireland	2.57	1.13	0.64
Italy	6.98	3.22	1.63

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(12) Several focus groups took place to identify the main object of the choice experiment and to define the attributes and their levels to build the questionnaire. All the details are available in La Notte et al. (2021).

(13) The difference between welfare and exchange values in ecosystem accounting is exhaustively explained in UN et al. (2014) (Section 5.3.2).

To apply and map this monetary value, we need to aggregate the values at the population level. For this, we multiplied the average WTP value by the number of households (14). This implies that population becomes an additional variable playing an important role (Table 3.1). As in the case of condition accounts (Czuck et al., 2021), there may be indicators that are not directly part of the ecological process meant to represent ESs; however, they can be useful for modelling ES flows needed for accounting purposes. These measurements are called 'ancillary data'. In the case of habitat and species maintenance, population is not part of the ecosystem metrics but it is needed to determine the ES flow. At the same time, population should not be considered an ES D because (as explained in Chapter 2, Section 2.2) the assessment of this ES is part of an overarching environmental target that is halting biodiversity loss, whose user is global society.

When WTP estimates are aggregated at country scale, the population size of the country plays a profound role (i.e. countries with a large population size will be assigned to higher WTP aggregate estimates than countries with a small population size). To address this issue, we propose the use of inverse probability weighting (OECD, 2009). The underlying idea is to down weight the influence that population size has on WTP mapping and aggregation. This can be achieved by applying weights that are inversely proportional to the sampling probability. Using random sample terms, each member of a population has an equal probability of being selected. Here, we assume that *n* represents the population of a country and *N* corresponds to the EU population. Then, the probability that the country is represented (selected) by *N* (i.e. the sampling probability) is:

$$p_i = \frac{n_i}{N} \qquad \text{(Equation 3.3)}$$

Then, sampling weights (w_i), which are inversely proportional to the sampling probability (p_i), will be defined as follows:

$$w_i = \frac{1}{p_i} \qquad \text{(Equation 3.4)}$$

The total weights will be:

$$\sum w_i = \sum \frac{N}{n_i} \qquad \text{(Equation 3.5)}$$

The aggregated WTP ($n_i \times WTP_i$) of each Member State *i* needs to be adjusted based on the inverse probability weights (w_i) explained above. To prevent the sum of the aggregated WTP values (*T_WTP*) being affected by the use of weights (in other words, to maintain the total aggregated WTP the same as before applying the weights), we propose the use of shares (s_i) instead of weights. The shares correspond to each weight as a proportion of the sum of weights (*T_w*). The sum of these shares (*T_s*) is equal to 1 and hence the WTP total remains the same. Table 3.6 depicts the weighting process.

Table 3.6. Inverse probability weighting procedure

Member state	Population size	WTP	Aggregated WTP	Weights	Share	WTP weighted
1	n_1	WTP_1	$n_1 \times WTP_1$	$w_1 = \frac{N}{n_1}$	$s_1 = \frac{w_1}{T\_w}$	$s_1 \times T\_WTP$
2	n_2	WTP_2	$n_2 \times WTP_2$	$w_2 = \frac{N}{n_2}$	$s_2 = \frac{w_2}{T\_w}$	$s_2 \times T\_WTP$
3	n_3	WTP_3	$n_3 \times WTP_3$	$w_3 = \frac{N}{n_3}$	$s_3 = \frac{w_3}{T\_w}$	$s_3 \times T\_WTP$
Total	N	$WTP = \sum WTP_i$	$T\_WTP = \sum n_i \times WTP_i$	$T\_w = \sum w_i$	$T\_s = 1$	T_WTP

Finally, the choice experiment is based on individual stated preferences and, as such, is not in line with exchange values characterising all the other ES accounts and the system of national accounts (SNA). For the sake of consistency with SEEA EA guidelines (UN et al., 2021), Table 3.5 reports the value per hectare as derived from the choice modelling estimates (welfare measures) and Table 3.7 reports the simulated exchange values (exchange prices).

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(14) Original data (La Notte et al., 2021b) are expressed as WTP/person/year. For the purpose of this valuation, we shifter from WTP/person/year to WTP/household/year by applying ad hoc coefficients ranging from 2.08 to 2.94.

Table 3.7. Simulated exchange values for habitat and species maintenance (EUR/ha/year)

	Hotspots in suitable habitats	Suitable habitats without hotspots	Hotspots at risk
Czechia	0.37	0.33	0.29
Germany	0.74	0.62	0.58
Ireland	1.76	1.31	1.21
Italy	3.55	2.84	2.61

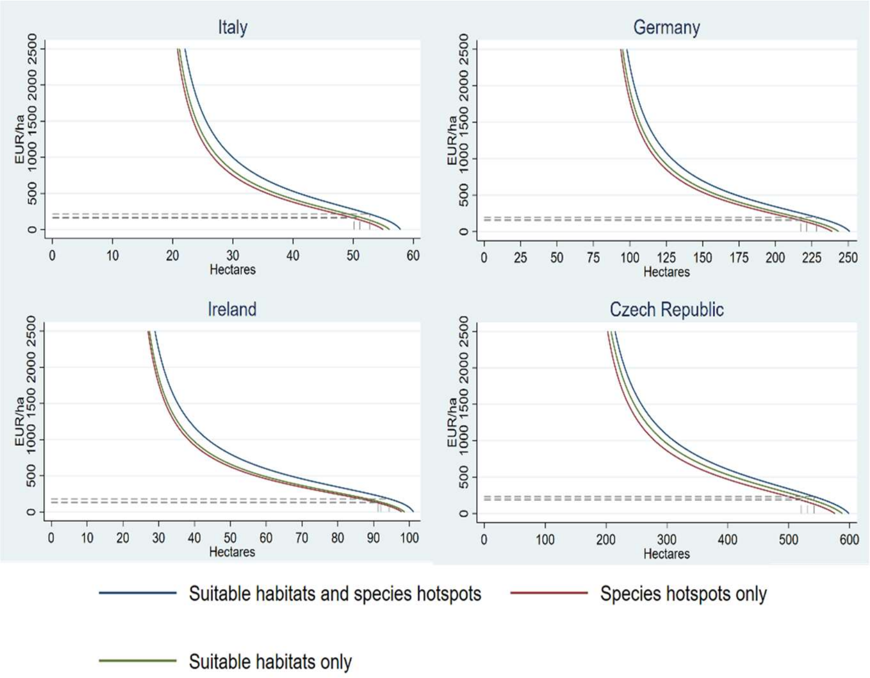
Differences exist between the methods. Welfare estimates can be derived at regional levels, whereas the exchange prices are applicable only at national level. Welfare estimates are rooted in economic theory and we derive estimates from choice experiment data using econometric models, whereas the simulated exchange value (SEV) method builds on choice experiment estimates and requires further assumptions on the supply side of habitat maintenance costs. The SEV method was proposed by Caparrós, Campos and Montero (2003) and Caparrós et al. (2017) as an alternative approach to derive monetary estimates for non-marketed ESs that are consistent with accounting principles based on stated preference data. The approach consists of simulating a demand function for the ES, which is estimated from stated preference data, and deriving the equilibrium quantity and value through assumptions on the market type (e.g. perfect competition). The SEV has been primarily used in the context of recreation in open-access areas. Therefore, the assumption on the supply curve for determining the equilibrium price represents a crucial point in determining solid exchange prices. In the paper by Caparrós et al. (2017), the SEV and the supply curve for ES provision are derived under conditions of given market institutional settings. In the context of recreational services provision, they argue that perfect competition can be a plausible institutional setting as long as the recreational sites provide the service without limitations and with similar conditions to each other.

These assumptions might apply to habitat maintenance if all those who manage the territory (e.g. farmers) can provide habitat maintenance services without restrictions and in a similar way to each other. In addition, Caparrós et al. (2017) also state that, in many instances, it is reasonable to assume that the cost of providing the services is fixed because, for example, marginal costs are negligible or there is no information on the shape of the supply curve. These conditions proposed by Caparrós et al. (2017) represent a 'strong' set of assumptions when other ESs are considered. We argue that, in contrast to the Caparrós et al. (2017) case study on recreation, the provision of habitat maintenance services entails fixed costs only if those who manage the territory face identical opportunity costs. However, following the suggestion by Caparrós et al. (2017) (in the absence of appropriate cost information), we assume that the marginal costs for habitat maintenance services are zero and the supply curve is flat. The equilibrium price is therefore located on the right-hand side of the simulated demand curve.

Figure 3.5 shows the simulated demand curves for four countries, considering the different service areas (i.e. hotspots in suitable habitats, suitable habitats without hotspots, hotspots at risk). The simulated curves show the agricultural areas that would be demanded for each price level. The results (Table 3.5 and Figure 3.5) show that the SEV per hectare is quite low, but this result depends entirely on the 'strong' assumption about the marginal costs suggested by Caparrós et al. (2017). For this specific service, the uncertainty regarding the true shape of the supply curve might imply an underestimate of the service and a lower provision of the service to future generations.

These SEV curves reflect the key limitations of this method: the habitat and species maintenance service is assumed to be provided under a specific market framework (e.g. perfect equilibrium), which is quite a difficult assumption to make for a disperse service such as agricultural management choices. This implies that the supply curve is flat and does not reflect the real costs of habitat maintenance. To overcome these limitations, we should derive habitat and species maintenance curves from observational data and determine the actual exchange prices, which, of course, is a costly and time-consuming task.

Figure 3.5. Simulated demand and supply curves for the four countries initially surveyed



In ideal conditions, when the marginal costs of the habitat maintenance service are available, the accounting table could adopt a costing procedure and truly reflect the market provision of habitat maintenance costs; however, as these costs are currently unknown, we argue that welfare estimates, which reflect the social preference for maintenance services, better reflect the value of this service.

3.4. Accounting tables

There is increasing awareness that species extinction and habitat degradation are linked to human well-being and that we need to identify habitat and species maintenance as a service and to assess and account for it. As mentioned before, habitat and species maintenance has a non-use value; therefore, it has no direct users. The relationship between habitats and species (on the one hand) and economy and society (on the other hand) is intricate and complex, but its existence is acknowledged by the many international initiatives meant to stop biodiversity loss (e.g. the Convention on Biological Diversity (15)). Habitat and species maintenance, like carbon sequestration, is a ‘global’ service. As described in Chapter 2 (see Section 2.2), when the demand is represented by global society, the ES potential flow is what people would be willing to pay if both habitat and species features were supplied in all service areas (Figure 3.6). Long-term plans such as the EU biodiversity strategy 2030 could in fact enhance habitat suitability to support species richness and reach the ES potential flow.

In Figure 3.7, the potential flow is the value of habitat and species maintenance attributed if all areas had both suitable habitats to support species populations and the presence of species hotspots; the actual flow is the value attributed to the current service areas; and missed flow is the difference between potential and actual flows. The assessment of this ES gap provides useful information for policymakers, as discussed later on (see Section 3.5.4).

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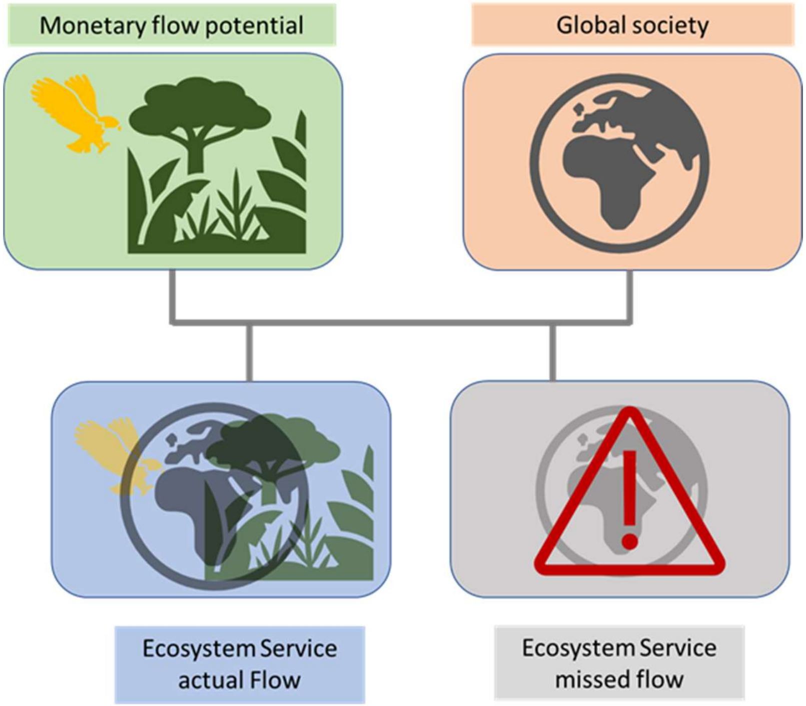
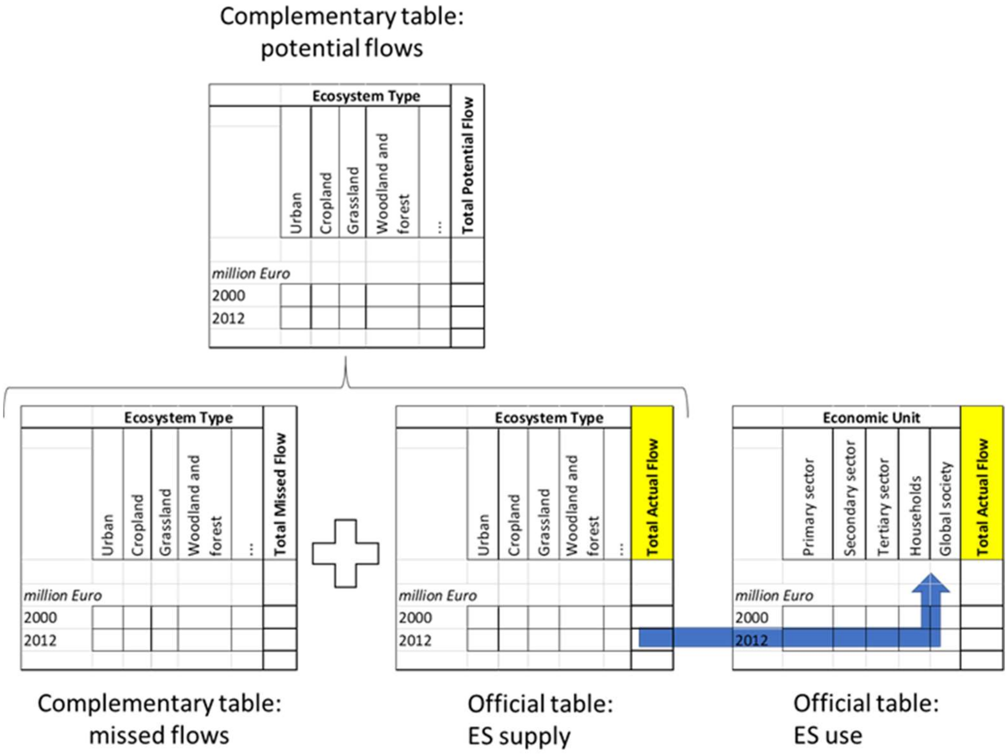
(15) https://www.cbd.int/convention/

Figure 3.6. Accounting framework for habitat and species maintenance



The missed ES monetary flow is that which people would be willing to pay if more ecosystem features (suitable habitats and species hotspots) were available. Within the INCA framework, this represents the ES mismatch. On the other hand, the actual flow is what people are willing to pay for the features that are effectively there (Figure 3.7).

Figure 3.7. Accounting framework for habitat and species maintenance



When a service is allocated to global society, this implies the impossibility of geographically mapping the demand in a specific place, within specific national boundaries. The identification of a service as ‘global’ underpins the concept of public good, which, in economics, requires non-exclusivity and non-excludability.

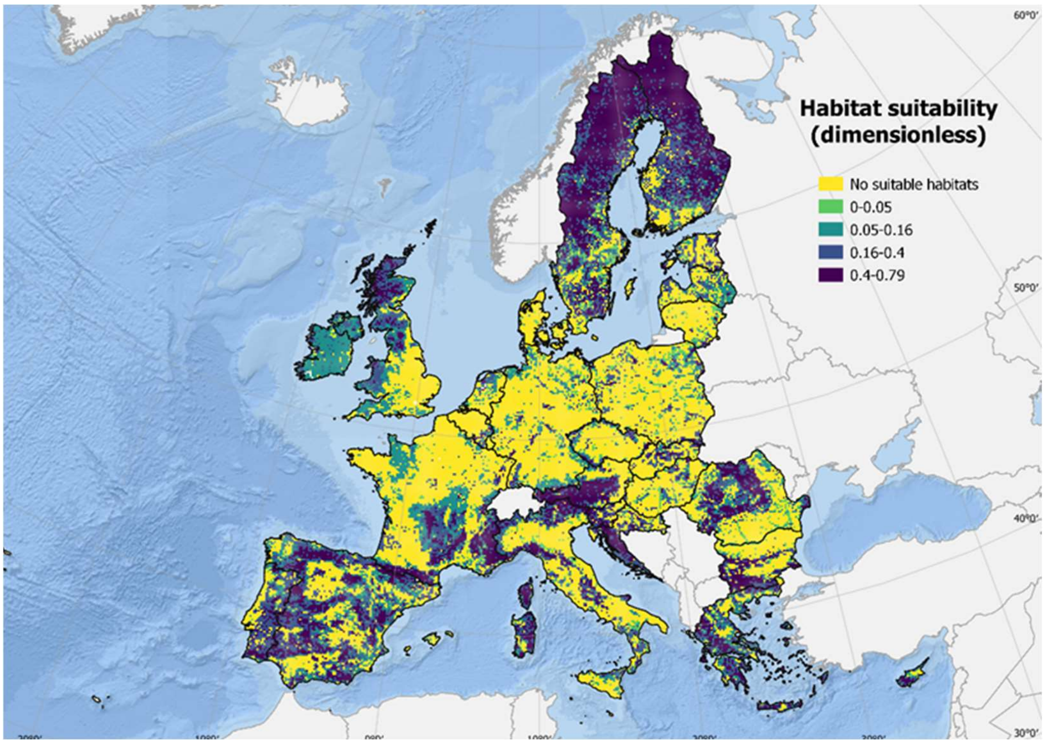
3.5. Results for habitat and species maintenance

3.5.1. Biophysical output

3.5.1.1. Habitat suitability to support species

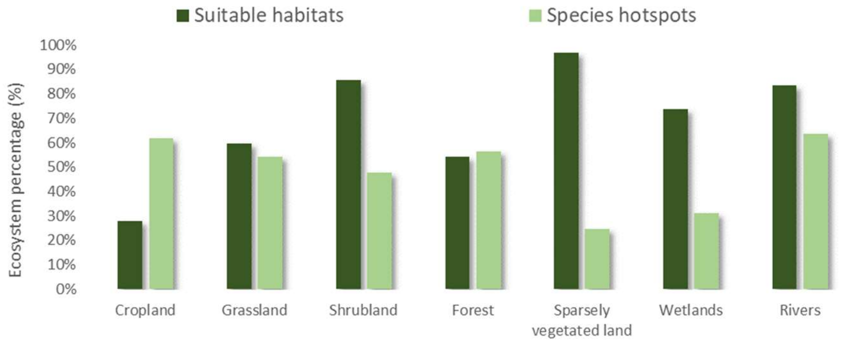
In the EU, about 40 % of the land area is identified as a suitable habitat to support species populations. Habitat suitability in these areas shows higher values in locations not greatly affected by human influence, such as in the north of the EU and mountainous areas (Figure 3.8). There are also some areas, especially in the Mediterranean region, with high habitat suitability, mainly due to the important role of high natural value farmland. In contrast, northern and central areas of the EU show an overall low suitability as a consequence of the high concentration of nitrogen in the soil, in combination with a large share of impervious areas (soil sealed). Note that the map in Figure 3.8 shows only the habitat suitability in areas identified as suitable habitats for the different ecosystem types. Maps of habitat suitability to support species by ecosystem type are provided in Annex MA6.

Figure 3.8. Map of habitat suitability in suitable habitats in 2012



Analysis of suitable habitats by ecosystem type (Figure 3.9) shows that sparsely vegetated areas and shrubland are the ecosystems with the largest shares of suitable habitats. These ecosystem types are mainly located in mountainous areas where environmental pressures such as mineral nitrogen in the soil and soil sealing (imperviousness) are very low. These results are also in line with the data reported under Article 17, which show the largest number of habitats reported as having a favourable conservation status for these ecosystem types (Table 3.3). Not surprisingly, cropland presents the lowest share of suitable habitats, since this ecosystem type is heavily affected by human activities. However, the definition of suitable habitats for this ecosystem type is not consistent with that for other ecosystems because of the lack of data (see Section 3.7 on limitations). In spite of only 21 % of wetland habitats being reported as having a favourable ecological condition (Table 3.3), wetlands provide a large share of suitable habitats in terms of total area. The most favourable ecological conditions for wetland are found in areas where the extent of these ecosystems is very large, especially in northern Europe. This results in high habitat suitability to support species in these areas (see Annex MA6); they are therefore selected as suitable habitats for a large share of wetland extent at EU level.

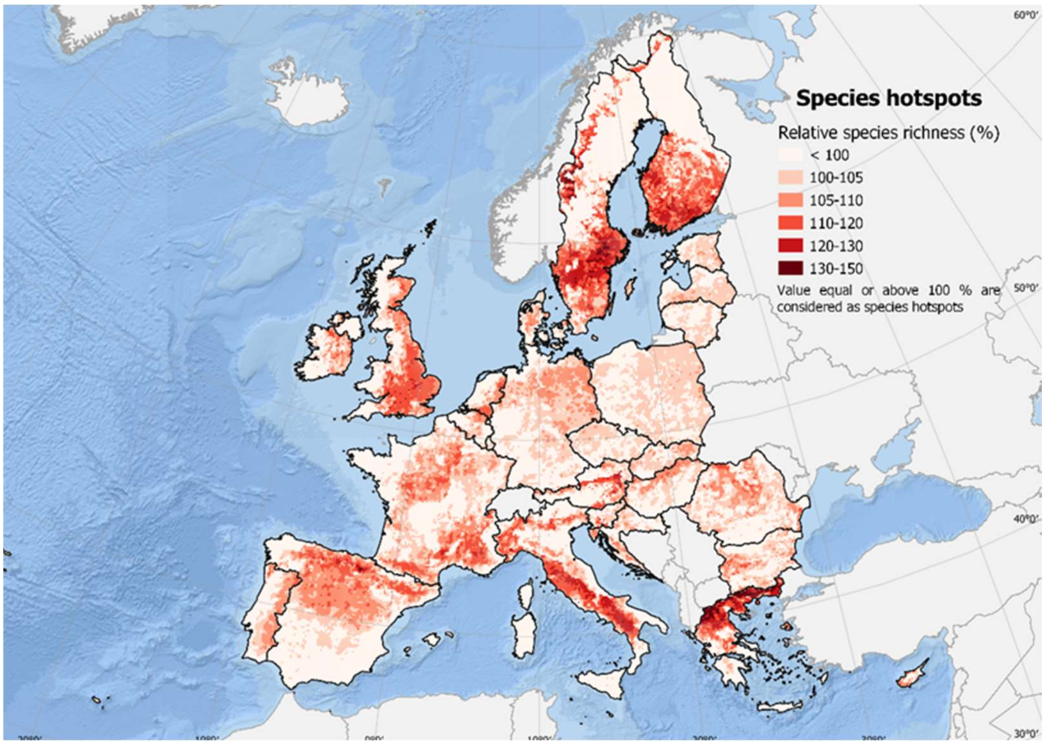
Figure 3.9. Importance of ecosystem features by ecosystem type



3.5.1.2. *Species hotspots*

Species hotspots represent 53 % of EU territory. Species richness hotspots, although identified at country level by biogeographical region, show spatial patterns that are still influenced by the biogeography of breeding birds in Europe (Figure 3.10). Breeding birds in Europe are predominantly from the Euro-Siberian region (continental species) and favour richness hotspots in the east of some countries, such as Ireland, Poland and Portugal. In the case of Greece and Spain, hotspots are found predominantly in the north of the peninsulas, where the terrestrial connection with the rest of the continent lies (many species come from there) and where the accompanying climatic diversity is probably higher. Importantly, we find bird species richness 'cold spots' in areas where there are extreme climatic conditions, such as at the top of the Alps and in the north of the Scandinavian countries. Climatic conditions in these areas do not favour the local coexistence of a large number of species at the scale of this analysis. It does not imply that species in these areas are not relevant in terms of maintenance, but they are simply not accounted for in this exercise. Similarly, bird species richness cold spots are also found in the islands, which is explained by the geographical isolation of these locations.

Figure 3.10. Relative species richness for hotspots of breeding birds



In some countries, such as Czechia and Poland, we can also see rather low values of relative species richness in comparison with other countries. Across these countries, patterns of species richness are very homogeneous, and therefore hotspots, based on relative species richness, are very close to the mean richness in the country. In contrast, countries with large differences in species richness across their territories show high values of relative species richness where there are more species (Scandinavian countries and Greece, for instance).

An artefact generated by the borders of biogeographical regions, such as in France and Sweden, is visible. In practice, borders between biogeographical regions are more gradual than those shown in the maps, and therefore species richness hotspots should be understood in the same terms. However, we found this method to be the most suitable for showing the presence of species richness hotspots by biogeographical region.

Analysis of species hotspots by ecosystem type shows that rivers and cropland, followed by forests and grassland, are the ecosystem types with the largest shares of species richness hotspots (Figure 3.9). Surprisingly, a small percentage of the total extent of wetland consists of species hotspots, even though wetlands are recognised as key ecosystems for biodiversity hotspots. There are various reasons for this.

- Most of the wetland extent in the EU is located in the north of Sweden and Finland, where relative species richness is not especially high (no species hotspots) (see Figure 3.10).
- The distributions of many water birds are restricted to small areas (i.e. where wetland areas, not necessarily very large, are present). In EBBA2, species that are very specialised in terms of certain habitat types and with narrow distributions were not modelled at a spatial resolution of 10 × 10 km^2 and therefore are missing from this assessment.
- Wetland areas in the MAES ecosystem classification are limited to peatbogs and inland marshes, which is a restricted definition of this ecosystem type when compared with wider definitions of wetland areas, such as the holistic definition provided by the Ramsar Convention. The results would be very different when considering a broader definition of wetland, including the coexistence of different land cover types.

3.5.1.3. Habitat and species maintenance areas

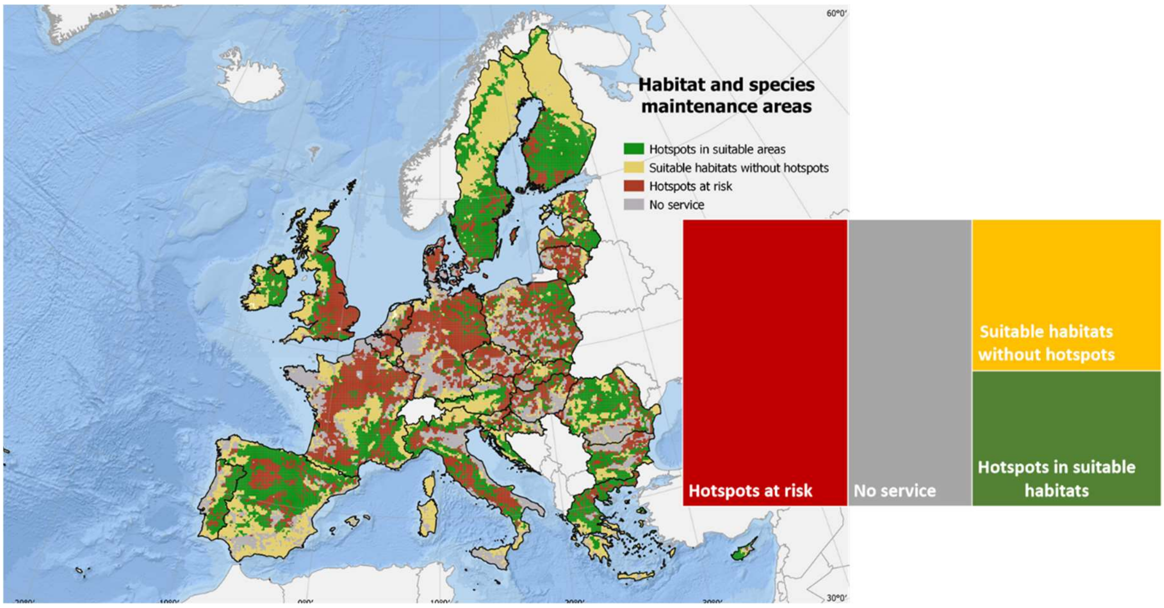
The final biophysical map used for the valuation of habitat and species maintenance includes all possible combinations of the ecosystem features (see Figure 3.3 and Table 3.4) delineating the different service areas: (i) hotspots in suitable habitats, (ii) suitable habitats without hotspots and (iii) hotspots at risk.

Hotspots in suitable habitats are found in only 19 % of the EU territory, showing a large mismatch between suitable habitats and species hotspots. Hotspots in suitable areas are found mainly in mountainous areas of the Mediterranean region, but also in the south of the Nordic countries (Figure 3.11). At ecosystem level, this optimal situation of hotspots in suitable habitats is mainly found in rivers, followed by shrubland (Figure 3.12).

Suitable habitats without hotspots are found in 21 % of the EU territory (Figure 3.11), mainly in mountainous areas (at high altitude), dominated by sparsely vegetated land and shrubland, where suitable habitats without hotspots are very important in relative terms (Figure 3.12), or in the north of Scandinavian countries, mainly due to the presence of wetlands. Although these areas do not present hotspots as considered in this assessment, they are of course also important for other components of biodiversity not considered here (e.g. endangered species, specialist species and other taxa). In this report, biodiversity includes only overall richness hotspots for birds. Complementary biodiversity layers would be useful for considering additional biodiversity features in the assessment of this ES.

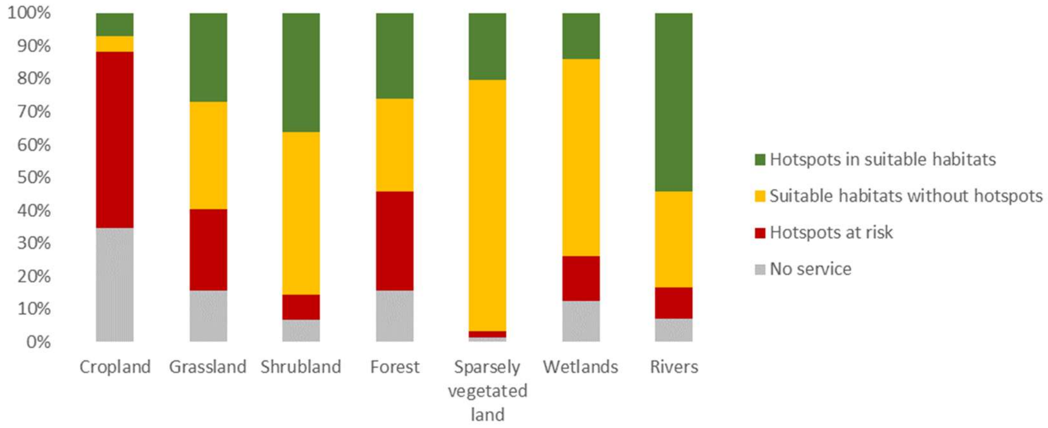
Importantly, about 35 % of the EU territory contains hotspots at risk (Figure 3.11), which implies that habitats are not supporting species populations in about 65 % of the richness hotspots, therefore compromising their population trends in the long term. Hotspots at risk are mainly found in central Europe, where mineral nitrogen in the soil and imperviousness is high, but also where there are very small areas of high natural value farmland (Figure 3.11).

Figure 3.11. Habitat and species maintenance areas in 2012



By ecosystem type, hotspots at risk are especially large in cropland, but also in forest and grassland (Figure 3.12). It is also in these ecosystem types where we find the largest share of areas where there is no service delivered by habitat and species maintenance.

Figure 3.12. Relative importance of service areas by ecosystem type



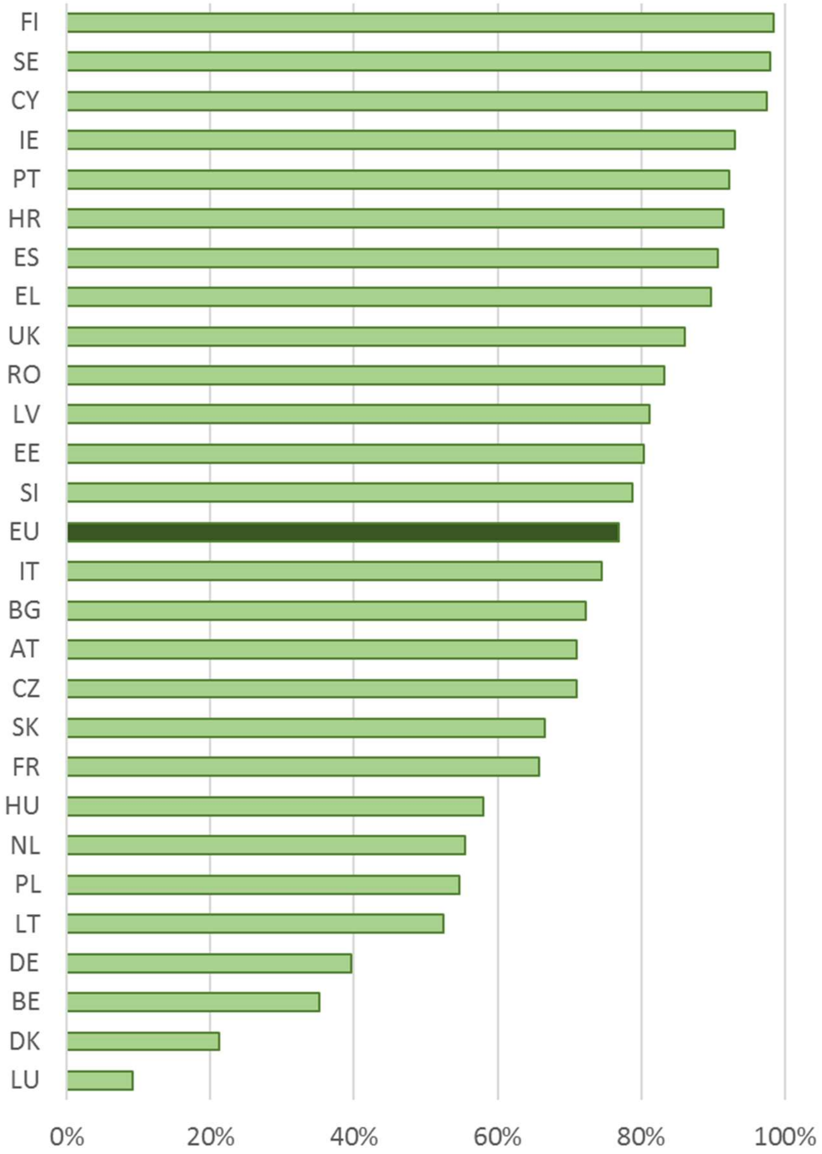
These results support the need to consider in particular the restoration of cropland, forests and grassland under the restoration action plan within the EU biodiversity strategy for 2030. Ecosystem restoration targeting the enhancement of the ecosystem condition in hotspots at risk would contribute to the halting, and even the reversal, of biodiversity decline.

3.5.2. Habitat and species maintenance in Natura 2000

Analysis of the overlap between the Natura 2000 network and suitable habitats shows an overall high habitat suitability to support species in Natura 2000 sites. At EU level, 77 % of Natura 2000 sites are within 10 × 10 km grid cells that are considered suitable habitats (Figure 3.13). Countries such as Belgium, Denmark and Luxembourg, with low percentages of Natura 2000 extent, should consider ecosystem restoration of Natura 2000 sites as an option for enhancing the ecological condition and therefore the habitat suitability to support species specifically in these areas.

The overlap between Natura 2000 sites and species hotspots was not taken into account in this study since designation of Natura 2000 sites is not meant to conserve overall species richness (as we considered in this study); rather it is meant to conserve species listed in the habitats and birds directives.

Figure 3.13. Percentage of the Natura 2000 extent considered a suitable habitat

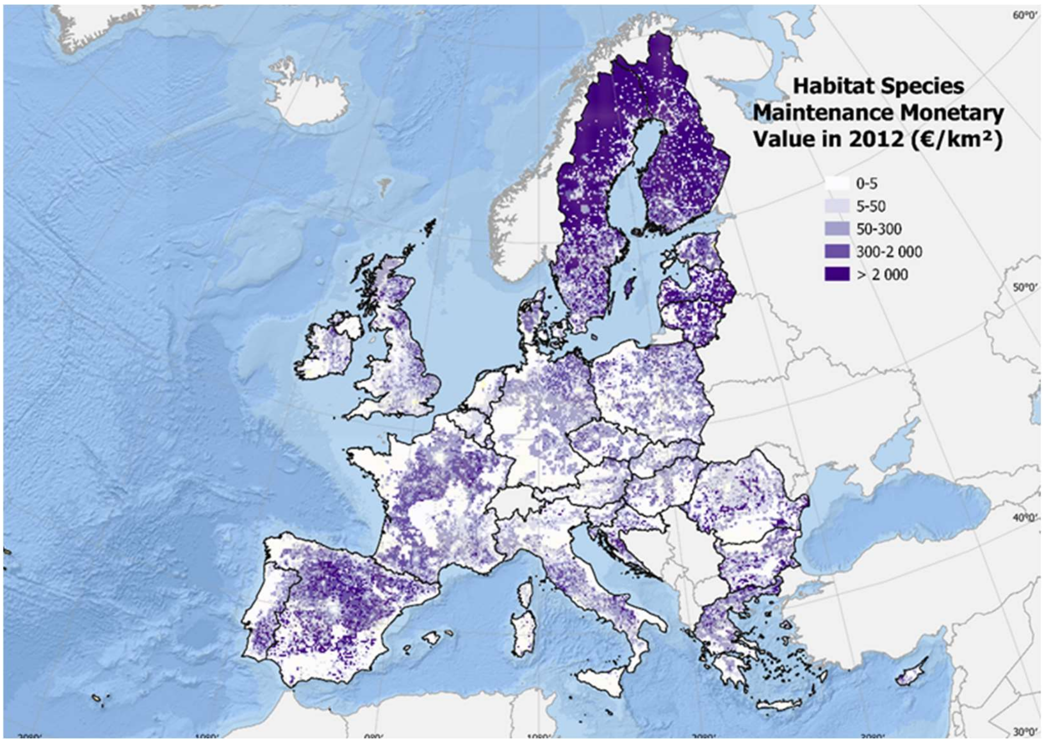


3.5.3. Monetary valuation: assessment of the actual flow

As previously explained (see Section 3.3), based on the biophysical model, it is possible to assign different monetary values to each 10 × 10 km grid cell according to the presence of different types of service areas. The actual flow for habitat and species maintenance is the cost that households are willing to pay in monetary terms for the maintenance of habitats and species (Figure 3.14). The actual flow represents what people are willing to pay, considering the current distribution of habitat and species maintenance areas in the territory. However, people would pay more if suitable habitats and species were found in all service areas.

As previously explained, where habitats are not suitable to support species populations in the future, there may be a risk of extinction unless the ecological condition of habitats is restored.

Figure 3.14. Actual flow of habitat and species maintenance in Europe, 2012



3.5.4. Accounting tables

The actual flow of habitat and species maintenance, available only in monetary terms, is reported in SUTs and aggregated for the EU-28. As previously explained (see Section 3.3), welfare values are used because SEV estimates show considerable methodological and data limitations and risk seriously underestimating flows, which, for this ES, may result in misleading interpretations. The supply table (Table 3.8) shows the provision of this ES by ecosystem type. In absolute terms, cropland provides 44 % of this ES, followed by woodland and forest (35 %), due to the large extent of these ecosystems in the EU. However, from Figure 3.12 we can see that the high value of cropland is mainly due to hotspots at risk; in fact, cropland species show negative population trends. Special attention is thus required in cropland.

Table 3.8. Supply table of habitat and species maintenance: actual flow, year 2012

	Ecosystem type										
	Urban	Cropland	Grassland	Woodland and forest		Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
				Available for wood supply	Other						
(million EUR)											
2000	NA	5 726	979	19 269		1 580	1 119	337	2 229	NA	31 238
2012	NA	5 516	985	20 416		1 689	1 176	369	2 363	NA	32 515
											NA: Not Available

If considering the ES value per type of habitat and species maintenance area, the value of species hotspots located in suitable habitats (16.7 blln euro on 19% of the area) is double the value of species hotspots located in unsuitable habitats (14.3 blln euro on 35% of the area) (Table 3.9) and the value that people attribute to suitable habitats without species hotspots (1.5 blln euro on 21% of the area) is one tenth lower than the value they attribute to suitable habitats with species hotspots. This difference in value is because the coexistence of both species hotspots and a suitable habitat generates an extra premium that people are willing to pay when the two components used to estimate the value of biodiversity are present: the whole is more than the sum of the parts.

Table 3.9. Habitat and species maintenance actual flow distributed by areas, 2012 (million EUR)

Cross-tabulation service areas		Habitat suitability	
		Suitable habitats	No suitable habitats
Species hotspots	Hotspots present	Hotspots in suitable habitat: EUR 16.7 billion (19 % of area)	Hotspots at risk: EUR 14.3 billion (35 % of area)
	No hotspots	Suitable habitats without hotspots: EUR 1.5 billion (21 % of area)	No service: not valued (26 % of area)

The actual flow that ecosystems offer is about EUR 32.5 billion/year. However, this flow is only one third of what it could currently be if all habitat and species features were present in the covered area (Table 3.10): the missed flow in 2012 is valued at about EUR 56 billion and is increasing (+ 5 % compared with 2000). This is a signal for policymakers to move towards ecosystem restoration, because the value people attribute to habitat and species maintenance could be much higher than currently recorded if adequate restoration measures were implemented.

Table 3.10. Complementary supply table of habitat and species maintenance: missed flow, year 2012

	Ecosystem type										
	Urban	Cropland	Grassland	Woodland and forest: Available for wood supply	Woodland and forest: Other	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)											
2000	NA	23 627	6 707	18 536		1 028	1 884	589	1 011	NA	53 383
2012	NA	24 709	7 026	19 551		1 073	1 964	604	1 082	NA	56 010
											NA: Not Available

With habitat and species maintenance, Europe provides a service to the global society (Table 3.11). In analytical terms, it is important, especially for those countries rich in natural resources and biodiversity, to separately assess and monitor their contribution beyond national boundaries, to the global society.

Table 3.11. Use table of habitat and species maintenance: actual flow, year 2012

	Economic unit						
	Primary sector: Agriculture	Primary sector: Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**
(million EUR)							
2000	0	0	0	0	0	31 238	31 238
2012	0	0	0	0	0	32 515	32 515

Information concerning both ES actual and missed flows can help policymakers pursue restoration targets and monitor over time whether and by how much the ecological gap is getting larger or is being closed. Information on the contribution to global society may become a concrete area of discussion when the international table on ecological public goods (hopefully) takes place.

Annexes AA1–AA4 contain SUTs detailed by country for 2000 and 2012.

3.6. Trend analysis

At EU level, between 2000 and 2012, there were no significant changes in either ecosystem features or service areas (Table 3.12). Note that data for the analysis of changes in species richness hotspots were not available. The small change in suitable habitats can be explained by the opposing direction of the drivers of changes in ecological condition. The decrease in mineral nitrogen in the soil together with a small increase in high natural value farmland have a positive impact on ecosystems, which appears to be compensated at EU level by the notable increase in imperviousness (Table 3.12). Importantly, hotspots in suitable areas are the only service areas showing a decrease (by 1.1 %), which shows that a decrease in suitable habitats took place also in locations with bird species hotspots.

Table 3.12. Summary of changes in habitat and species maintenance at EU level

		2000	2012	Change	Percentage changes
Ecosystem features					
Suitable habitats (1 000 km²)		1 705	1 698	– 6	– 0.36 %
Drivers of changes in ecological condition	Imperviousness (mean)	2.74	2.82	0.08	2.9 %
	Mineral nitrogen in soil (kg N/ha)	44.18	43.36	– 0.82	– 1.9 %
	High natural value farmland (mean)	0.34	0.34	0.00	0.3 %
Species hotspots (1 000 km²)		2 282		Not available	
Habitat and species maintenance areas (service areas) (1 000 km²)					
Hotspots in suitable habitats		812	803	– 9	– 1.10 %
Suitable habitats without hotspots		893	896	3	0.32 %
Hotspots at risk		1 471	1 480	9	0.61 %
No service		1 112	1 109	– 3	– 0.25 %
Monetary values					
Actual flow (million EUR)		31 238	32 515	1 276	4.09 %
Actual flow per capita (EUR per capita)		113.3	113.4	0.07	0.06 %
Potential flow (million EUR)		84 622	88 525	3 903	4.61 %
Potential flow per capita (EUR per capita)		307	309	1.73	0.56 %
Missed flow (million EUR)		53 383	56 011	2 628	4.92 %
Missed flow per capita (EUR per capita)		194	195	1.67	0.86 %
Population in service areas (1 000 inhabitants)		275 673	286 70	11 097	4.03 %
Total population (1 000 inhabitants)		461 463	477 906	16 443	3.56 %

Changes in the population living in service areas (+ 4.03%) caused the variation in ES actual flows (+ 4.09 %). The decrease in hotspots in suitable habitats (– 1.1 %) explains why there is an increase in the ES missed flow (+ 4.92 %). In fact, in 2012 there were more areas that missed the full value of having both suitable habitats and species hotspots. This decrease is partially counterbalanced by the effect of the growing population, which increases the overall monetary value. In absolute terms, the increase in the total ES potential flow (which equals the sum of actual and missed flows) is mostly due to an increase in the ES missed flow, which is in turn explained by a decrease in the suitable habitats and habitat and species maintenance areas. In relative terms, when we consider values per capita (considering only populations in habitat and species maintenance areas), we can clearly see that while the actual flow remains almost unchanged (0.06 %) and the missed flow has increased of almost 1%. Policymakers receiving such a message should not consider whether the overall flow of ES habitat and species maintenance has increased, but rather if ES missed flow has decreased. In fact, increases in missed flow are explained by decreases in hotspots in suitable habitats, which remains an ecological issue to be solved.

3.7. Discussion and limitations

Habitat and species maintenance is one of the most complex and controversial services in the list of INCA ESs assessed and valued so far. Its complexity lies not only in the biophysical and monetary assessments, but also in interpreting its meaning and in framing its accounting structure. It is a controversial service because it represents a non-use value; as such, there may be resistance (especially from some economic schools of thought) to accept it as a final service. Here, we summarise some of the many issues raised throughout the assessment of habitat and species maintenance.

The urgency and relevance of habitat and species maintenance for society is too high for it to be treated as an additional, voluntary and complementary assessment/valuation. There are ways to integrate this service into the standard ecosystem accounts that are consistent with accounting mechanisms and principles and consistent with the treatment of other ESs.

In fact, only full integration into the standard accounts would provide comprehensive information about the complete bundles of services provided by ecosystems and thus provide direction in different kinds of land use conflicts, particularly between land development and further intensification of land use on the one hand and nature conservation on the other hand.

A complementary valuation of the change in ecosystem extent and condition cannot serve this purpose: the yearly flow of ESs, which does not count habitat and species maintenance, will provide a lower value for those ecosystem types that provide this service. For example, if ecosystem restoration actions are going to improve (or not) habitat suitability to support species, then the habitat and species maintenance ESs will increase (or not), and this flow can be monitored and used to assess and appropriately value the effectiveness (or failure) of such policies.

More in general, any change in land cover and use will generate synergies and trade-offs among ES flows: habitat and species maintenance reported as a flow will add value, for example to nature conservation planning compared with urbanisation or monoculture transformation planning.

Finally, the monetary account computed for ecosystem assets, based on the net present value of the ES yearly flow, will, once again, provide a lower value for those ecosystem types that provide habitat and species maintenance, if the service flow is not inserted and eventually actualised. It matters which ES is chosen to assess and value. Choosing habitat and species maintenance implies valuing biodiversity, by taking as proxies habitat suitability and species hotspots.

To be consistent with the logic underpinning the accounting mechanism, we have to insert as ESs in the SUTs those flows that provide a relevant linkage with the socioeconomic system. Since people have habitat and species maintenance in their utility function, and since habitat and species maintenance addresses internationally acknowledged overarching environmental targets, this ES should be accounted for in the SUTs to gain effective policy attention and to provide concrete tools for monitoring and strategic planning.

One of the major limitations of this study is the lack of data to model ecological condition for cropland. Cropland is a key ecosystem in the EU given its large extent, but it is also a key driver of environmental pressures, and therefore is of key importance for biodiversity conservation. More data on the ecological condition of cropland would be needed to cover this large knowledge gap. Furthermore, the logistic regression model is reasonably good but not extremely good. Model accuracy could potentially be enhanced by increasing the consistency of reported data among countries and by having a better spatial representation of polygons, more restricted to the location where the habitat is located, under Article 17 of the habitats directive.

Another important limitation of this study is the use of species richness hotspots as the indicator for the assessment of the biodiversity feature. Although this was the most suitable biodiversity indicator available at EU level, the main limitations, as previously described, can be summarised as follows.

- Species richness covers only a small part of the overall biodiversity.
- The indicator is focused only on birds.
- There are no data to assess changes over time.

Furthermore, the definition of the reference value to calculate relative species richness was based on the mean values per biogeographical area and country. A definition of the reference values with a stronger ecological basis is recommended. This would allow for the identification of the reference level of species richness, reflecting ‘intact’ ecosystems, required to consider an area as important because of the species it contains. Defining reference values for ecosystem indicators is still very challenging (Jakobsson et al., 2020). The strengthening of the ecological basis for the definition of reference levels would require the identification of species richness in reference areas (those identified as 'intact' ecosystems); however, this approach would fail to identify species hotspots in agricultural areas, where the concept of 'intact' ecosystems does not apply. Moreover, not all species have the same importance in terms of conservation or prioritisation. Ideally, the definition of reference levels for biodiversity should better integrate the value of the community composition based on species' environmental tolerances or functional species attributes (Lewis et al., 2014). However, this type of approach is not available for birds at EU level and would require the development of a complementary study.

Another limitation concerns the monetary assessment. A choice experiment study is time-consuming and resource intensive, and it is difficult currently to imagine this sort of exercise systematically recurring over time in many countries of Europe and of the world. One solution that could accommodate this issue is a meta-regression benefit transfer to enable the use of already available valuation studies with respect to the important pillars reached, thanks to the application explained in this report. An appropriately structured valuation database could greatly facilitate the systematic review and update of the regression model coefficients and eventually the economic modelling of habitat and species maintenance.

Finally, on the accounting structure, to calculate the ES potential flow, we considered only three types of habitat and species maintenance areas. This can be considered a conservative hypothesis because habitats could also be restored in areas where none of the features considered are currently present. It would be interesting, for future developments, to also include other areas, after carefully checking by land cover type, where suitable habitats could be expected to be able to be restored, which in turn could host target species. That would (as an initial effect) increase the overall ES potential flow and in turn modify the ES actual and missed flows.

Key messages

- Habitat and species maintenance is assessed as a 'maintenance' service provided by terrestrial ecosystems; it is assessed as a 'final' service for 'global society' to address the overarching environmental target of biodiversity loss.
- In 2012, habitat and species maintenance provided a yearly flow of EUR 32.5 billion (EUR 113 per capita), mostly from cropland (44 %), followed by woodland and forest (35 %).
- Habitat and species maintenance missed flow was about EUR 56 billion in 2012. This assessment implies that there is significant room to restore ecosystems to improve ecological condition and enhance biodiversity.
- From 2000 to 2012, a negative change (– 1.1 %) in the extent of hotspots in suitable habitats (9 000 km^2) can be explained by the increase in imperviousness (+ 2.91 %). The overall decrease in hotspots in suitable habitats took place at a higher rate than the decrease in suitable habitats (– 0.36 %), which means that this decrease took place especially in species hotspots.
- From 2000 to 2012, in absolute terms we recorded an increase in the ES actual flow (+ 4.09 %). This is largely due to an increase in the population. We also recorded an increase in the ES missed flow (+ 4.92 %), which demonstrates that there is room to improve policies to improve ecosystem condition.

4. On-site soil retention

On-site soil erosion from rainfall is regarded as one of the major causes of environmental degradation, with large impacts on terrestrial ecosystem conditions (Panagos et al., 2015a; Borrelli et al., 2017). Ecosystem degradation is accentuated by soil erosion and worsened by the impacts of land use and climate change (Paustian et al., 2016). In this context, the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2018) and other studies (Perrings et al., 2010; Díaz el al., 2018) have highlighted the role of healthy ecosystems in preventing soil erosion and maintaining soil ecological processes and related services (nutrient cycling, decomposition, etc.). In this study, soil retention as an ES refers to the ability of ecosystems to reduce on-site erosion rates resulting from rainfall (modified from CICES version 5.1, Haines-Young and Potschin (2018)).

The degree to which an ecosystem can retain soil on site depends on both abiotic and biotic factors, as well as on human activity. The role of human activity is especially relevant in highly modified ecosystems such as cropland and depends on management practices (Adhikari and Hartemink, 2016). Climatic characteristics, soil characteristics and terrain (slope) characteristics are the main drivers of soil erosion, whereas higher vegetation cover and sustainable land management practices limit soil loss due to erosion. In this sense, biotic factors extensively affect on-site erosion, and the drivers of possible changes depend on the vegetation cover density and vegetation characteristics (Guerra et al., 2020); in turn, soil retention by ecosystems is strongly related to changes in land use and land cover. Generally, natural and semi-natural ecosystems tend to retain more soil than areas under intensive human use, which are affected by local agricultural practices (Panagos et al., 2015b). In this context, soil retention can be defined as the amount of soil retained in comparison with the maximum erosion, which can occur without the protective effects of soil cover.

The overall ecological importance of soil retention is in supporting healthy soil conditions. The economic importance of the soil retention service is in providing the material base for agricultural production. Soil retention also affects soil fertility, as soil retained by ecosystems supports agricultural production by providing nutrients, thus avoiding the necessity for additional inputs. In ES terms, soil retention accounts can be split into two different service flows: (i) the ES flow (actual flow), measured in both physical and monetary terms, and (ii) the intra-ecosystem flows, measured in biophysical units only (tonnes of soil). They are both important because the ecosystem can be, at the same time, the provider and the beneficiary of the retention of soil. The integrated system of natural capital accounting allows the reporting of the ES contribution to both economic sectors and ecosystem types as intra-ecosystem flows through the SUTs.

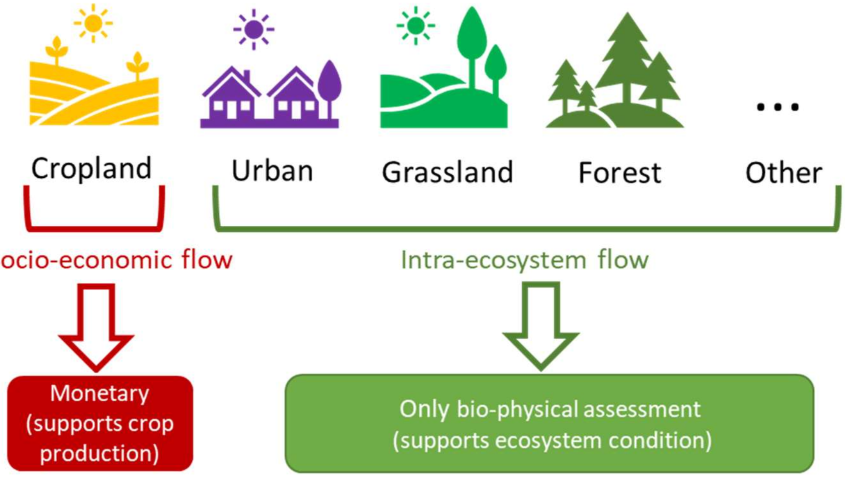
Soil retention may refer to both on-site and off-site effects. On-site effects of erosion include the loss of topsoil material, which decreases cropland productivity and can potentially lead to further erosion; off-site effects occur in areas of soil material accumulation and can lead to sedimentation or pollution of water channels, roads and other ecosystems (Burkhard et al., 2019). In this application, we focus on on-site soil retention as the result of the on-site impact of rainfall and do not consider loss of topsoil material due to wind, water or ice. Off-site effects concerning sedimentation are another service flow to be added to on-site soil retention. Depending on the assessment procedure adopted, the soil retention service could be considered an intermediate service or a final service (see Chapter 2). In our previous assessment and valuation of crop provision (Vallecillo et al., 2019), the role of soil was partially included in the overall ecosystem contribution. With this application, we extract the soil retention flow from the crop provision quantification to assess and value it separately as a final flow. This implies modifications in the flow of the crop provision service, which will not include soil fertility as an ecosystem input, as explained in Chapter 6, and the two ESs (crop provision and on-site soil retention) can be aggregated (see Chapter 7) without counting the same ES twice.

This application of on-site soil retention is in line with the INCA approach adopted so far and with the SEEA EA guidelines because:

- in SUTs, there is room to record the intra-ecosystem flows (see the SEEA EEA technical recommendations (UN, 2017)) – we do in fact record the flows of the service as physical flows to both economic units and ecosystem units, but (compliant with the SEEA EA) we value in monetary terms only the ecosystem contribution to the agricultural sector (Figure 4.1);

- when aggregating all the ESs estimated for INCA, we do not double count on-site soil retention because we extract the role of soil from the 'crop provision' service, as theoretically illustrated in Chapter 2 and practically applied in Chapter 6.

Figure 4.1. Visual simplification of soil retention flows from different ecosystem types



Soil retention was modelled for 3 years (2000, 2006 and 2012) to provide accounts for the same reference years as for other INCA ESs (Vallecillo et al., 2018; Vallecillo et al., 2019a).

4.1. Biophysical assessment

4.1.1. Introduction to the revised universal soil loss equation

For accounting purposes, we aimed to calculate the amount of soil retained by ecosystems (i.e. actual flow) for the three accounting years of reference: 2000, 2006 and 2012. A first step is the quantification of actual soil loss by water erosion. Estimates of soil erosion due to rainfall can be based on a variety of models working at different spatial and temporal scales (Karydas, Panagos and Gitas, 2014). The universal soil loss equation and its revised version (RUSLE) (Renard et al., 1991) are the models most widely used at regional and national scales, and also at EU level (Panagos et al., 2015a; Borrelli et al., 2017). In this study, we apply the RUSLE to estimate soil erosion following the methodology described in Panagos et al. (2015a). The RUSLE is formulated as:

$$A = R \cdot K \cdot LS \cdot C \cdot P \qquad \text{(Equation 4.1)}$$

where *A* is the actual rate of soil erosion due to rainfall expressed in tonnes ha^{-1} year^{-1}; *R* is the rainfall erosivity (MJ · mm · ha^{-1} · h^{-1}); *K* is the soil erodibility (tonnes · h · MJ^{-1} · mm^{-1}); *LS* is the (dimensionless) topographic factor representing the slope length and angle; *C* corresponds to the vegetation cover factor (dimensionless); and *P* is the anthropogenic support practices (dimensionless).

For the modelling of changes over time, *R*, *K*, *LS* and *P* are considered static parameters, and only the *C*-factor is dynamic over time. The vegetation cover (*C*) is indeed the factor directly related to the role of ecosystems and is certainly of major interest when assessing soil retention by ecosystems. Rainfall erosivity (*R*) is considered in this study as a fixed parameter over time. Although climate change and variations in rainfall patterns may play an important role in determining soil erosion, the temporal scale of our study (only 12 years) is not long enough to integrate changes in climatic variables, which usually take place over a period of 30 years (16). In fact, the *R* parameter (available at the European Soil Data Centre portal; see Annex MA7) refers to a temporal scale of 40 years (predominantly based on data between 2000 and 2010). Soil erodibility (*K*), related to soil texture,

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(16) https://old.wmo.int/extranet/pages/index_en.html

and the topographic factor (*LS*) are considered static parameters since they are related to geomorphological factors. The *C*-factor is driven by land cover and land use and management, which are very dynamic over time (i.e. expansion of agriculture, reforestation, clearcutting and land take).

All the input data for the application of the RUSLE at EU level are provided in Annex MA7. Mapping of the constant factors (*R*, *K*, *LS* and *P*) are available at the European Soil Data Centre portal. Only the *C*-factor is originally modelled in this study to cover the time series of interest (years 2000, 2006 and 2012). Modelling of the *C*-factor was based on the approach of Panagos et al. (2015b). The main differences between our study and those of Panagos et al. (2015a) and Panagos et al. (2015b) are related to the following.

- **Agricultural input data set.** Panagos et al. (2015b) used Eurostat statistics [agr_r_landuse], which are currently not available. Thus, we used statistics provided in [apro_cpsh1], which were used previously in other ES accounts.
- **The Corine land cover (CLC) inventory classes included as study areas (see Annex MA8).** In contrast to Panagos et al. (2015a), we included green urban areas in the modelling, since this land cover type also contributes to soil retention and the removal of dunes and beaches. Thus, urban ecosystems are also presented as providers of soil retention in accounting terms. Bare rocks, dunes, beaches, glaciers and artificial land cover (except green urban areas) were excluded from the analysis. These land cover types lack developed soils (e.g. bare rocks), or are not affected by rain erosion because the soil is sealed (artificial land covers), or are affected by other erosive processes (i.e. weathering, coastal erosion and wind erosion), such as in the case of beaches and dunes. The study area in 2012 was 3 850 000 km^2, which represents 88 % of the total EU-28 land extent. CLC classes were then aggregated using the MAES ecosystem aggregation system (Maes et al., 2020) (see Annex MA8).

4.1.2. Assessment of soil retention by ecosystems

The RUSLE is frequently used in the literature to model soil retention as an ES by comparing the current soil retention with the erosion under a hypothetical situation in which protection from ecosystems is not provided (Syrbe et al., 2018; Guerra et al., 2020). This approach is known as a counterfactual model, which compares a given situation with the absence of the key driver of this situation. Soil retention by ecosystems is calculated as:

$$Soil\ retention\ =\ RUSLE\ worst - case\ scenario\ -\ RUSLE\ current\ erosion \qquad \text{(Equation 4.2)}$$

where $Soil\ retention$ is the total amount of soil retained by the ecosystems, which is the actual flow of the service provided; $RUSLE\ worst - case\ scenario$ corresponds to the hypothetical amount of soil that could be lost under a scenario in which ecosystem protection is not provided; and $RUSLE\ current\ erosion$ is the amount of soil lost, estimated using Equation 4.1. With this approach, soil retention by ecosystems is quantified in physical units as tonnes of soil retained per hectare and year (tonnes ha^{-1} $year^{-1}$).

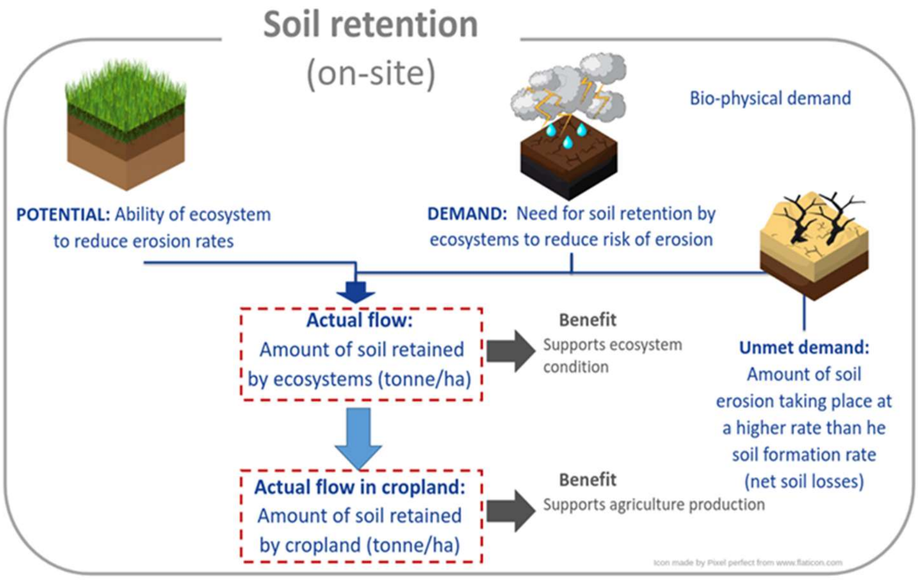
4.1.3. Consistency with the INCA accounting framework

The use of the counterfactual model described in Section 4.1.1 is consistent with the INCA framework for ES accounts, in which ES P, ES D, ES use and ES unmet demand are defined (Vallecillo et al., 2019b) (Figure 4.2). The correspondence between the ES components and the counterfactual model to assess soil retention is described below.

The ES P measures the ability of ecosystems (soil and vegetation) to reduce soil erosion. The *C*-factor is frequently used in the literature as a proxy for the ES P (Maes et al., 2015; Guerra et al., 2020). High *C*-factor values correspond to a low ability of the ecosystems to retain soil, whereas small *C*-factor values indicate a high ability for soil retention (Table 4.1 and Figure 4.2). A detailed description of the assessment of ES P is included in Section 4.1.4.

All terrestrial ecosystems benefit from the protective role of vegetation, which reduces soil erosion rates and prevents land degradation. ES D for soil retention is understood as the need for soil retention by ecosystems to reduce the risk of erosion and maintain soil fertility (Wolff, Schulp and Verburg, 2015). Areas with higher risks of erosion present higher demands for the protective role of ecosystems. In this sense, the erosion under a hypothetical situation in which protection from ecosystems is not provided (*RUSLE worst case scenario*) can be considered a proxy for the risk of erosion (Table 4.1). Since all terrestrial ecosystems benefit from the protective role of vegetation in reducing soil erosion rates, here we consider the overall ecosystem demand. A detailed description of the assessment of the demand for soil retention can be found in Section 4.1.5.

Figure 4.2. Visual simplification of soil retention flows from different ecosystem types



From an ecological point of view, most terrestrial ecosystems have a 'demand' for soil retention (i.e. are prone to a certain level of erosion, which is mitigated by the presence of vegetation). From a socioeconomic perspective, the main ecosystem in which soil erosion more directly affects human well-being is cropland (17): it is important to know where vegetation is needed to control erosion because soil erosion undermines the material substrate needed to grow crops and can decrease soil fertility, which negatively affects agricultural production. Although the final human use is represented by the agricultural sector, what allows the generation of this service is an ecosystem demand.

The actual flow of soil erosion is directly quantified as the amount of soil retained according to Equation 4.2 (Table 4.1). Soil retention by ecosystems (the actual flow) contributes to supporting the ecosystem condition and preventing soil degradation. When the actual flow takes place on cropland, then this service flow also contributes to supporting agricultural production. In this sense, it is only the ES flow taking place in cropland that can be presented / have values in monetary terms (Figure 4.2).

Table 4.1. Correspondence between components for the assessment of soil retention and INCA framework for ES accounts

Components of the counterfactual model	ES components
Complementary of the *C*-factor rescaled between 0 and 1 (Equation 4.3)	Soil retention potential: ability of ecosystems to reduce erosion rates
Erosion under a hypothetical situation in which ecosystem protection is not provided	Demand: need for soil retention by ecosystems to reduce risk of erosion by water
Soil retention as estimated by Equation 4.2	Actual flow (use): amount of soil retained by ecosystems
Current soil erosion (RUSLE current erosion) minus soil formation	Unmet demand: amount of soil loss taking place at a higher rate than the soil formation rate (net soil losses)

Under the INCA framework for ES accounts, we usually consider the share of the ES D not covered by ecosystems as 'ES unmet demand'. However, in this case, soil erosion is a natural process and, as such, certain levels of soil erosion have no negative consequences on the ecosystem condition as long as the ecosystem is capable of regenerating soil at a balanced rate. This is referred to as 'tolerable soil erosion', which should be

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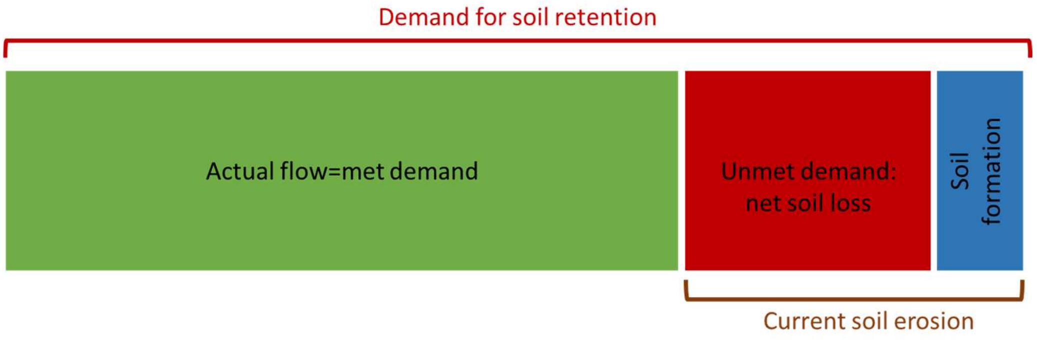
(17) Soil erosion due to lack of vegetation can nevertheless be important in other ecosystems (e.g. to prevent landslides).

below the soil formation rate. Where the soil erosion rate (based on Equation 4.1) is above the average soil formation rate, we consider that the protective role of the ecosystem is not enough, leading to an unmet demand for soil retention and therefore to the degradation of ecosystem condition. In this case, we consider as ES unmet demand for soil retention the net soil losses, calculated as the difference between the soil erosion and soil formation rates (Figure 4.3). Due to the lack of more accurate data on soil formation rates, we took an average soil formation rate for the whole EU of 1.4 tonnes/ha/year, which is considered unsustainable under most conditions in Europe (Verheijen et al., 2009). The assessment of the ES unmet demand is useful to identify areas where the ecosystem restoration should be enhanced to avoid ecosystem degradation. Section 4.5 provides limitations of the approach.

Figure 4.3. Schematic of the proportions of the different components of soil retention as an ES



The following sections describe the methods and data sets used for mapping and assessment of the ES P and ES D, which require a more detailed description. The ES actual flow and ES unmet demand are calculated as described above. All analyses were carried out at a spatial resolution of 100 × 100 m (i.e. the resolution of CLC layers). Therefore, all input data (see Annex MA7) were resampled at that spatial resolution. All ES components were later aggregated at the level of the EU, countries and MAES terrestrial ecosystem types (Maes et al., 2013). Finally, results are presented at the three aggregation levels, as well as in terms of ecosystems per country.

4.1.4. Ecosystem potential for soil retention

The potential of ecosystems to retain soil is defined as the ability of ecosystems to reduce erosion rates, which depends primarily on the ecosystem type, land use and management. This ability is an intrinsic characteristic of the ecosystem that depends on physiological and ecological characteristics of vegetation, such as vertical and horizontal canopy structure, root system and specific plant functional traits, under given abiotic conditions. As in other studies (Maes et al., 2015; Guerra et al., 2020), soil retention potential is quantified as the complementary value of the vegetation cover factor (*C*-factor) in relation to the maximum *C*-factor, rescaled between 0 and 1 (see Equation 4.3). In this way, lower *C*-factor values result in higher soil retention by the ecosystem.

$$Soil\ retention\ potential\ = \frac{(C_{max} - C) - C_{min}}{C_{max} - C_{min}} \qquad \text{(Equation 4.3)}$$

The *C*-factor was calculated following the methodology of Panagos et al. (2015b), using the best available data to cover the three years modelled (2000, 2006 and 2012). Input data are described in Table 4.2 and Annex MA7. It is important to highlight that interannual variation for soil retention depends solely on the changes in the ES P, driven by the land cover type, vegetation cover (condition of the ecosystem), land use and management practices (Table 4.2). Changes to more protective land covers, increase in vegetation cover, use of protective crops and implementation of soil conservation measures will enhance soil retention by ecosystems. Following Panagos et al. (2015b), estimates of the *C*-factor for arable and non-arable land (18) require different approaches and data sources, which are described below (Table 4.2).

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(18) Following Panagos et al. (2015b), arable land includes non-irrigated arable land, irrigated arable land and rice fields. Non-arable land refers to all other land covers.

Table 4.2. Summary of the input data used to model the *C*-factor stem

Factor	Data source	2000	2006	2012
Land cover	Accounting layers of the CLC	Map: 2000	Map: 2006	Map: 2012
Vegetation cover (for non-arable land)	Fraction of vegetation cover (Copernicus Sentinel-1 PROBA-V sensor)	Map: 2000	Map: 2006	Map: 2012
Land use (crop type for arable land)	Share of crop types at NUTS 2 level [apro_cpsh1]	Mean for 2000 and 2001	Mean for 2005–2007	Mean for 2011–2013
Land management (arable land)	Eurostat's farm structure survey (soil management measures)	Not included: measures not consolidated at EU level	Data: 2010	Data: 2010
Nomenclature of territorial units for statistics (NUTS) 0, NUTS 1, NUTS 2	NUTS 2 (geographic information system for the Commission)	—	—	—

4.1.4.1. *C-factor in arable land* (C_{arable})

Arable land accounts for 28 % of the study area and is particularly relevant for the assessment of soil retention because the latter constitutes an important pressure on these ecosystems, especially in areas of intensive agricultural management, with important economic consequences (García-Ruiz et al., 2013; Panagos et al., 2015a). Two main factors determine the ecosystem potential in arable land: the C_{crop} and the $C_{management}$ (see Equation 4.4). The C_{crop} is crop type specific depending on physiology and composition of the crop, whereas the $C_{management}$ is related to the influence of management practices.

$$C_{arable} = C_{crop} \cdot C_{management} \qquad \text{(Equation 4.4)}$$

C_{crop} is calculated at regional level (NUTS 2) because of the lack of data at a finer resolution. C_{crop} depends on the specific C_{crop} value assigned to each crop type and the shared composition of the different crop types present in a region:

$$C_{crop} = \sum_{n=1}^{n} C_{crop_n} \cdot \%NUTS2_n \qquad \text{(Equation 4.5)}$$

where C_{crop} is the crop-specific C and $NUTS2_n$ is the share of the specific crop in each NUTS 2 unit. The C_{crop}-specific values for each crop type were obtained from a literature review of the most commonly used values in Europe (Panagos et al., 2015b; Borrelli et al., 2017). Eurostat's agricultural production data set [apro_cpshr] (19) provides information on regional crop composition at NUTS 0, NUTS 1 and NUTS 2 regional levels from the year 2000, and includes 23 different crops. In contrast to the study by Panagos et al. (2015b), fallow land is not included in the data set, and results differ given the high C_{crop}-specific value for fallow land. To smooth interannual variability, 3-year moving windows were used to calculate the total crop area for each of the reference years. For example, for 2006, we used the average share of arable land covered by each crop type for 2005, 2006 and 2007. For cases in which data at NUTS 2 level were missing, the best available data at NUTS 1 level or national level (NUTS 0) were used. The Ccrop value for each region and each year was assigned to the respective year, and the arable land cover in CLC was extended. Annex MA9 shows the C_{crop} for each crop type as well as each crop type as a proportion (%) of the total arable land in the EU-28 for 2000, 2006 and 2012.

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(19) https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=apro_cpshr&lang=en

The enhancement and improvement of management practices through policies, such as the common agricultural policy, or agro-environmental standards aim to increase soil protection in arable land by limiting bare soils, promoting reduced tillage and mainstreaming crops that are more protective. Therefore, different management practices ($C_{management}$) targeting soil protection change the overall C_{arable} factor (see Equation 4.4). Soil conservation measures such as tillage management ($C_{tillage}$), leaving plant residues on soil ($C_{residues}$) and use of cover crops (C_{cover}) contribute to an increase in soil retention in agro-ecosystems (see Equation 4.6).

$$C_{management} = C_{tillage} \cdot C_{residues} \cdot C_{cover} \quad \text{(Equation 4.6)}$$

Data on management practices at EU level are taken from Eurostat's farm structure survey. The farm structure survey provides data on the extent of tillage practices (conventional, reduced and zero tillage), plant residues and cover crops at NUTS 2 territorial unit level for the year 2010. For the modelling of soil retention over time, management practices data from 2010 were included to model soil retention in 2006 and 2012, assuming they were fixed for this period. In the case of the year 2000, we did not include $C_{management}$ since soil conservation measures were still not consolidated at EU level (Table 4.2). Implementation of these measures started only at the end of the 20th century and became a key pillar in the programming period for 2006–2013. Measures in the farm structure survey that reduce the impact of tillage on soil erosion include conservation tillage and zero tillage. Tillage greatly influences soil retention in arable land by removing vegetation residues and effectively breaking physical soil aggregates. Depth, direction and timing of ploughing, the type of tillage equipment used and the number of passages made are some of the tillage characteristics that affect soil rates in arable land. Conservation tillage and zero tillage are effective methods for retaining soil and reducing nutrient leaching into groundwater. $C_{tillage}$ is calculated according to Equation 4.7.

Plant residues refer to the practice of leaving non-marketable residues of a main crop in the soil (e.g. stubble) to provide an organic cover to the soil (Equation 4.8). In arable land, cover crops refer to crops grown between the main crops to avoid leaving the soil bare (e.g. in winter) (Equation 4.9).

$$C_{tillage} = \%NUTS2_{conventional} \cdot 1 + \%NUTS2_{conservation} \cdot 0.35 + \%NUTS2_{Notill} \cdot 0.25 \quad \text{(Equation 4.7)}$$

$$C_{residues} = (0.88 \cdot \%NUTS2_{residues}) + (1 - \%NUTS2_{residues}) \quad \text{(Equation 4.8)}$$

$$C_{cover} = (0.80 \cdot \%NUTS2_{cover}) + (1 - \%NUTS2_{cover}) \quad \text{(Equation 4.9)}$$

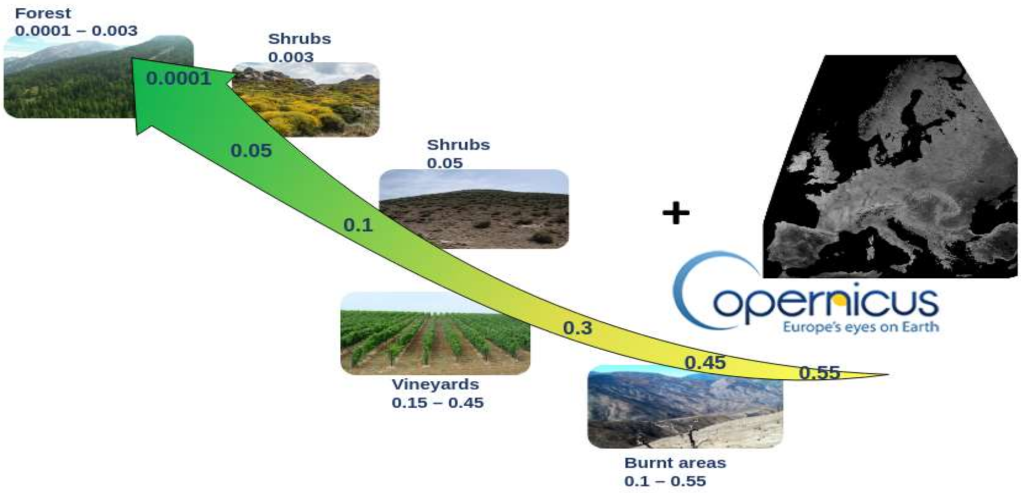
4.1.4.2. C-factor in non-arable land ($C_{non\text{-}arable}$)

Non-arable land includes all the other land covers not considered arable land (see Annex MA8). It is composed of a variety of natural and semi-natural land cover classes, as well as some agricultural land uses (permanent crops and pastures). The type of vegetation cover determines the ability of ecosystems to retain soil. A more developed canopy structure and higher vegetation density increase the role of ecosystems in retaining soil (Panagos et al., 2015b; Guerra et al., 2020). For instance, broad-leaf forests generally retain more soil than grassland. Figure 4.4 presents graphically the variability of the C-factor for different land cover types. Within each land cover type, the C-factor also varies according to the vegetation density. The fraction of green vegetation cover (F_{cover}), from Copernicus's Sentinel-1 PROBA-V sensor, provides an approximation of the vegetation density of soil covered by vegetation (see Annex MA7). F_{cover} takes a value of zero when there is no vegetation and 1 when the full pixel is covered by green vegetation. The $C_{non\text{-}arable}$ factor is calculated as follows:

$$C_{non-arable} = \min(C_{land\ use}) + range(C_{land\ use}) \cdot (1 - F_{cover}) \quad \text{(Equation 4.10)}$$

where $C_{land\ use}$ refers to the range of C-factor values for each land cover type. $C_{land\ use}$ ranges were taken from Panagos et al. (2015b) (see also Annex MA8). F_{cover} is the fraction of green vegetation cover, ranging between 0 and 100. In Equation 4.10, we rescale $C_{land\ use}$ according to the vegetation density. For instance, if a coniferous forest in a given area has an F_{cover} close to 0, then the $C_{land\ use}$ factor would take the largest value of the range (0.003) resulting in low soil retention. If F_{cover} in a forest is close to 100, then $C_{land\ use}$ would take the smallest value of the range (0.0001). In this situation, soil retention by the ecosystem is maximised (see Annex MA8).

Figure 4.4. Examples of *C*-factor values in non-arable land



NB: Values depend on the land cover type, as well as fraction of vegetation cover (F_{cover}).

4.1.5. Ecosystem demand for soil retention

Soil erosion is a natural process that affects all landforms. In this sense, all terrestrial ecosystems benefit from the protective role of vegetation, which contributes to a reduction in the amount of soil that can be lost due to the impact of rain. Soil retention supports the maintenance of soil condition, and more concretely soil fertility, which has an important impact on the economy. In this study, ES D is defined as the need for soil retention to reduce risk of erosion. It is quantified as the total amount of soil lost (tonnes ha^{-1} year^{-1}) when ecosystem protection is not provided; this is calculated using the lowest ecosystem potential to retain soil (hereafter referred to as the worst-case scenario). Therefore, soil retention is considered to be needed for all ecosystem types as long as there is a soil stock (see Annex MA8). This demand is ecosystem based, and the maintenance of ecosystem condition in cropland has economic consequences that can be valued in monetary terms.

A 'reference scenario' to assess soil retention is frequently defined in the literature (Syrbe et al., 2018; Guerra et al., 2020). However, this definition differs between studies. Syrbe et al. (2018) used a fixed reference *C*-factor (C = 0.40, except for hops, where C = 0.80) to simulate a scenario with reduced protection by ecosystems; however these values are slightly arbitrary, or at least justification is not provided. Guerra et al. (2020) assumed a *C*-factor equal to 1, which implies that the ecosystem, as quantified by the *C*-factor, does not have any impact on reducing soil erosion. This assumption (*C*-factor = 1) as a reference scenario might lead to an overestimation of the role of the ecosystem in retaining soil in other scenarios, since a total lack of capacity to retain soil is a rather theoretical and unrealistic scenario. In real-world circumstances, even highly degraded ecosystems still have some retention capacity. Remaining ecosystem structures (e.g. death roots) maintain a portion of the soil stock, justifying the use of a reference *C*-factor smaller than 1. We propose that, to better simulate the reference scenario lacking ecosystem protection, the maximum possible *C*-factor corresponding to the lowest ecosystem potential to retain soil that can be found in the study area should be used.

In this context, based on the *C*-factors assigned to different land cover types and conditions, the maximum possible *C*-factor is found in burnt areas when there is no vegetation cover (F_{cover} = 0), exposing bare soil to erosion. In this situation, the *C*-factor takes a value of 0.55. This reference *C*-factor, derived from the modelling parameters, corresponds to the baseline of the ecological transition in which vegetation cover is completely removed. We assumed this maximum possible *C*-factor as the lowest ES P (soil retention potential of zero).

It is important to highlight the potential that *C*-factors larger than 0.55 might have been found when considering arable land. Certain crop types, such as aromatic plants and hops, present a *C*-factor of 0.8, which is larger than 0.55 (see Annex MA9). However, for the following reasons we did not use 0.8 as the reference *C*-factor.

- In practice, crop data are available only at NUTS 2 level, weighted by the relative extent of each crop type (see Equation 4.5). Therefore, empirically a *C*-factor of 0.8 cannot be found for any pixel of arable land.
- A hypothetical scenario in which the whole EU is covered by aromatic plants and hops was less plausible than a potential scenario in which ecosystems are burnt, bringing them back to the baseline of the ecological succession.
- Aromatic plants and hops represent a very low share of arable land at EU level (see Annex MA9), and therefore are not representative in terms of the definition of the worst-case scenario under the lowest ecosystem potential to retain soil.

By applying a constant *C*-factor of 0.55 for the whole EU, we can quantify and map the amount of soil that could potentially be lost due to water erosion under the lowest ES P by applying Equation 4.1. The lowest ES P was found in burnt areas without any vegetation cover, and therefore this land cover type presents the lowest ecosystem potential to retain soil. The mapping shows areas with a high risk of erosion due to the lack of the protective role of vegetation. In these areas, the protective role of ecosystems to retain soil is greatly needed.

4.2. Monetary valuation

The translation of the biophysical flow into monetary terms is undertaken only for the actual flow from cropland contributing to the agricultural sector, not including livestock. The forestry sector could also be considered in future experimental accounts of soil retention. The maintenance of the upper soil layer is a necessary condition for any agricultural activity; therefore, soil retention contributes to preserving the conditions for agricultural food production. The main valuation approaches applied in the literature to estimate this kind of value are cost-based methods such as opportunity costs, avoided costs and the replacement cost approach. Turner et al. (2016), in their review of the soil retention literature, highlight that the most appropriate valuation methods to be used in the valuation of soil retention are avoided costs, replacement costs and hedonic pricing. Benefit transfer based on peer-reviewed research is an alternative method (e.g. Kay et al., 2019).

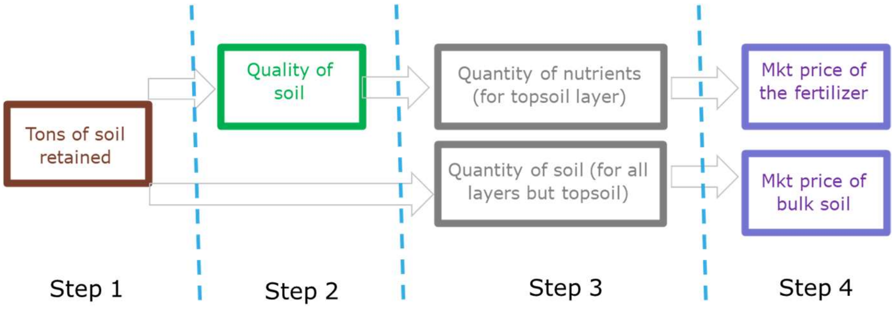
The replacement cost approach investigates the cost of replacing the lost service with the most likely alternative method, which should also be the cheapest feasible option. The loss of soil retention results in lost soil (quantity) and reduced soil fertility (quality). This implies that the cost of replacing the service can be estimated through (i) the cost of replacing the lost soil in terms of overall soil structure, and (ii) the cost of replacing top soil (with the highest level of fertility). The latter refers to topsoil layers that have the highest concentration of organic matter, nutrients and microorganisms. Operationally, it is a matter of multiplying tonnes (of soil and/or soil nutrients) by price (of soil and/or specific types of fertilisers). This methodology was feasible from a practical point of view and was in line with the biophysical modelling.

Alternative techniques suggest replacing soil retention through artificial means, such as manufactured barriers and other built infrastructure providing the same level of soil retention. In this case, the market price of the infrastructure required to provide an equivalent level of soil retention would be the replacement cost. However, estimating the cost of artificial means would involve a significant number of assumptions and generalizations; this technique is feasible in small-scale, rather than EU-wide, applications.

Hedonic pricing techniques are applicable when information about the quality of the land for agricultural production is reflected in the prices that farmers and agricultural businesses are willing to pay for the land. Through econometric modelling, it is possible to determine how much the specific characteristics of properties contribute to their valuation, by assessing the price differentials between similar properties and thus trying to statistically identify the value of different variables. In this case (i.e. for agricultural land), the approach should identify the premium paid for land with superior soil retention services, and therefore estimate the implied value of soil retention. This method, although theoretically possible, can be difficult to apply because of (i) lack of appropriate data to conduct the statistical analysis, (ii) complexity of interactions among numerous variables, making it hard to isolate the effects of the desired variable, (iii) issues with producing statistically significant and robust estimates that can be used across different regions, for different agricultural uses and for land under different policy regimes, and (iv) an unreliable underlying assumption that land purchasers are fully informed (and thus aware) of the exact level of soil erosion / avoided soil erosion.

The approach chosen for this application is therefore the replacement cost method, which focuses on replacing (i) the fertility loss due to loss of soil, by using mineral fertilisers in the topsoil layer (up to 25 cm), and (ii) the soil structure, by using all remaining soil layers except topsoil. The clear quantification of the different layers guarantees that there will be no overlaps either in the biophysical quantification or in the monetary valuation. This approach aligns with the current economic system, in which a large fertiliser market is in existence and applied extensively across the EU. The valuation model applied to the soil retention service is summarised in Figure 4.5.

Figure 4.5. Flow chart of the valuation model applied to the soil retention service



Step 1 is the result of the biophysical model: soil retention is quantified as the amount of soil that ecosystems retain each year (tonnes per year) compared with the hypothetical worst-case scenario, in which the role of ecosystems in retaining soil is minimised. Since we are considering only ‘on-site’ features of soil retention (and not sedimentation), we concentrate on soil fertility as the ability to sustain agricultural plant growth. Considering soil structure, it is the topsoil that provides essential macronutrients (mainly nitrogen and phosphorus). For this reason, once the actual flow is calculated in physical terms, a complementary assessment needs to be carried out to estimate the quality of the soil retained, and specifically the amount of nitrogen and phosphorus within the retained soil, which depend on and, in turn, reflect soil type and structure (Graves et al., 2015). This calculation (step 2) quantifies only a small fraction of the total amount of soil retained each year. The measurement of nitrogen and phosphorus content are indicators of soil condition. In our model, the nitrogen and phosphorus amounts in the soil retained are estimated using the map of chemical properties of soils in Europe based on 2009 land use / land cover area frame survey data (no changes in concentration are assumed over time because of the lack of data). When considering the amount of soil retained, the hypothetical loss of soil when what is lost is topsoil will be different from the hypothetical loss of soil when what is lost is not topsoil (deeper horizons/soil).

Step 2 (soil quality) needs further processing. Considering the rationale behind the use of replacement cost techniques, we need to estimate the amount of artificial substitute for fertile soil that is required when the natural fertility is decreased. In terms of fertilisers, we need to assess the quantity of fertiliser needed to replace the natural fertility of soil. The ratio between nutrient soil content and nutrient fertiliser is not 1:1, due to several processes that occur in the soil system once fertilisers are applied. In fact, only some of the total active nitrogen applied is taken up by plants; a share of input nutrients is lost due to run-off, leaching or atmospheric dispersion. Part of the purchased fertiliser is also lost before application (e.g. during storage). Therefore, an ‘uplift’ factor, or ‘input efficiency ratio’, should be applied. This is the equivalent nutrient content in fertiliser required to replace the nutrient content in the retained soil, which reflects how much of the input fertiliser nutrients will be retained in the soil. We thus need to calculate a ‘retention ratio’.

The common agricultural policy regionalised impact (CAPRI) model (Britz and Witzke, 2014) features a specific module that estimates nitrogen flows throughout the whole nitrogen cycle. In particular, it estimates the following quantities per crop type at NUTS 2 level:

- nitrogen inputs to soil as the sum of the following variables – biological fixation, mineral fertiliser nitrogen input net of gaseous losses and run-off, manure input net of all surface losses (applied intentionally to agricultural land), manure input net of all surface losses (deposited by grazing animals), atmospheric deposition and crop residues;

- nitrogen effectively retained by the crops.

The ratio between the overall nitrogen input and the nitrogen retained by the crops enables estimation of the quantity of nitrogen that must be added to the soil for each unit of nitrogen that is used by the plant. At the moment, there are no sources available to calculate ad hoc coefficients for phosphorus, so we needed to adopt some assumptions. The study by Graves (2015) states that 'enrichment ratios describe the relative concentrations of nutrients in deposited material and in the soil from which that eroded material came'. Graves et al. (2015) provide average enrichment ratios for phosphorus (2.15) and nitrogen (1.37). Although enrichment ratios (which refer to off-site eroded soil) differ from retention ratios (on-site soil), the enrichment ratio for nitrogen is very similar to the retention ratio for nitrogen. Because the enrichment ratio for phosphorus is higher than that for nitrogen, the estimated replacement coefficient for nitrogen is also applied for phosphorus as a conservative assumption (20). Table 4.3 reports the retention ratios used to calculate the quantity (in tonnes) to be multiplied by the price of fertilisers (Figure 4.6), as described in the following paragraphs.

Table 4.3. Input retention ratios based on CAPRI data for nitrogen

Country	**Retention ratio**
Austria – AT	1.24
Belgium – BE	1.75
Bulgaria – BG	1.22
Croatia – HR (a)	1.43
Czechia – CZ	1.66
Germany – DE	1.52
Denmark – DK	1.69
Estonia – EE	1.44
Finland – FI	1.37
France – FR	1.32
Greece – EL	1.44
Hungary – HU	1.56
Ireland – IE	1.40
Italy – IT	1.29
Latvia – LV	1.11
Lithuania – LT	1.24
Luxembourg – LU	1.83
Netherlands – NL	1.66
Poland – PL	1.34
Portugal – PT	1.27
Romania – RO	1.35
Slovakia – SK	1.78
Slovenia – SI	1.35
Spain – ES	1.54
Sweden – SE	1.49
United Kingdom	1.49
EU	1.43

(a) The CAPRI model does not report data for Croatia. The EU coefficient is applied for Croatia.

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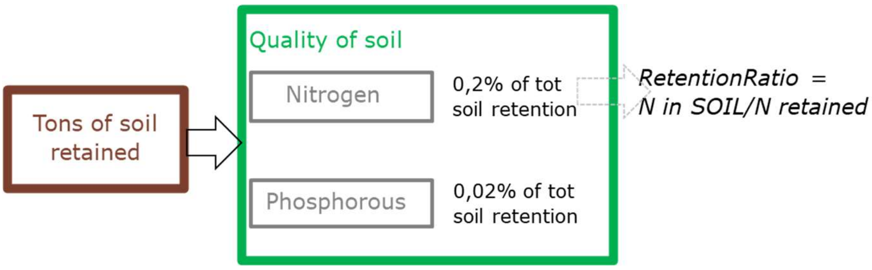
(20) The assumption is defined as 'conservative' because we would expect a higher retention ratio for phosphorus (considering the comparison with enrichment ratios).

Figure 4.6. Flow chart concerning the quantification of soil quality in topsoil layers



Using the replacement coefficients, step 3 can be undertaken by multiplying the replacement coefficient by the nitrogen, phosphorus and soil organic carbon (SOC) fractions of soil (in tonnes) for the topsoil layers. For all the other layers, it is necessary to subtract the fraction of soil already considered as topsoil from the total amount of soil retained to avoid double counting.

In step 4, two different sets of prices are multiplied by the two amounts (in tonnes) resulting from the previous step:

- nitrogen and phosphorus components, as proxies for topsoil,
- the residual amount of soil, as a proxy for soil structure.

The first set of prices concerns fertilisers. Prices are based on multiple sources covering nitrogen, phosphorus and SOC (Graves et al., 2011, 2015; Redman, 2018), as well as the monthly average prices for agricultural inputs (fertilisers) in the EU published by the European Commission (21), specifically:

- Commodity price dashboard, No 89, November 2019 (22);
- 'Fertilisers in the EU – Prices, trade and use', *EU Agricultural Markets Brief*, No 15, June 2019 (23).

Where not available, EU averages can be applied, potentially adjusting for the purchasing power parity of specific countries. In addition, the following source has been integrated:

- Agricultural market information system Market Monitor, No 74, December 2019 (24).

The average value applied for the nitrogen component is about EUR 130/tonne; for the phosphorus component, it is about EUR 133/tonne. These prices are multiplied respectively for the nitrogen and the phosphorus components.

The second set of market prices concerns the cost of those soil components other than topsoil. Those costs were retrieved from an ad hoc dealer website (25) and are in line with the prices reported by other dealers (26) This specifically concerns the cost of septic fill that does not retain moisture. Its standard cost (using the same US dollar–euro exchange rate and US gross domestic product inflator employed for the cost of fertilisers) is about EUR 10/tonne. The decision to include this estimate is justified by the need to account for the structural role of soil, which remains a crucial component not only of assessment in physical terms but also for valuation. On the one hand, it is not realistic to think of replacing all soil in the EU since there may not be that much soil supply available; on the other hand, it would be a serious underestimate to value only topsoil and to ignore the other retained soil that plays a crucial structural role. Still, the important and peculiar role of topsoil is given appropriate importance since the price per tonne attributed to the fertility component (EUR 103–133) is much higher than that attributed to the structural component (EUR 10).

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(21) https://ec.europa.eu/agriculture/markets-and-prices/price-monitoring_en

(22) https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/markets/prices/commodity-price-dashboard_en

(23) https://ec.europa.eu/info/files/market-brief-fertilisers-eu_en

(24) http://www.amis-outlook.org/amis-monitoring#.XekaVJP7SUk

(25) We specifically checked the HomeAdvisor website (https://www.homeadvisor.com/cost/landscape/deliver-soil-mulch-or-rocks/).

(26) We specifically checked the HomeGuide website (https://www.homeguide.com) and the Home Depot website (https://www.homedepot.com).

Finally (step 4), the amount of replacement means (in tonnes) is multiplied by their costs (euro per tonne). The results aggregated at EU level are reported in the following section; results aggregated per country are reported in Annex MA8. For the sake of consistency with the other ESs calculated for INCA, we apply a constant price for the years 2000, 2006 and 2012.

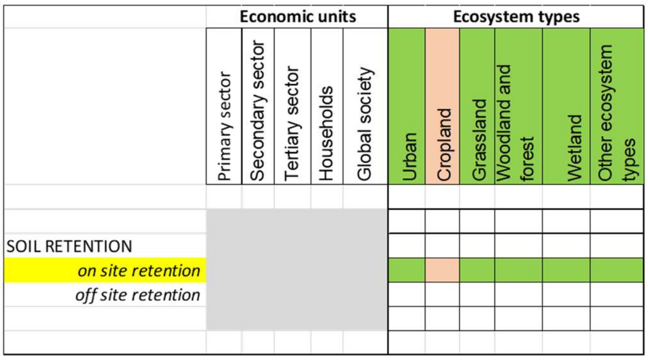
4.3. Accounting tables

On-site soil retention is reported in SUTs in both physical and monetary terms. In physical terms, all the flows can be recorded (i.e. flows used by socioeconomic system and flows used by ecosystem type). The flows used reported by socioeconomic system should be recorded as a flow from the ecosystem type cropland to the economic agricultural sector; all the other flows concern intra-ecosystem flows whose recording matters to appropriately quantify the role and importance of this service. This explains why in the use table, in physical terms, the cropland column will remain empty: its flow is allocated to agriculture. However, in practice there is also a contribution to the maintenance of cropland condition. For all the other ecosystem types, the soil retention flow remains within the same ecosystem that supplies it (intra-ecosystem flows).

In monetary terms, the SUTs only address the transaction between ecosystem type and economic unit because this directly enters into the economic system. No monetary value can be attributed to intra-ecosystem flows: their role as ‘fortifiers’ of ecosystem types is intermediate in terms of maintaining the ecosystem condition, which, in turn, will be provided to the economic systems through other flows. This explains why the only flow that is reported estimates the transaction between ‘cropland’ and the ‘primary sector’; all the other intra-ecosystem flows are not reported. Figure 4.7 summarises these concepts.

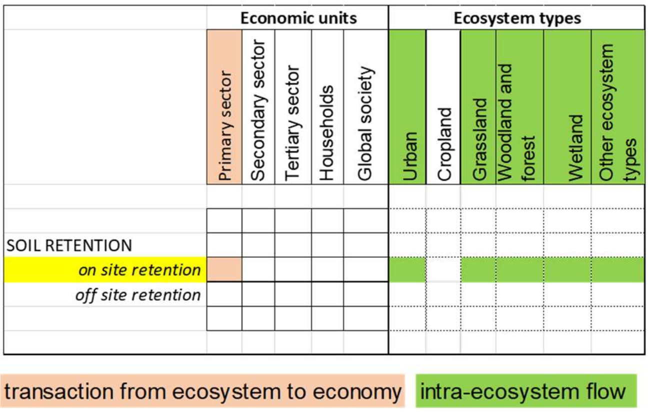
Figure 4.7. Structure of the SUTs in physical terms

(a) Supply Table



	Economic units					Ecosystem types					
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Other ecosystem types
SOIL RETENTION	▨	▨	▨	▨	▨						
on site retention	▨	▨	▨	▨	▨	🟩	🟧	🟩	🟩	🟩	🟩
off site retention	▨	▨	▨	▨	▨						

(b) Use Table



	Economic units					Ecosystem types					
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Other ecosystem types
SOIL RETENTION											
on site retention	🟧					🟩		🟩	🟩	🟩	🟩
off site retention											

🟧 transaction from ecosystem to economy 🟩 intra-ecosystem flow

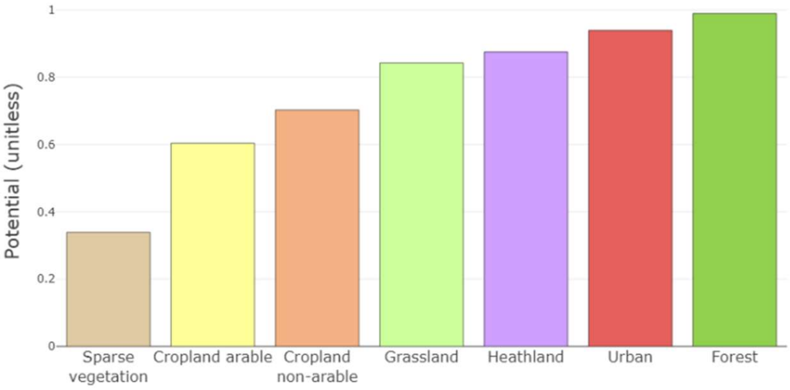
As already known by practitioners, SUTs for on-site soil retention only record transactions from the ecosystem to the economic unit that first uses this specific service. How the economic unit will operate thanks to the service is beyond this stage of recording. The SUTs are thus not estimating the overall flow of soil services to society because they measure only the contribution of soil to agricultural activity, a very tiny part of the crucial role played by soil.

4.4. Results

4.4.1. Ecosystem service potential for soil retention

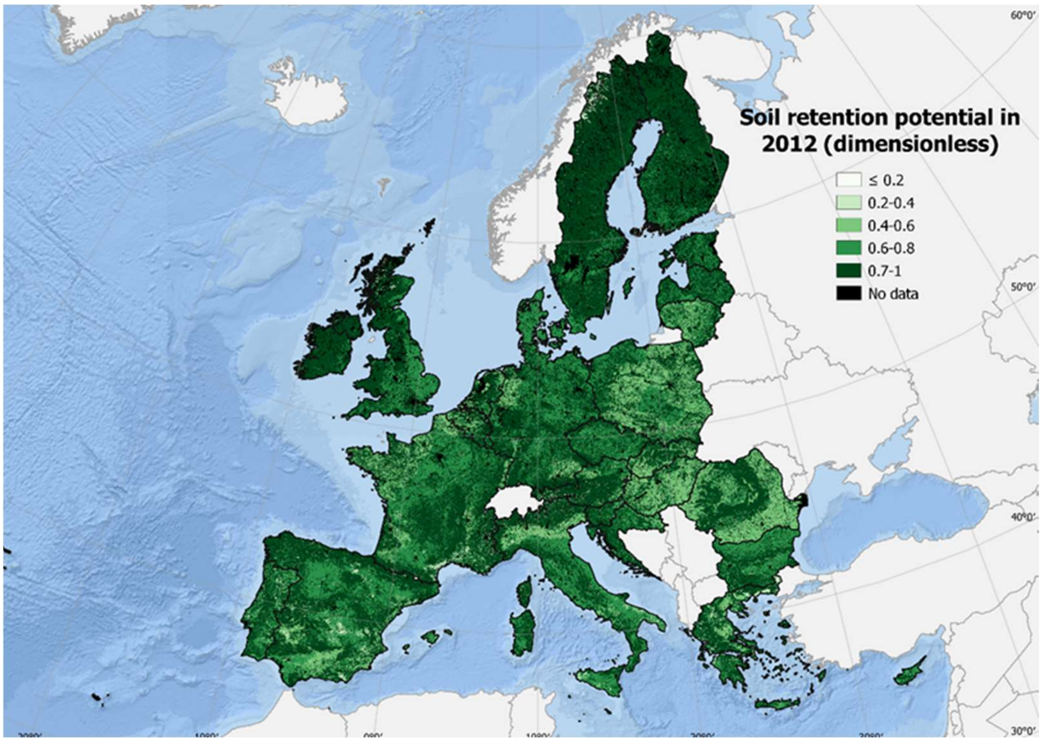
At EU level, the average ecosystem potential to retain soil in 2012 was about 0.81 (dimensionless indicator). Forests, green urban areas and heathland provide the highest ES P (Figure 4.8). We found sparsely vegetated land and cropland (arable and non-arable) to have the lowest soil retention potential.

Figure 4.8. Flow chart showing the quantification of soil quality in topsoil layers



Through mapping ES P, we find high ES P in mountainous areas of the EU-28 and forest-dominated countries such as Sweden and Finland (Figure 4.9). Specialised agricultural areas, such as those in the Guadalquivir Valley (southern Spain), the lower Danube (Bulgaria and Romania) and the Po Valley in northern Italy, present some of the lowest ES P. The Benelux region, the north of France and England also have relatively low ES P for soil retention, due to higher shares of land cover under agricultural use. In general, natural and semi-natural ecosystems provide higher soil retention potential than agriculture areas do.

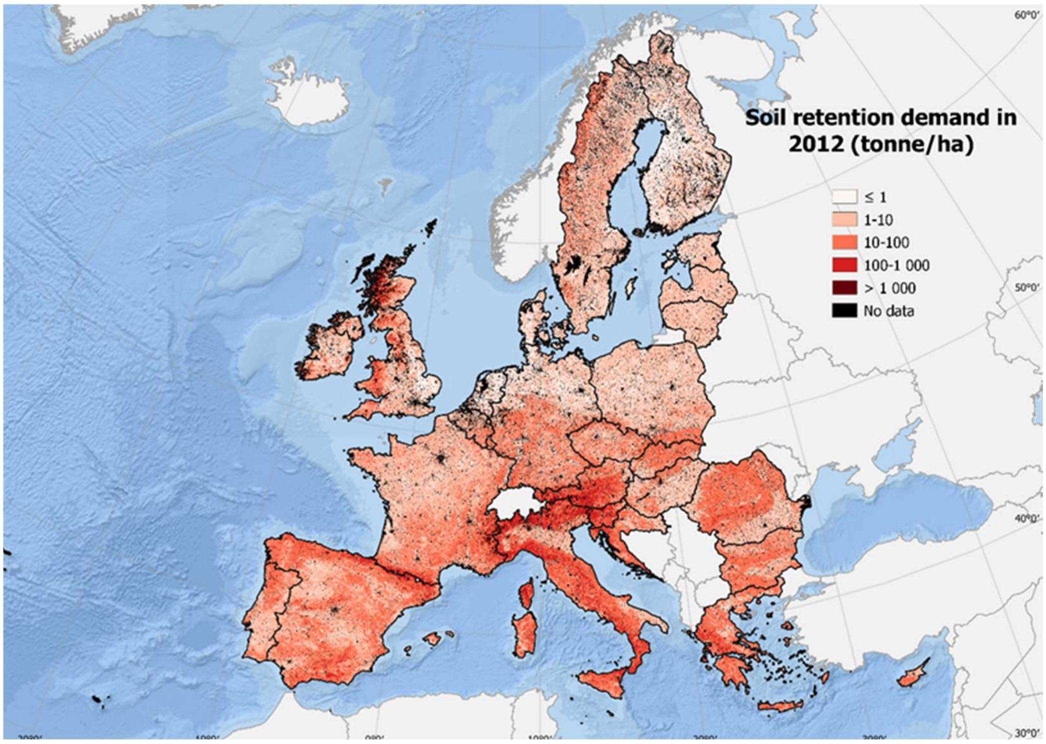
Figure 4.9. Map of the ES P for soil retention in the EU-28 in 2012



4.4.2. Ecosystem service demand for soil retention

Figure 4.10 presents the spatial distribution of demand for soil retention in the EU. The maps are useful to identify areas at high risk of soil erosion if ecosystems do not provide protection. In this sense, high demand is generally located in mountainous areas with steep slopes (Pyrenees, Alps, Apennines and Carpathians). ES D for soil retention is also high in Mediterranean and eastern EU regions, particularly in countries such as Greece, Croatia, Italy and Slovenia, because of the abrupt terrain (high *LS* factor in Equation 4.1) in combination with the erosive impact of precipitation in these areas (high *R* in Equation 4.1). Northern Europe has particularly low rates of demand for soil retention due to lower values of the *K* parameter related to soil type (lower erodibility).

Figure 4.10. Map of the demand for soil retention in the EU-28 for 2012



Under this worst-case scenario, without the protective role of ecosystems the total amount of soil that could potentially have been eroded in 2012 in the EU is about 8 294 million tonnes, at an average of 21.5 tonnes ha^{-1}. Using a reference bulk density of 1.2 g cm^{-3} and converting the units (27), this would be equivalent to eroding the top 0.17 cm of soil in just 1 year. The ES D for soil retention per unit areas by ecosystem type follows a gradient of the erosion risk where different ecosystems are located (Figure 4.11).

For instance, sparsely vegetated land and heathland are the ecosystem types with the largest ES D per unit area. This is due to the spatial distribution of these ecosystems, which are generally located at high altitudes in mountain ranges, where no other ecosystem can develop due to the abrupt topography, which provides initial but limited protection to the soil, reducing the risk of erosion. These ecosystems are also especially abundant in Mediterranean regions. In contrast, arable land, green urban areas and non-arable cropland are located in flat areas, where erosion risk is lower. For these ecosystems, the absence of the protective role of vegetation will result in lower soil losses when compared with ecosystems with higher demand (e.g. sparsely vegetated land). However, soil losses in agricultural areas will have a much bigger impact on the economy (see Section 4.4.5).

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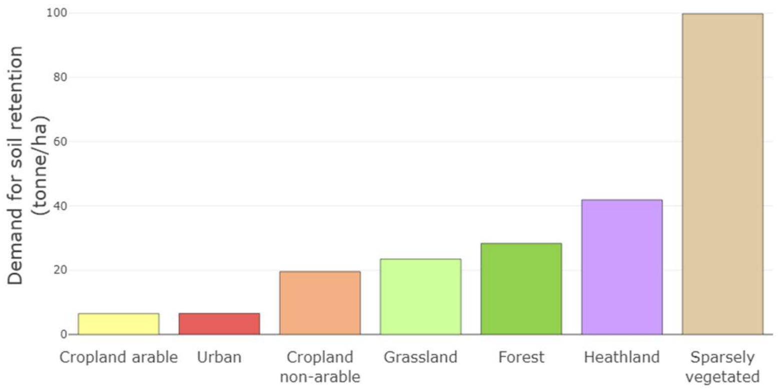
(27) $\frac{21.5\ \text{tonnes}}{\text{ha}} : \frac{1.2\ \text{g}}{\text{cm}^3} = \frac{21.5\ \text{tonnes}}{10000\ \text{m}^2} : \frac{1.2\ \text{tonnes}}{\text{m}^3} = 0.0017\ \text{m}$

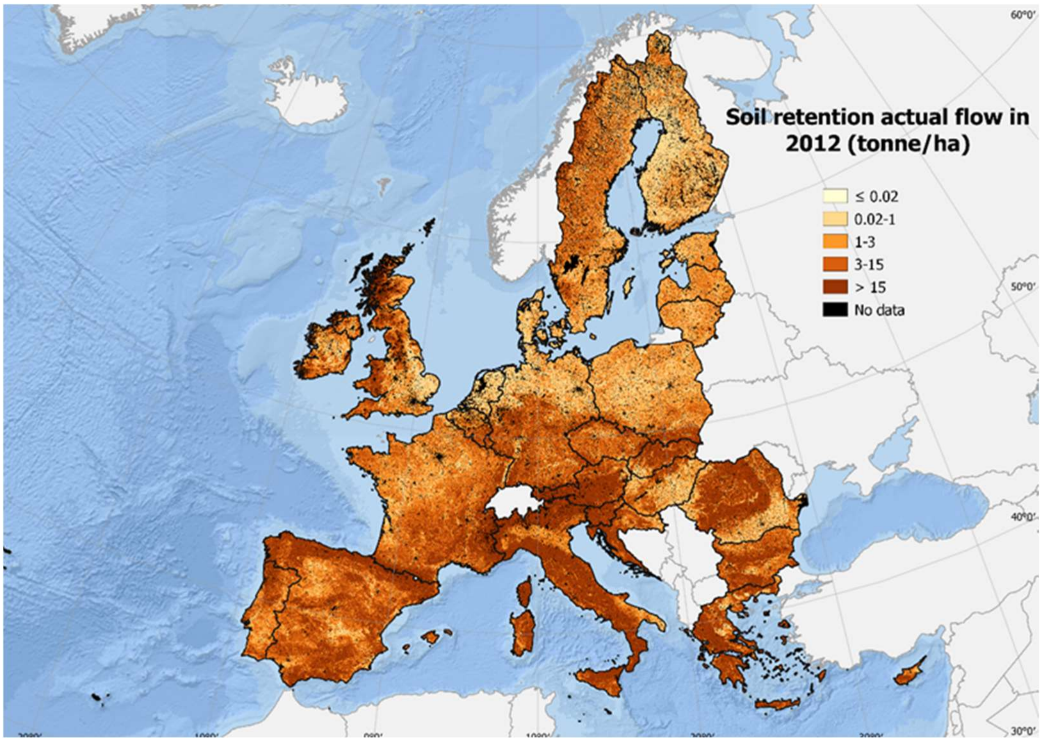
Figure 4.11. Demand for soil retention by ecosystem type at EU level in 2012



4.4.3. Actual flow of the soil retention ecosystem service

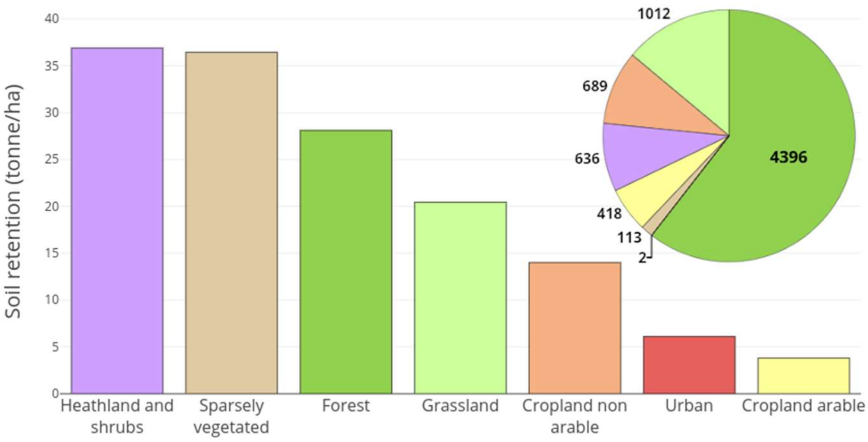
The spatial distribution of the actual flow for the EU-28 in 2012 is presented in Figure 4.12. The largest amounts of soil retained (actual flow) are usually found in areas where high demand and high potential to retain soil overlap. For instance, mountainous regions combine both high potential for soil retention (Figure 4.9) and high demand (Figure 4.10), resulting in high amounts of soil retained by ecosystems. Other areas such as northern European countries, despite having a high soil retention potential, show low values of actual flow due to the relatively low demand for soil retention. Importantly, flat areas dominated by arable land also show low soil retention because of the low potential to retain soil, but also because of the low demand when compared with hilly regions. Although in Figure 4.12 the amount of soil retained is not visually remarkable, it shows where soil retention is more relevant in economic terms. Only the soil retained by agricultural areas is valued in monetary terms (see Section 4.5).

Figure 4.12. Map of the actual flow of soil retention in the EU-28 in 2012



In the EU-28, about 7 270 million tonnes of soil were retained by ecosystems in 2012. On average in the EU-28, 18.9 tonnes ha^{-1} of soil were retained in 2012, equivalent to retaining 15 cm (28) of soil. This means that, on average, about 2 cm of soil was lost in 2012. Forests provided 60 % of the total service flow (pie chart in Figure 4.13). Forests play an important role because they are frequently located in mountainous areas, where there is higher need for soil retention, but also due to the large extent of this ecosystem type, which covers about 40 % of the whole EU (see Annex MA10). Conversely, cropland accounts for another 40 % of the land surface of soil in the EU, but provides only 15 % of the total soil retention at EU level. In fact, only this 15 % of the total actual flow will be valued in monetary terms, which corresponds to 1 115 million tonnes of soil retained in cropland. Within cropland, arable land provides about 38 % of the soil retention, despite occupying almost 70 % of the total extent of this ecosystem. In this sense, arable land presents the lowest rate of soil retention per unit area, with about 4 tonnes/ha of soil retained (Figure 4.13). The ecosystem types with the highest rates of soil retention per unit area are heathland and shrubland, and, surprisingly, sparsely vegetated areas (Figure 4.13). These ecosystem types provide soil retention at high altitudes in mountainous areas, which present a high risk of erosion by water (high demand). This means that if these areas are burnt (as simulated under the worst-case scenario), the amount of soil lost by unit area would be the highest because of the high demand for soil retention in these areas. Therefore, in mountainous areas, even the protection provided by sparsely vegetated land makes an important difference in the prevention of soil loss.

Figure 4.13. Soil retention rates by ecosystem type and pie chart showing the total amount of soil retained by ecosystem type in 2012 in million tonnes



4.4.4. Ecosystem service unmet demand

The total amount of soil retained covers about 88 % of the total ES D for soil retention. This means that the remaining 12 % of the ES D was eroded, showing a soil loss in the EU-28 of 1 020 million tonnes in 2012. This amount of soil loss is very close to the 970 million tonnes estimated by Panagos et al. (2015a). Although we followed the methodology described by Panagos et al. (2015a), some slight differences, such as the use of different input data for crops, were applied (29). A fraction of the soil eroded is compensated by soil formation, and only net soil losses are considered ES unmet demand for soil retention (see Section 2.3). ES unmet demand in 2012 was about 771 million tonnes at an average of 2 tonnes ha^{-1}, which is equivalent to 1 cm (30) of net soil loss. The majority of ES unmet demand is concentrated in the Mediterranean region (Figure 4.14), with very low values of soil erosion in Finland and Sweden (with the exception of the Scandinavian Mountains).

The assessment of the ES unmet demand per ecosystem type is a useful indicator to better understand the performance of ecosystems in retaining soil. If ecosystems are not able to retain the amount of soil that is needed to reduce the risk of erosion, and soil losses are larger than the soil formation rate (unmet demand), soil degradation takes place.

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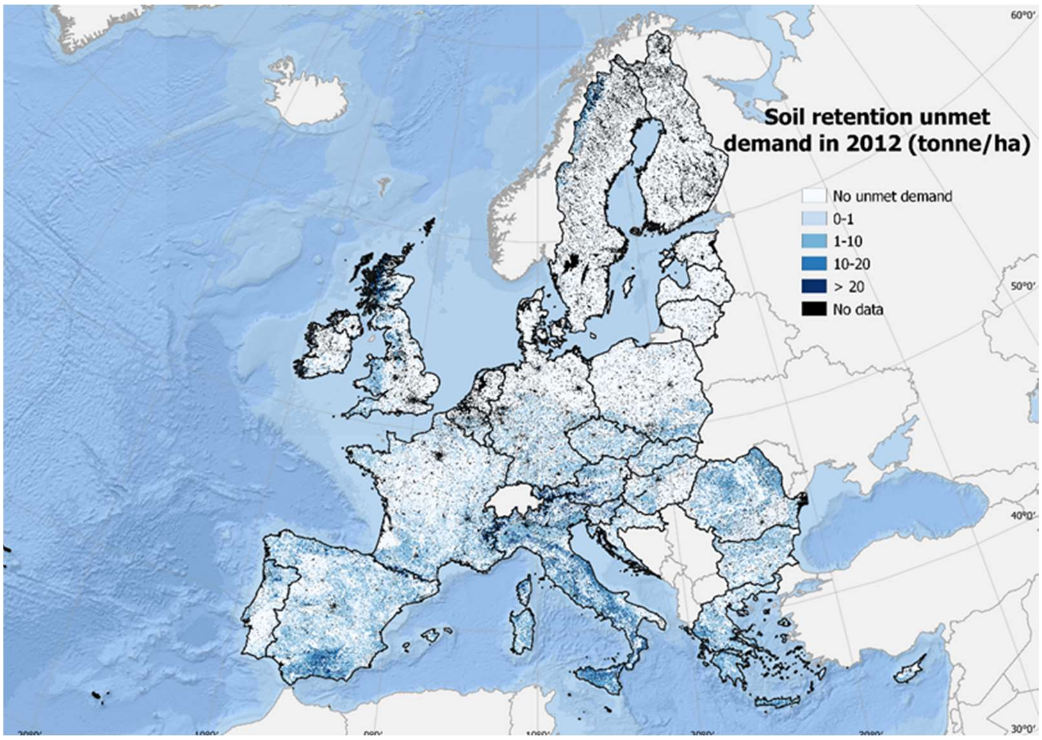
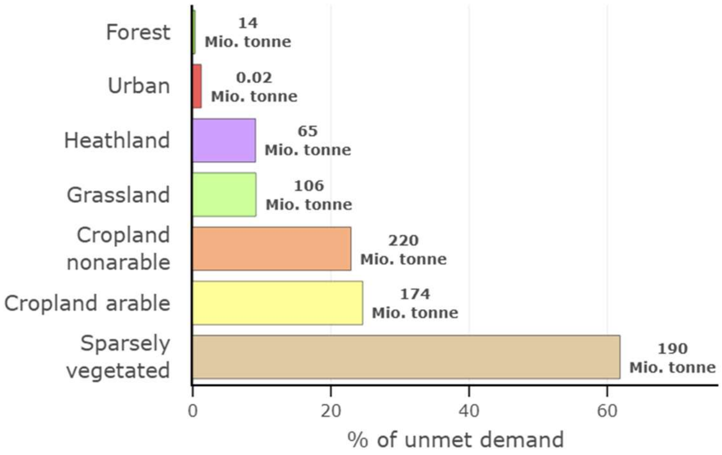
(28) Using the same standard bulk density (1.2 g/cm^3) and unit conversion as in footnote 26.
(29) Differences from the methodology used by Panagos et al. (2015a) are described in Section 4.1.
(30) Using the same standard bulk density (1.2 g/cm^3) and unit conversion as in footnote 26.

Figure 4.14. Soil map of the unmet demand for soil retention in the EU-28 in 2012



The proportions of unmet demand by ecosystem type are shown in Figure 4.15. The Baltic countries (Estonia, Latvia and Lithuania) and Denmark are net gainers of soil: soil formation rates are higher than the levels of soil erosion caused by water. Although sparsely vegetated land retains large amounts of soil per unit area (Figure 4.13), this retention satisfies only 38 % of the total demand, therefore showing high unmet demand (Figure 4.15) and poor performance-retaining soil. The Netherlands, Finland and Sweden are where most of the net soil loss in this ecosystem type is concentrated. After sparsely vegetated land, arable and non-arable cropland show the largest proportions of unmet demand, at 25 % and 23 %, respectively (Figure 4.15). High ES unmet demand for soil retention in cropland is due to the impact of agriculture, which exposes agricultural soils to water erosion. Soil conservation measures in areas with high ES unmet demand could potentially mitigate the impacts of soil loss (Figure 4.14). The unmet demand in cropland could even be larger than that estimated in this study. We assumed a constant soil formation rate across the EU because of the lack of more accurate data; however, soil formation in agricultural areas might be lower due to the impact of agricultural practices on the soil (Parikh and James, 2012).

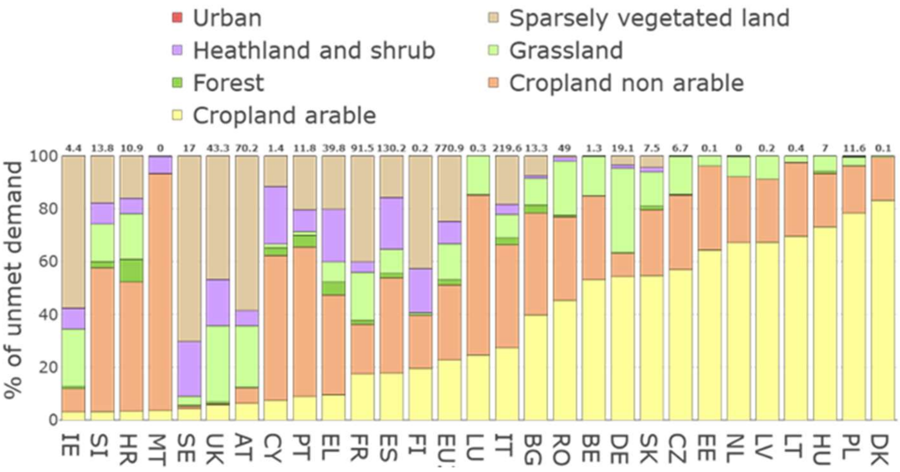
Figure 4.15. Proportions of unmet demand for soil retention by the different ecosystem types in 2012



NB: Values to the right of the bars are the total amount (million tonnes) of unmet demand in each ecosystem type in 2012.

The large share of ES unmet demand in cropland is especially important when looking at the total amount of net soil losses. The poor performance of cropland in retaining soil, together with the large extent of this ecosystem type, covering 28 % of the EU, generates the highest amount of net soil losses at EU level (Figure 4.16). Net soil losses in cropland represent about 51 % of the ES unmet demand at EU level, and cropland is the ecosystem type with the largest total amount of net soil losses in most countries (Figure 4.16). Within cropland, non-arable land is responsible for about 55 % of the ES unmet demand, while arable land accounts for the other 45 %. The proportion of net soil loss in non-arable cropland is particularly high in Croatia, Cyprus and Malta. For Belgium, Czechia, Germany, Hungary, Poland and Slovakia, > 50 % of the net soil loss is located in arable cropland (Figure 4.16). These countries have significant amounts of net soil loss. Denmark, Latvia, Lithuania and the Netherlands also have most net soil loss in arable land, but in much smaller amounts. Austria, Ireland and the United Kingdom also have high concentrations (> 50 %) of net soil losses in sparsely vegetated land.

Figure 4.16. Net soil losses by ecosystem type in the EU-28 in 2012



NB: The values on top of each column represent the total amount (million tonnes) of net soil loss in each Member State in 2012.

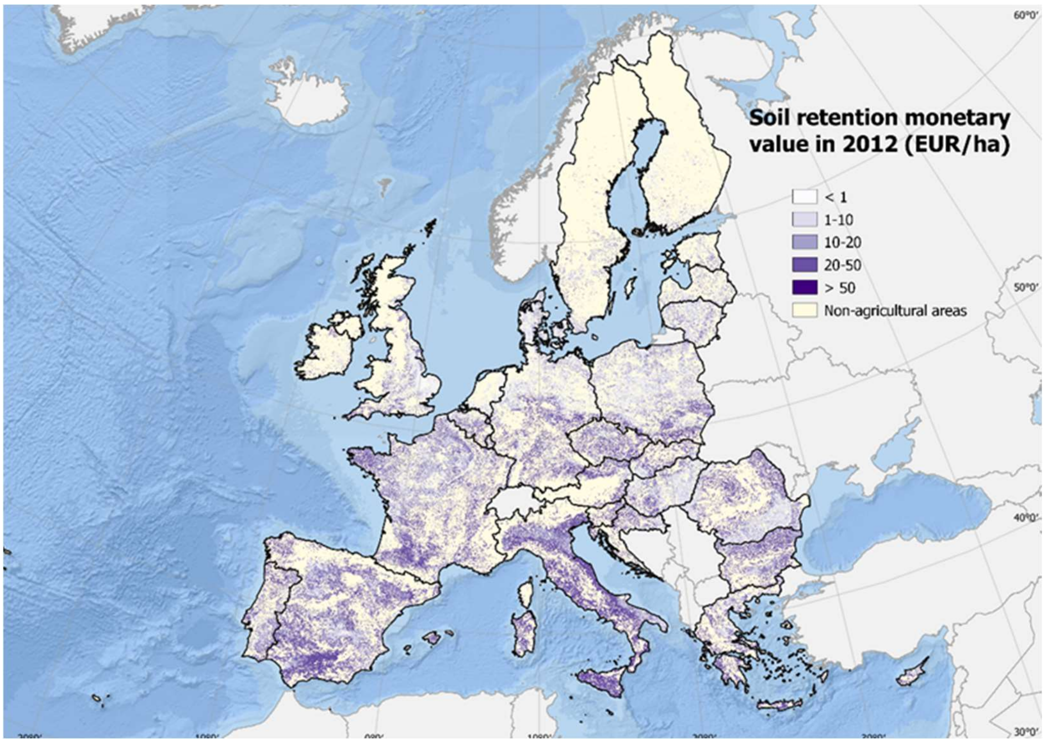
4.4.5. Monetary valuation

When comparing the SUTs in physical terms, only 15 % of the soil retention service provided by ecosystems is directly used in the economic system, specifically by the agricultural sector. The role of ecosystems in terms of on-site soil retention is much larger (the remaining 85 %) than what is perceived by looking only at agricultural activities. It is thus very important to record the whole role of ecosystems, at least in physical terms, to adequately evaluate impacts and consequences of actions and measures meant to act on the soil or to change land use.

The annual flow of EUR 11.5 billion (mapped in Figure 4.17) represents the final service that contributes to agricultural production, but in terms of the role of soil retention it captures only a tiny part of the real value of this service since most of the ecological contribution works in terms of intra-ecosystem flows. However, although it should be acknowledged that the ES actual flow to the agricultural economic sector is only a small part of the overall biophysical flow, this should not be used as an argument to neglect that this flow exists and to neglect valuing and accounting it; this would in fact further underestimate the role of soil in agricultural production.

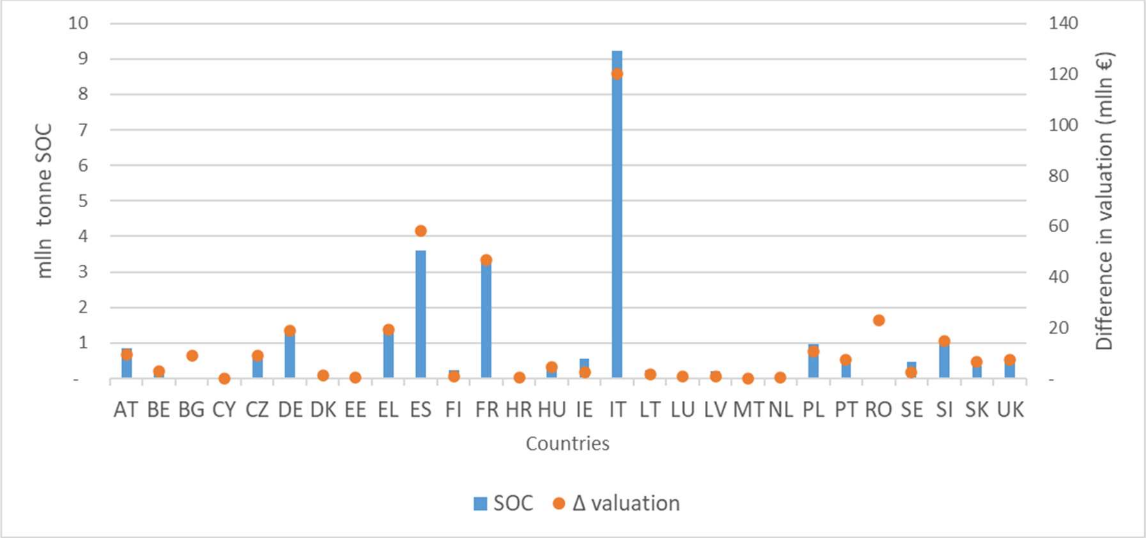
Moreover, it is important to value separately the two components of soil retention: the topsoil layer that captures nutrient components and the residual layers that are used as a proxy for soil structure. The separate valuation of the topsoil layer, as a proxy for fertility, does in effect make a difference. We compared two valuations: (i) the estimation undertaken in this chapter and (ii) an additional estimation in which the same value is attributed to the whole amount in tonnes of soil retention (e.g. the market price of bulk soil). We then calculated the difference between the two (reported as ‘Δ valuation’) and checked how this difference relates to the value of SOC quantified in tonnes (Figure 4.18).

Figure 4.17. Map of the monetary value of soil retention in the EU-28 in 2012



The higher the difference in monetary terms, when attributing a higher value to the topsoil layer, the higher the value of SOC (i.e. the SOC amount in tonnes is quantitatively more in those countries where the monetary value of the topsoil layer is higher). Since SOC influences a range of soil quality aspects of crucial importance to soil functions, with our approach we can detect countries whose annual flow is higher because they are richer in topsoil: the approach adopted highlights quality versus quantity.

Figure 4.18. Comparison showing higher values of soil retention due to the presence of topsoil and SOC



4.4.6. Accounting tables

The SUTs are compiled in biophysical and monetary terms for the soil retention service. Table 4.4 (in physical terms) clearly shows that only the flow generated by cropland enters the economic system. The flows generated by all the other ecosystem types are recorded as inter-ecosystems flows.

Table 4.4. SUT in physical terms

	Economic unit					Ecosystem type						
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Heathland and shrubland	Sparsely vegetated land	**Total**
(1 000 tonnes)												
Supply												
2000						1 861	1 076 861	1 015 492	4 398 103	115 676	115 676	6 723 668
2006						1 849	1 128 730	1 008 860	4 395 854	634 532	111 027	7 280 853
2012						1 873	1 115 392	1 010 190	4 395 439	634 189	113 109	7 270 193
Use												
2000	1 076 861					1 861		1 015 492	4 398 103	115 676	115 676	6 723 668
2006	1 128 730					1 849		1 008 860	4 395 854	634 532	111 027	7 280 853
2012	1 115 392					1 873		1 010 190	4 395 439	634 189	113 109	7 270 193

Table 4.5. SUT in monetary terms

	Economic unit					Ecosystem type						
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Heathland and shrubland	Sparsely vegetated land	**Total**
(million EUR)												
Supply												
2000							11 114					11 114
2006							11 648					11 648
2012							11 512					11 512
Use												
2000	11 114											11 114
2006	11 648											11 648
2012	11 512											11 512

The soil retention service plays, as many other ESs do, an important role not only in terms of the direct contribution to agriculture (which must be appropriately assessed, valued and reported) and, in turn, food production. Its role goes beyond that: by recording intra-ecosystem flows, it will be possible (once a fair number of ES assessments are available) to analyse the resilience and vulnerability of ecosystem types and eventually the correlation with the amount of other ESs they will be able to provide.

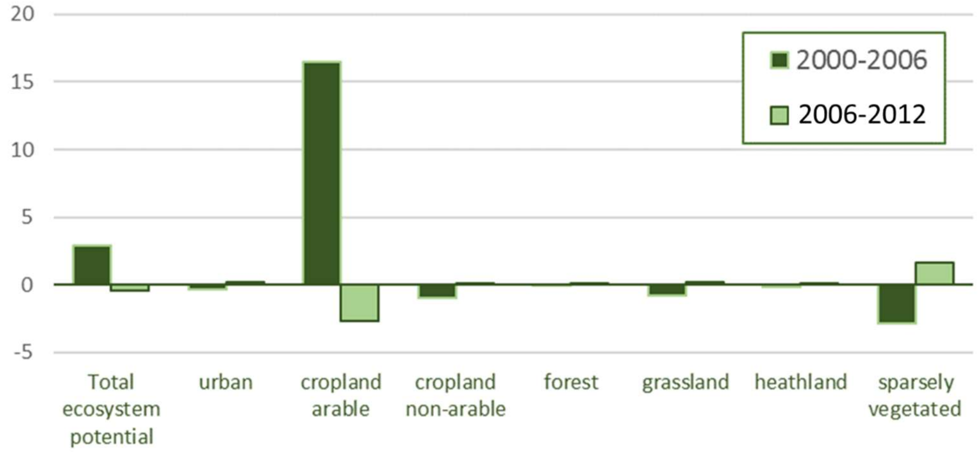
Table 4.5 shows that a monetary value is attributed only to the ES flow that is allocated to an economic unit. In this case, we consider a final service: the role of soil retention is in fact withdrawn from the 'crop provision' service and accounted separately, as theoretically explained in Chapter 2 and empirically reported in Chapter 6. All the other flows, being intra-ecosystem flows, are not final and any attempt to attribute a monetary estimate would risk double counting the value of other final ESs that those ecosystem types can generate.

Annexes AA5–AA16 report SUTs by Member State.

4.4.7. Trend analysis

Changes over time for the years 2000, 2006 and 2012 were analysed. Soil retention potential improved by 2.4 % between 2000 and 2012. This increase was mainly due to the enhancement of soil retention potential in the first period analysed (2000–2006), since between 2006 and 2012 there was a decrease of 0.5 % (Figure 4.19). When looking at changes by ecosystem type, arable land is the ecosystem type showing the most important changes, followed by sparsely vegetated land (Figure 4.19). These changes in arable land are driven by the variables included to model soil retention potential (i.e. complementary of the *C*-factor): vegetation density, crop type and management practices (Table 4.6). For the first period analysed (2000–2006), the increase in the ES P in arable land can be explained only by the implementation of soil conservation measures in 2006, which were not yet in place by 2000 (Table 4.2). For the second period analysed (2006–2012), we assumed no changes in the soil conservation measures because of the lack of data, but shifts in crop composition towards less protective crops, such as grain maize, led to a decrease in soil retention potential in arable land. For other ecosystem types, including non-arable cropland, we find a generalised decrease for the first period, followed by a moderate increase for the second period, in line with the changes in the vegetation cover (Table 4.6).

Figure 4.19. Changes in the overall soil retention potential by ecosystem type (%)



The decrease in vegetation cover (except for arable land) during the first period could be explained by the period of extreme heat and drought in 2003 (Rebetez et al., 2006). In this sense, it is important to consider the indirect effects that climate change might have on soil erosion. Future heat and drought episodes may decrease the ecosystem potential to retain soil by reducing vegetation cover. Moreover, climate change may also increase soil losses in the medium to long term if rainfall intensity increases. This highlights the importance of climate change mitigation and adaptation policies to reduce and cope with soil erosion (Lal et al., 2010). Together with support practices (*P*), land management programmes such as reforestation and soil conservation measures have the most immediate results in terms of enhancing soil retention potential.

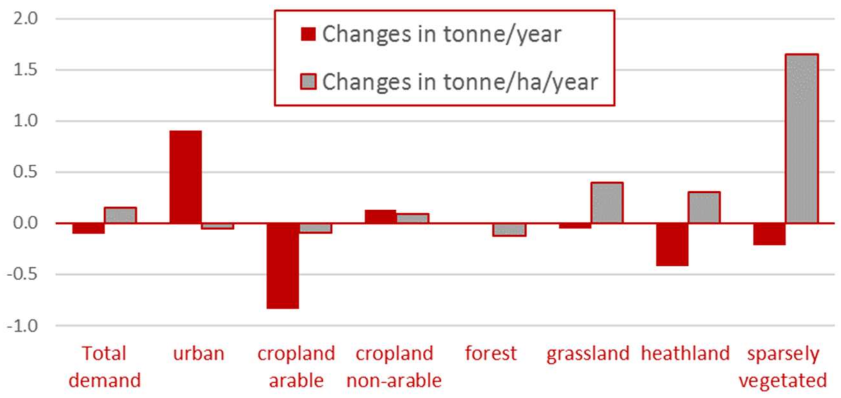
Table 4.6. Changes in input parameters for soil retention potential at EU-28 scale

Period analysed	Vegetation cover (F_{cover}) (non-arable)	Crop type (C_{crop}) (arable)	Management practices ($C_{management}$) (arable)
2000–2006	↓ (– 5.2 %)	↓ (– 2.5 %)	↑ (+ 100 %)
2006–2012	↑ (+ 1.5 %)	↓ (– 7.4 %)	Not available

NB: Red colour indicates negative impacts reducing ES P; green colour indicates increases in soil retention potential.

Contrary to the ES P, the demand for soil retention is quite static over time, with most changes being below 1 % (Figure 4.20). ES D for soil retention is driven by the extent of each type of land cover as well as its risk of erosion. In this sense, the ES D for soil retention in green urban areas increases when measuring demand in absolute terms (tonnes/year) because of the expansion of this ecosystem type from 2000 to 2012. However, changes are negligible when measured in tonnes/hectare (Figure 4.20). Actually, changes in ES D per unit area of ecosystem are especially important for sparsely vegetated land followed by grassland, which shows how the decrease in the extent of these ecosystems has increased their relative share in areas with higher erosion risk (e.g. steep areas), and therefore more measures would be needed to retain soil.

Figure 4.20. Changes in the demand for soil retention at EU level between 2000 and 2012 (%)



Soil retention by ecosystems increased by nearly 24 million tonnes between 2000 and 2012, a slight increase of 0.34 %. This increase is due to the increase in soil retention in arable cropland, which increased by 15 % between 2000 and 2006 as a consequence of the increased implementation of soil conservation measures (Figure 4.21).

Figure 4.21. Changes in the amount of soil retained by ecosystems at EU level between 2000 and 2012 (%)

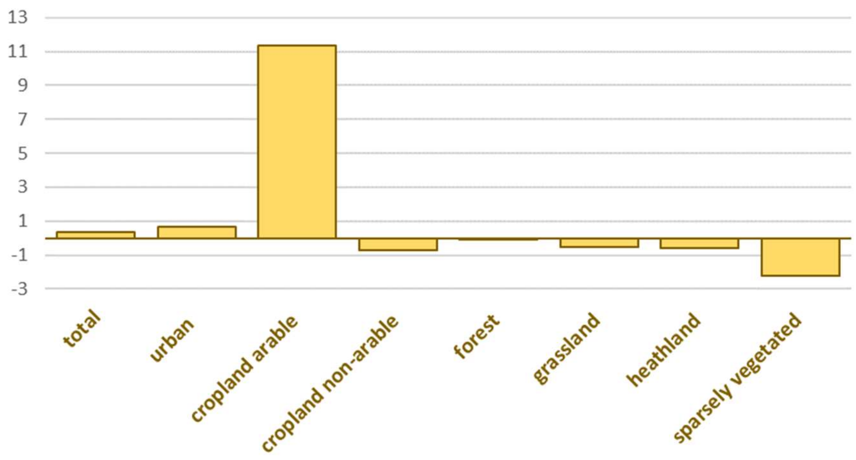
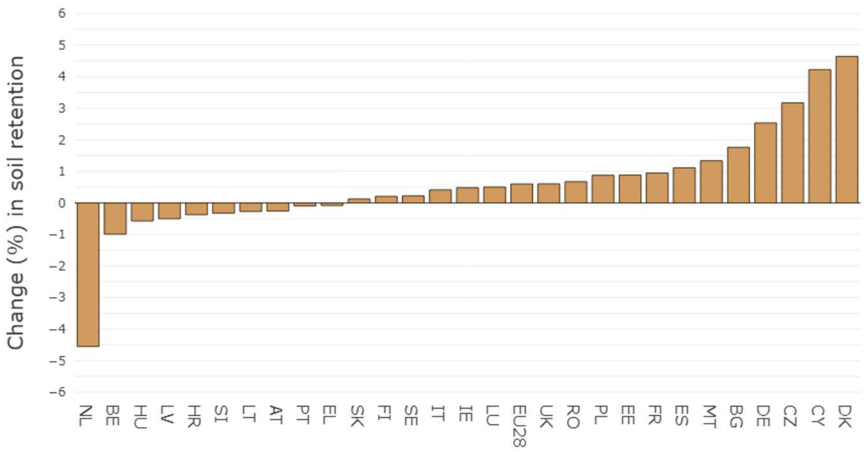


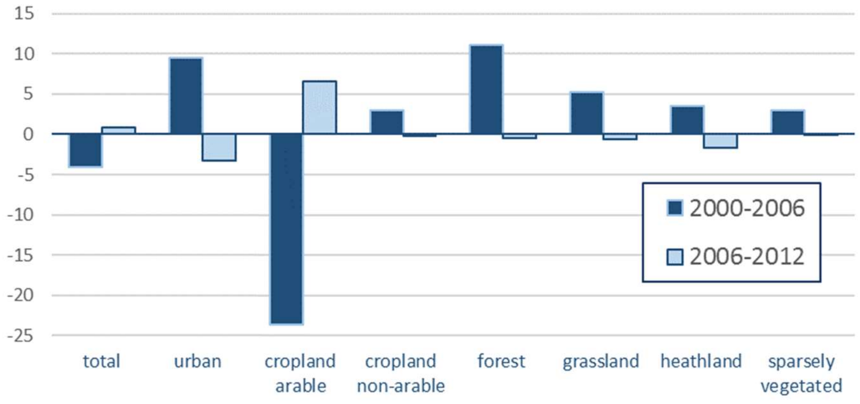
Figure 4.22 shows the change (%) in soil retention in EU-28 Member States between 2000 and 2012. Changes in the actual flow are mainly explained by changes in the ES P following exactly the same trends. Denmark was the country with the largest relative increase (4.64 %) in soil retention between 2000 and 2012. The Netherlands, on the other hand, had the largest drop in soil retention during the same period, with a decrease of 4.55 %. In both cases, these changes are mostly related to changes in the arable cropland potential due to increases or decreases (respectively) in more protective cultivars, as well as the introduction of soil conservation measures. This is the general trend across the EU, where changes in soil retention are mainly limited to arable cropland.

Figure 4.22. Changes in the amount of soil retained at country level between 2000 and 2012 (%)



The ES unmet demand for soil retention was reduced by a gross amount of 27 million tonnes (– 3 %) between 2000 and 2012. As a consequence of the changes in the ES P, and therefore in the ES actual flow, the ES unmet demand was mainly reduced between 2000 and 2006, while there were almost no changes between 2006 and 2012. For this second period, the increase in net soil losses in arable land was compensated by the decrease in net soil losses in the other ecosystem types (due to an improvement in the vegetation cover in this second period; see Table 4.6). It is important to highlight that, without the implementation of new soil conservation measures in arable land, net soil losses can increase if the same trend of cultivating less protective crop types continues (Figure 4.23). Moreover, episodes of heat and drought may have a very relevant impact on natural vegetation, as found between 2000 and 2006. Forests show the largest increase in net soil losses for this period, increasing the ES unmet demand by 11 % (Figure 4.23).

Figure 4.23. Changes in the unmet demand per unit area by ecosystems at EU level (%)



4.5. Limitations and further developments

There are two main limitations of the biophysical model. First, the definition of the reference scenario, which we termed the worst-case scenario, could be considered somewhat arbitrary. Although we have justified our decision to use the largest *C*-factor, which corresponds to the lowest ecosystem potential to retain soil, estimates of the amount of soil retained may vary largely when considering the reference values used by other authors (see Section 2.5). Second, the assessment of the ES unmet demand is based on an average rate of soil formation, considered constant all over Europe. This is a huge assumption, since soil formation rates may vary according to temperature, precipitation and soil typology, among other factors. However, due to the lack of spatially explicit data on soil formation rates, it was not possible to obtain better estimates.

As for all ESs, we used proxies and assumptions to assess soil retention. First, we addressed only on-site soil retention and not off-site soil retention (i.e. sedimentation), the latter of which is also an important ES to be considered and accounted.

Second, we considered only the erosion caused by water and did not include wind and other factors. On-site water erosion represents only a partial accounting of the overall retention service.

Third, in monetary terms we considered only soil retention concerning agricultural production. No assessment was attempted for livestock activities or forestry. Thus, this addresses only a part of the whole ES, which is not explored in all its economic utilisations.

Fourth, the valuation technique is based on market prices of mineral fertilisers only; improved methodologies could introduce different treatments for different fertilisers and include organic fertilisers (e.g. manure and compost), which are currently missing, or consider other agro-ecological measures to provide nutrients (e.g. the use of nitrogen-fixing crops). In addition, the price of bulk soil represents a rough estimate for the soil structure, for which a more sophisticated technique could be employed.

Key messages

- Soil retention was assessed by focusing on the erosion due to the on-site impact of rainfall. The RUSLE was applied to model soil retention as an ES by comparing the current soil retention with the erosion under a hypothetical situation in which protection from ecosystems is not provided. ES actual flow was quantified as the amount of soil retained when comparing the two situations.
- When soil retention flow takes place on cropland, then the flow contributes to supporting agricultural production and represents a transaction between ecosystem types and economic units. When soil retention takes place in other ecosystem types, it is accounted as an intra-ecosystem flow.
- In the EU-28, about 7 270 million tonnes of soil was retained by ecosystems in 2012. On average, about 2 cm of soil was lost in 2012 than 2006.
- Retained soil covers about 88 % of the total ES D. The remaining 12 % is eroded, showing a soil loss in the EU-28 of 1 020 million tonnes in 2012.
- Soil retention provides an annual flow of EUR 11.5 billion. It represents the ecological contribution to agricultural production, but in terms of overall soil retention it captures only 15 % of the total value of this service since most of the ecological contribution consists of intra-ecosystem flows.

5. Water purification

Water purification as an ES refers to the removal of pollutants from water that is mediated by microorganisms, algae and plants and other ecosystem processes such as filtration and sequestration. In the Millennium Ecosystem Assessment (2005), water purification and waste treatment are considered a benefit obtained from the ecosystem processes that contributes to human well-being by providing clean water. The service refers to the intrinsic self-purification capacity of the ecosystems to filter out and decompose organic waste and pathogens introduced into terrestrial and water ecosystems. In TEEB (2010), the service is categorised mainly as wastewater treatment, which refers to the capacity of the microorganisms in soil and in wetlands to detoxify pollutants and decompose human and animal waste. In IPBES (Diaz et al., 2018), the water purification service is included mainly in the reporting category of nature's contributions to people – 'Regulation of freshwater and coastal water quality' (examples are the regulation by ecosystems or particular organisms of the quality of water by filtration of particles, pathogens, excess nutrients and other chemicals). Finally, in CICES version 5.1, the service of water purification is among the regulating and maintenance (biotic) services, classified in the groups 'Mediation of wastes or toxic substances of anthropogenic origins by living processes' and 'Water conditions'. Indeed, CICES version 5.1 mentions as examples the filtration by macrophytes under the first group and makes reference to the removal of nutrients in buffer strips along water courses in the second group. However, it has been noted that, for bioremediation and water quality maintenance services, there are overlapping classes in CICES that are hard to discriminate in a practical assessment context (Czúcz et al., 2018).

The service of water purification is associated with the need for high water quality for human well-being and ecosystem health. Water quality requirements are generally defined according to specific water uses, such as drinking, domestic supply, recreational activities, aquaculture, irrigation, livestock and industrial cooling. Sufficient water quality standards are also needed for maintaining the natural habitat and biodiversity of water ecosystems and sustaining aquatic life. Elements impairing water quality can affect its microbiological characteristics, such as the presence of pathogens and coliforms, or alter the chemical composition. Sediments, nutrients, organic matter and metals are naturally present in water, but their excess, due to agricultural practices and human domestic and industrial waste practices, can strongly affect the aquatic environment. Similarly, synthetic chemicals, such as synthetic compounds, plastics, pesticides and pharmaceuticals, once discharged into water, pose harm to human and ecosystem health.

Different processes contribute to the purification of water, depending on the type of pollutant and the ecosystem component involved. Water purification can take place in soils, groundwater, wetlands, rivers, lakes, estuaries and coastal and marine environments. Indeed, in a river basin the fate of pollutants depends on the processes of transport and transformation associated with the hydrological cycle. In soils, chemicals and organic matter dissolved in water can be decomposed by fungi and bacteria. Vegetation in forests, natural grassland and wetlands has the important role of slowing the movement of water, facilitating biological processes. Metals, sediments and chemicals are filtered out and absorbed by soil particles in wetlands and riparian areas. Some plants and macrophytes also have the capacity to uptake toxic compounds, improving water quality. Pathogens are degraded by microorganisms in soils and groundwater. The concentration of nutrients (nitrogen and phosphorus) can be reduced by algae and plant uptake in aquatic ecosystems and wetlands. In particular, nitrogen is lost to the atmosphere by the process of denitrification performed by bacteria in anoxic conditions (Saunders and Kalff, 2001), which can occur in soils, wetlands, groundwater, hyporheic zones and riparian areas, and in sediments and the water columns of lakes, estuaries and large rivers (Seitzinger et al., 2006).

Water purification accounting is undertaken by identifying and quantifying the proxy to be used for the biophysical assessment (Section 5.1), choosing the valuation technique that best translates it in monetary terms (Section 5.2) and allocating the results in SUTs (Section 5.3). These steps are described in this chapter together with their limitations.

5.1. Biophysical assessment

In large-scale assessments, nitrogen retention has been adopted as a proxy to quantify the service of water purification (La Notte et al., 2015; Liquete et al., 2015; Grizzetti et al., 2019). Nitrogen retention can be assessed as the removal of nitrogen from the water system (Howarth et al., 1996; Billen et al., 2012). One of the reasons for this choice is the widespread problem of excessive nitrogen (and phosphorus) loadings to aquatic ecosystems, which cause the disproportionate growth of algal biomass and consequent hypoxia and collapse of the ecosystem (Howarth et al., 2011). This phenomenon of eutrophication has been observed in estuaries and coastal waters, and can occur also in shallow lakes and large river reaches receiving high anthropogenic nutrient loads from the river basin, from both diffuse sources (agriculture) and point sources (discharges from wastewater treatment plants, industries and urban sewage) (Diaz et al., 2018). A high nitrate concentration in groundwater, mostly due to an excessive use of nitrogen fertilisers in agriculture, also impairs water quality for drinking purposes. Assessing nitrogen retention in the water system implies computing the nitrogen budget (input minus output) at the relevant spatial and temporal scale.

Hydrological and biogeochemical catchment models are appropriate tools for assessing ESs related to water, as they can take into consideration the sources and location of pollution, the hydrological processes and their different pathways. They can also enable the effects of land use, management practices and climate changes on water quality to be predicted (Brauman et al., 2007; Vigerstol and Aukema, 2011; Guswa et al., 2014). However, their application can be demanding in terms of data, processing time and expertise (Vigerstol and Aukema, 2011).

5.1.1. The GREEN model

The geospatial regression equation for European nutrient losses (GREEN) is a statistical model developed to estimate nitrogen and phosphorus fluxes in surface water in large river basins (Grizzetti et al., 2012, 2015). For this study, we used the results presented in Grizzetti et al. (2021). Table 5.1 provides a summary of all input data used throughout the whole assessment process.

Table 5.1. Input data used to account for water purification

Name		Spatial resolution	Temporal resolution
Total agricultural area, mineral and manure fertiliser application, crop fixation	CAPRI model[31]	CAPRI NUTS 2 regions	Annual data (2005–2012)
	Food and Agriculture Organization of the United Nations[32], for European countries not covered by CAPRI	Country	Annual data (2005–2012)
Total nitrogen atmospheric deposition	European monitoring and evaluation programme model[33]	European monitoring and evaluation programme (EMEP), 0.1° × 0.1° longitude–latitude grid (EMEP01deg)	Annual data (2005–2012)
Nitrogen inputs to surface waters from domestic waste (urban WWTPs and scattered dwellings)	Information reported by EU Member States under the urban wastewater treatment directive (Vigiak et al., 2020)	Country	Annual value for the reference period (2014–2015)
Nitrogen inputs to surface waters from industrial discharges	European Pollutant Release and Transfer Register[34]	Reported point emissions	Average of annual data available for the 2010s
Land cover	CLC map (CLC, 2012)	100 × 100 m	2006 and 2012
	Climate change initiative land cover map[35] for European countries not covered by the CLC	300 × 300 m	Annual data (2005–2012)

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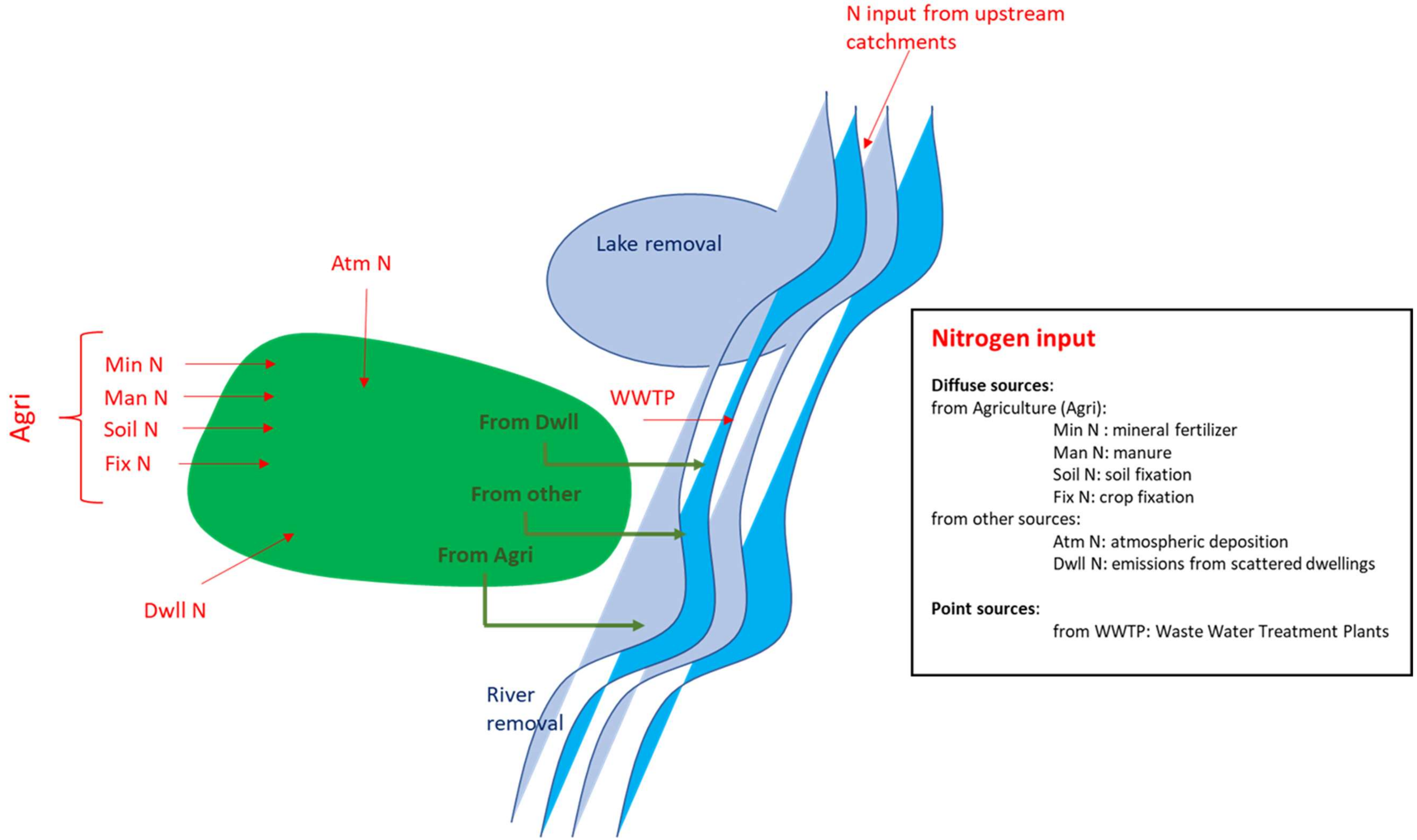
[31] https://www.capri-model.org/dokuwiki/doku.php
[32] https://www.fao.org/faostat/en/#data
[33] https://www.emep.int/
[34] https://industry.eea.europa.eu/
[35] https://www.esa-landcover-cci.org/

Figure 5.1. Summary of the flows extracted from the GREEN model



Nitrogen input

Diffuse sources:
from Agriculture (Agri):
Min N : mineral fertilizer
Man N: manure
Soil N: soil fixation
Fix N: crop fixation
from other sources:
Atm N: atmospheric deposition
Dwll N: emissions from scattered dwellings

Point sources:
from WWTP: Waste Water Treatment Plants

The model covers the European continent and uses catchments as spatial assessment units (669 175 catchments covering the EU-28; each catchment has an average surface area of about 7 km^2). The catchments are connected according to the river network structure. The model considers inputs of nitrogen from diffuse sources in the agriculture sector (mineral fertiliser (Min N) application, manure (Man N), soil (Soil N) and crop fixation (Fix N)), scattered dwellings (Dwll N), atmospheric deposition (Atm N), and point sources from households and industry (wastewater treatment plants (WWTPs). A proportion of the diffuse nitrogen sources reaches the surface water following run-off or leaching through soils and groundwater to the river system. However, crop uptake and retention processes such as denitrification remove large amounts of nitrogen before it reaches the river system.

This fraction of diffuse nitrogen sources together with the point sources define the total nitrogen input to the surface water. In surface water, nitrogen is retained through uptake by algae and water plants, denitrification and sedimentation. Figure 5.1 summarises the main flows captured by GREEN per catchment: (i) nitrogen input to the basin, (ii) nitrogen input that flows from the basin to rivers and lakes, (iii) nitrogen input that enters rivers and lakes directly, and (iv) nitrogen input that flows from upstream sub catchments.

For every catchment, the model estimates the nitrogen load at the catchment outlet and the nitrogen retention:

$$Li = (1 - LRi) \times (1 - RRi) \times (DSi \times (1 - BRi) + PSi + Ui)) \qquad \text{(Equation 5.1)}$$

where *Li* is the nitrogen load leaving the catchment *i* (103 kg N year^{-1}); *DSi* is the sum of the diffuse sources (103 kg N year^{-1}); *PSi* is the sum of the point sources (103 kg N year^{-1}); *Ui* is the nitrogen load received from upstream catchments (103 kg N year^{-1}); *BRi* is the basin retention (the aggregated retention taking place in soil and groundwater) (fraction, dimensionless); *RRi* is the river retention (fraction, dimensionless); and *LRi* is the lake retention (if lakes are present in the catchment) (fraction, dimensionless).

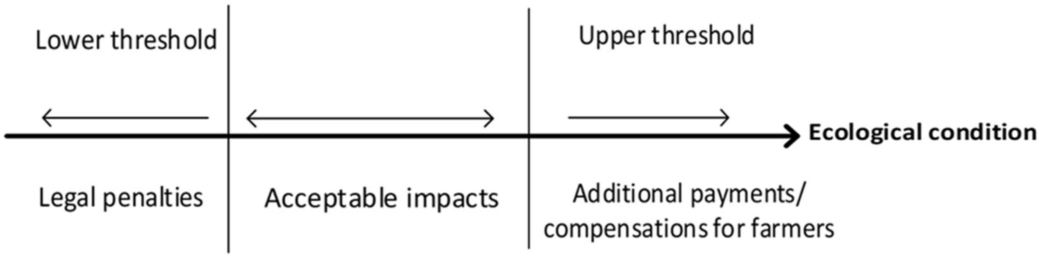
Basin retention (*BRi*) and river retention (*RRi*) are estimated as functions of rainfall and river length in the catchment, respectively. The retention occurring in lakes (*LRi*) is computed according to Kronvang et al. (2004). Nitrogen retention in surface waters is the sum of river and lake retention (103 kg N year^{-1}). For more details of the model parameterisation and calibration, see Grizzetti et al. (2012, 2021)).

For this study, the model presented in Grizzetti et al. (2021) was applied considering the land cover and nitrogen inputs of two years, 2006 and 2012, but under the weather and hydrological conditions in 2012, to make the comparison of nitrogen retention between the two years less dependent on the hydrological conditions.

5.1.2. Addition to the GREEN model

Nitrogen retention is a good proxy to represent the actual flow for the water purification service. While the meaning of the actual flow is consistent and understandable from an accounting point of view, it does not provide the full story, especially when policymakers are interested in sustainability issues. In fact, ecosystems may be able to remove nitrogen beyond their sustainability thresholds: the actual flow alone is not able to provide information about the level of degradation of ecosystems. For this reason, we reprocess the actual flow by considering how much it diverges from a sustainable nitrogen load (i.e. when ES overuse occurs). To compute water purification overuse, we need to refer to a sustainability threshold, as explained in La Notte et al. (2017, 2019) and also briefly mentioned in the SEEA EA (UN, 2021). This threshold can range from a lower level that can at least guarantee not incurring legal penalties to higher levels in which the aim is to improve the ecological condition (Figure 5.2). This can be key information for informing policies that, especially in the agricultural sector, aim to support sustainable practices.

Figure 5.2. Visual simplification of possible sustainability threshold ranges



To calculate the nitrogen load, we applied Equation 5.2 with reference to La Notte et al. (2012). We defined the critical nitrogen load for rivers (L_{crit}) as the load corresponding to a nitrogen concentration threshold above which the aquatic ecosystems may be adversely affected. We substituted the nitrogen loading Li with L_{crit} in Equation 5.1 and solved as follows:

$$N_{crit} = L_{crit} \times RRi \times (1 - RRi) - 1 \qquad \text{(Equation 5.2)}$$

where N_{crit} is the critical nitrogen removal by the river network assuming a critical loading L_{crit}; and RRi is the river retention coefficient (as a proportion).

5.2. Monetary valuation

GREEN provides the actual flow of water purification in terms of nitrogen removal. We need to translate this physical outcome into monetary terms. The most important criterion driving the choice of valuation technique to be used to value water purification is its ability to translate in monetary terms any change occurring in the biophysical model driven by human pressure. When looking at the literature, the biophysical model–economic measures and accounts nexus is evident in many studies, such as those by Duku et al. (2015) and Pedro-Monzonís et al. (2016), which on the one hand describe the pathway to accounting, but on the other hand stress the difficulty of providing monetary valuation of water purification services.

Valuation techniques that may be applicable to water purification are:

- production function (or cost function) – values service flow as an input to the production of a (market) good or service;
- avoided damage and preventive measure costs – values service flow based on production losses or damage if ES provision is impaired or lost;
- replacement cost – values service flow based on the cost of replacing it through alternative (synthetic) assets.

A production or cost function analysis is a conceptually appealing approach since it directly links a service flow (e.g. raw quality) to a specific use (e.g. public water supply) and associated benefits. The service flow is, therefore, valued in relation to other factor inputs (i.e. the output or cost of water supply is a function of the cost of treatment, which in turn is determined by raw water quality). Application of the approach, however, requires an understanding of how water utilities manage and operate treatment processes in order to ensure that public water supplies meet drinking water standards (e.g. the World Health Organization recommendation of 50 mg/l of nitrate, which underpins national legislation). Examples of factors to consider include whether nitrate removal processes are in place, how raw water inputs may be blended from low- and high-nitrate sources, and threshold concentration levels above which new equipment is required to remove nitrates (and/or other pollutants). Publicly available data are likely to be limited and, if analyses are available, they may not be generalisable to a (national) ecosystem accounting level due to location-specific factors.

Production cost methods require the availability of production inputs (e.g. cleaned water) over time and the modelling strategy needs to disentangle the marginal changes in output due to the water purification service. Onofri et al. (2017) present an example of this approach but econometric identification problems, availability of data and intrasectorial effects might have an impact on the economic value. It is likely that this method will play an important role in valuing water purification services as more data become available, although single-industry costs are frequently kept private and aggregation error might undermine the reliability of water purification services.

Avoided damage costs are spatially sensitive and dependent on the receptors and uses of water within a specific catchment. There is also some overlap with the production function approach. The damage costs for the public water supply are the (additional) treatment costs that are required to ensure that drinking water standards are met. Again, this is a local-level issue – not all treatment works operate in catchments with nitrate concentrations that require additional levels of investment for removal.

Borrego-Marín, Gutiérrez-Martín and Berbel (2016) proposed a cost recovery approach for valuing water services. The recovery costs for water services are reported at EU level and the authors suggest using a partitioning system based on SNA water players to estimate water measures. However, they acknowledge that this approach is not viable for accounting for diffuse pollution as the existing cost recovery instruments do not include important pollutants such as nitrogen and phosphate.

Preventive cost methods such as the set of farmers' activities presented in Collins et al. (2018) determine the investments needed to minimise the diffuse water pollution from the agricultural sector. In this case, the investment needed to prevent the loss of water purification services represents the market value of the service. However, this value can underestimate the transition costs for farmers and can overestimate the nutrients' management options as the multiefficacy of combined technologies is not taken into account. A similar approach is proposed by Shrestha, Hurley and Wemple (2018), in which the cost of installing in-house preventive technologies is covered by households. In this case, the loss of water purification services leads to lower water quality, which is moderated by installing technologies. Considering preventive costs from polluting sectors or final users can represent a strategy for valuing water purification services, but it is likely that estimates will mainly reflect the availability of technologies, agricultural management practices and household education and wealth. In terms of accounting, the costs of these 'preventive' technologies are already included in the SNA, and accounting in the water ES might lead to double counting.

The replacement cost approach is potentially more generalisable. This is because it is not necessarily concerned with a specific use and – in the context of nitrogen removal – can be broadly aligned with public policy objectives, such as reducing input loads to water bodies to protect aquatic habitats and species. Indeed, as noted above, options for 'replacing' nutrient retention are effectively concerned with reducing nitrogen inputs in terrestrial or aquatic ecosystems. This is the emphasis of the previous analysis for water purification, in which nitrogen retention was 'replaced' by preventing the load from entering water bodies through constructed wetland (CW). Taking a wider perspective, nitrogen can be removed from the nitrogen cycle at various points, including – for example – by reducing agricultural inputs (reducing run-off and leaching), by reducing atmospheric emissions (reducing deposition) and through treatment of wastewater effluent (reducing point source emissions to water bodies). If the requirement is to value the water purification service based on options for reducing/removing nitrogen loads, this perspective suggests that a wide set of measures can be considered potential candidates for replacement costs.

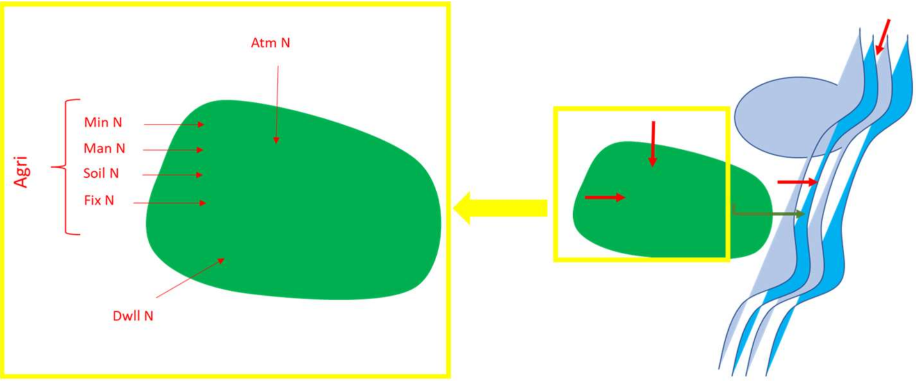
The replacement cost approach is the most popular technique for accounting for water purification. Grossman (2012) employed this approach to identify the set of measures that minimise the costs of water purification in the River Elbe. Glen et al. (2008) considered the cost of diverse land management strategies to reduce nitrites and phosphate in the Baltic Sea. The study tackled the costs of point and diffuse pollution sources. Aspects particularly relevant for valuing water purification services were the transboundary aspect of the hydrological systems, variations in land and industry discharge policies, and the chain of effects on water retention function. The paper stressed the importance of considering a multisectorial approach to account for the total costs of nutrient loss and phosphate costs. In La Notte et al. (2017), the explicit target of the valuation was the service flow – effectively nitrogen removal by water bodies as an indicator of water purification – rather than the benefit(s) derived from the service (i.e. clean water). This is consistent with the application of the SEEA EEA conceptual framework for ES accounts at the SUT level. The underlying assumption is that if water bodies are not able to provide a nitrogen retention function, an artificial replacement is required to maintain the water purification service. CW is selected as the substitute technology. This is judged to be the most appropriate alternative since a CW performs a similar function to aquatic ecosystems. In contrast, WWTPs – the other option identified – are not applicable to diffuse sources (agriculture and run-off) and are designed to treat household and industrial wastewater with higher concentrations of nitrogen (i.e. for efficient removal). Replacement cost estimates are calculated based on the equivalent CW area that would remove the same amount of nitrogen estimated to be retained within each sub catchment. Estimates are differentiated by various CW technologies. The first technology considered is a 'free water surface' (FWS) system, which is applied for nitrogen inputs from diffuse sources; the second technology considered is a 'horizontal subsurface flow' (HF) system, which is applied for inputs from point sources. A range of cost sensitivities is factored in for variance in construction, material and labour costs across both scale (CW area) and European countries. Land purchase costs are excluded from the main analyses due to lack of data.

In this application, we apply the replacement cost, based on CW. In addition to river and lake retention (as described in La Notte et al., 2017), we estimate a value for basin retention that also includes crop uptake. Regarding the latter, the role played by basin retention in water purification should not be confused with 'crop provision'. When we consider the purification service, we are referring here to the removal of nitrogen, which in the case of crop uptake is undertaken by plants. The use of fertiliser (whether mineral or manure) constitutes a human input and cannot be part of any ES, whether crop provision or soil retention (when disentangled from crop provision), which considers only ecosystem contribution. In this respect, there is no risk of overlapping or misplacing any ES flow. On the other hand, we need to be careful with the definitions used as, when it comes to basin retention, crop uptake should not be considered 'pollution'.

5.2.1. Constructed wetland: free water system for basin retention

For basin retention (Figure 5.3), we consider nitrogen removed within soil and not flowing into freshwater ecosystems. The nitrogen input (i.e. diffuse sources) is from agriculture, atmospheric deposition and scattered dwellings. The valuation procedure requires the estimation of the number of CW hectares equivalent to the amount of nitrogen removed (in tonnes) by the basin, and then the multiplication of the area (in hectares) by the cost per hectare in euro, considering the costs needed to build and maintain the CW.

Figure 5.3. Part of the biophysical model that is assessed through FWS systems for basin retention



FWS systems are densely vegetated basins that contain open water, floating vegetation and emergent plants. FWS systems, like natural wetlands, remove or transform contaminants in water using many different mechanisms, which may consist of physical, chemical or biological processes. Removal of suspended solids is usually a rapid physical process. The major removal mechanisms are sedimentation, aggregation and surface adhesion. Technical details concerning the size and parametrisation of FWS systems are reported in La Notte et al. (2012).

Once the amount of nitrogen removed by ecosystems is 'translated' into hectare of CW, we can consider the cost of building and maintaining the FWS system. The main components of a FWS system are an inlet distribution system, followed by an inlet deep zone to allow the removal of heavier sediments; shallow marsh areas of varying depths (0.4–0.6 m) with wetland vegetation; an outlet deep zone to clarify the final effluent; and an outlet device to control the water level. Based on the cost review reported in La Notte et al. (2012), and including the economy of scale assessment, we apply the following equation:

$$FWS_{cost} = 149.34 \times (Area_{CW})^{0.69} \times 1\,000 \qquad \text{(Equation 5.3)}$$

where 149.34 is the calculated average cost (converted in euro) of building CW on a 10 m^2 surface; 0.69 is the parameter used to consider economy of scale; and $Area_{CW}$ is the outcome of the previous step in which tonnes of nitrogen were converted into hectares of CW. The outcome of Equation 5.3 is the total building cost; Equation 5.4 is applied to calculate a yearly flow:

$$y_{FWS} = \frac{FWS_{cost} * i * (1 + 0.03)^{N}}{(1 + 0.03)^{N - 1}} \qquad \text{(Equation 5.4)}$$

Where y_{FWS} is the yearly flow of the FWS system total building cost, 0.03 is the discount rate and N is the lifetime horizon. For basin retention, we consider a lifetime horizon of 50 years.

Regarding operation and maintenance (O&M) costs, FWS systems have very low intrinsic costs, including the costs of pumping energy, compliance monitoring, maintenance of access roads and berms, harvesting of vegetation and mechanical component repair. Based on the review of costs of wetland systems (36), an O&M cost of EUR 3 850/ha for FWS systems was used. The yearly flow calculated for building costs and the O&M cost can now be summed.

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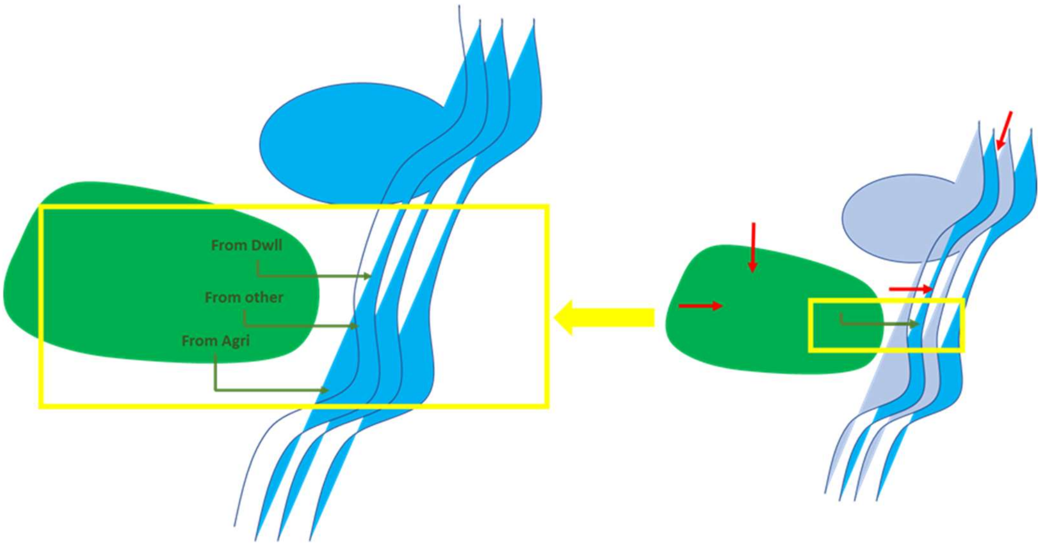
(36) Refer to La Notte et al. (2012), Annex I.

5.2.2. Constructed wetland: free water system for river and lake retention

For river and lake retention of diffuse sources of nitrogen (Figure 5.4), we consider (i) nitrogen not removed within soil and flowing into inland waters, and (ii) nitrogen not removed by upstream inland water catchments. The diffuse sources of nitrogen not removed by the basin are agriculture, atmospheric deposition and scattered dwellings. The valuation procedure remains the same: first, we estimate the number of CW equivalent to the tonnes of nitrogen removed by the basin, and then we multiply the area (in hectares) by the cost per hectare in euro, considering the costs needed to build and maintain the CW.

Figure 5.4. Part of the biophysical model that is assessed through FWS systems for river and lake retention



As in the case of basin retention, the FWS system is used as a proxy for the replacement cost of water purification. There are some differences in the procedure followed. First, in estimating the area in hectares equivalent to the tonnes of nitrogen removed by rivers and lakes, the nitrogen load removed by the FWS system should be proportional to the ratio between non-point and point input sources to the basin (37).

Another difference concerns the FWS system's lifetime horizon: in contrast to basin retention, in the case of river and lake retention we hypothesise a shorter lifetime horizon (in line with natural engineering guidelines concerning CW) of 20 years. This difference can be explained by the fact that the removal rate in the water system can be considered faster than that in the soil system.

We applied the economy of scale and the maintenance costs by replicating the same procedure adopted for basin retention.

5.2.3. Constructed wetland: horizontal flow for river and lake retention

For river and lake retention from point sources (Figure 5.5), we consider (i) nitrogen emissions from (mainly) WWTPs that occur in the catchment and (ii) nitrogen not removed by upstream inland water catchments. Although the valuation procedure remains the same (i.e. first we estimate the number of CW equivalent to the tonnes of nitrogen removed by the basin, and then we multiply the area (in hectares) by the cost per hectare in euro, considering the costs needed to build and maintain the CW), the typology of CW changes.

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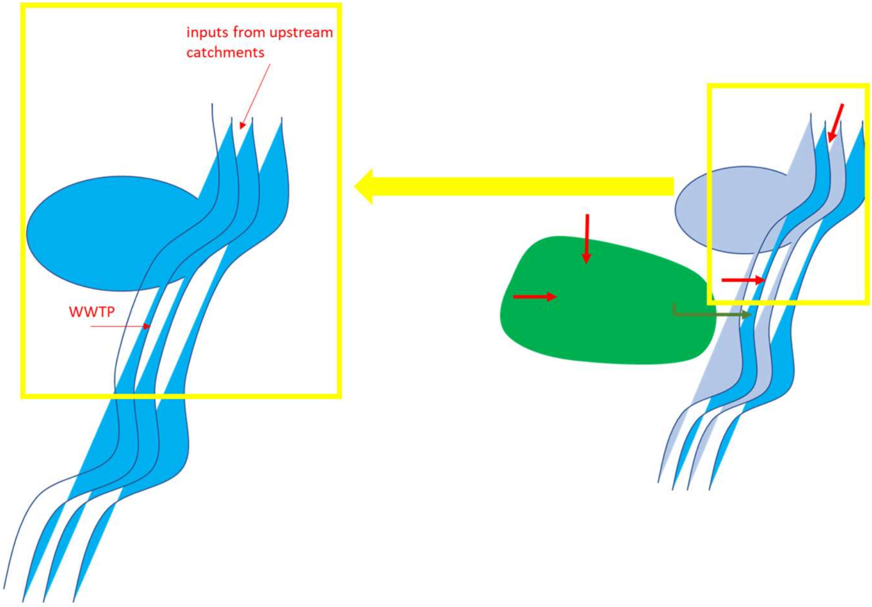
(37) The ratio Ci:Ce of diffuse sources should consider (load at catchment inlet + diffuse input sources to the river) and divide it by (load at catchment inlet + diffuse input sources to the river – % nitrogen removed by FWS × total nitrogen removed by the river).

Figure 5.5. Part of the biophysical model that is assessed through HF systems for river and lake retention



CW has long been used primarily for the treatment of municipal or domestic wastewater. HF CW is commonly used to treat municipal and domestic wastewater as both secondary and tertiary treatment stages. Especially important is the fact that HF CW can successfully treat wastewater with very low concentrations of organic matter and nitrogenous compounds. The major removal mechanism for nitrogen in HF CW is denitrification because, due to its prevalently anoxic conditions, nitrification is limited. Microbial pollution removal is achieved mainly through a combination of physical, chemical and biological factors. Technical details concerning the size and parametrisation of HF systems are reported in La Notte et al. (2012).

Once tonnes of nitrogen are transformed into CW area in hectares, they can be translated into monetary terms. Based on the cost review reported in La Notte et al. (2012), the following equation is applied to calculate the building cost for HF systems:

$$HF_{cost} \ = \ 502.04 \ \times \ (Area_{CW})^{0.704} \ \times \ 1\ 000 \qquad \text{(Equation 5.5)}$$

where 149.34 is the calculated average cost (converted into euro) of building CW on a 10 m^2 surface; 0.69 is the parameter used to consider economy of scale; and *Area*$_{CW}$ is the outcome of the previous step that converted tonnes of nitrogen into hectares of CW. The outcome of Equation 5.5 is the total building cost; Equation 5.6 is applied to calculate a yearly flow:

$$y_{HF} \ = \ \frac{HF_{cost} * i * (1 + 0.03)^{N}}{(1 + 0.03)^{N\,-\,1}} \qquad \text{(Equation 5.6)}$$

where y_{HF} is the yearly flow of the total building costs for the HF system, 0.03 is the discount rate and *N* is the lifetime horizon. Based on literature studies, HF systems are able to operate for at least 15–20 years if properly designed and maintained. For the river and lake retention attributable to point sources, we consider a lifetime horizon of 20 years.

Regarding O&M costs, based on the cost of wetland systems review (38), an O&M cost of EUR 7 700/ha for HF systems was used. The yearly flow calculated for building costs and the O&M cost can now be summed.

5.3. Accounting tables

Water purification is an ES that requires further processing in allocating the actual flow in the supply table and further discussion in allocating the flow in the use table. We first address the supply table.

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(38) Refer to La Notte et al. (2012), Annex I.

In the previous application (La Notte et al., 2017b), we considered only river and lake retention; the allocation to this ecosystem type was straightforward (i.e. 'inland waters', comprising both rivers and lakes). In this application, we also consider basin retention, and this implies that the service flow is allocated to different ecosystem types. This information is not directly provided by the GREEN model, although the model works with major land cover typologies. We thus need to use *ex post* processing for the allocation to ecosystem types as classified in MAES, which still presents major limitations.

To solve the issue of allocation to different ecosystem types, a literature review was undertaken to assess the role of each ecosystem type in retaining nitrogen, based on nitrogen retention estimates, and to allocate the total amount of basin retention to the different ecosystem types in proportion to the role assessed. Nitrogen retention estimates were identified for 13 CLC types (Table 5.2). In total, these land cover types represent approximately 61 % of terrestrial land cover in Europe. Reported values are indicative as variation in nitrogen fluxes are captured within the estimates reported by different studies (see Annex MA11 for the ranges of values used to estimate the averages reported in Table 5.2).

Table 5.2 is based on 'critical load estimates' that represent a threshold for nitrogen input to the environment above which there is a risk of significant harmful effects and damage to habitat quality due to eutrophication or acidification.

Table 5.2. Propaedeutic weights for allocating basin retention to ecosystem types

Ecosystem type	CLC type	% of basin retention at EU level	Estimated average basin retention	Nitrogen retention weights (w_N)
Urban	112. Discontinuous urban fabric	2.1	5	5
Cropland	211. Non-irrigated arable land	16.7	20	18
	242. Complex cultivation patterns	4.1	20	
	243. Agricultural mosaics	3.9	7.5	
Grassland	231. Pastures	5.4	7.5	7.5
	321. Natural grassland	2.9	7.5	
Woodland and forest	311. Broad-leaved forest	7.5	10	10
	312. Coniferous forest	10.2	10	
	313. Mixed forest	4.7	10	
	324. Transitional woodland shrubland	4.6	5	
Heathland and shrubland	322. Moors and heathland	2.2	5	5
Sparsely vegetated land	333. Sparsely vegetated areas	3.3	7.5	7.5
Wetland	412. Peat bogs	1.4	5	5

Estimates are included in Table 5.2 for comparison with nitrogen retention estimates. However, caution is required, since critical loads are mainly estimated in the context of atmospheric deposition of nitrogen and correspond to ecological damage caused by excess nitrogen, rather than export via leaching or surface run-off. As with nitrogen retention estimates, critical loads are ecosystem and location specific, and show a large variation across Europe (Sutton et al., 2011). The main sources used in Table 5.2 are:

- the natural capital project (2016) database – nitrogen retention efficiency estimates (approximately 30 observations);
- Berg et al. (2016) – nutrient removal in coastal watershed (Maine and New Hampshire, United States);
- Sutton et al. (2011) – European nitrogen assessment – nitrogen fixation;
- Van Dobben et al. (2013) – critical loads for nitrogen deposition in Natura 2000 habitats (the Netherlands);
- Achermann and Bobbink (2003) – critical loads for nitrogen.

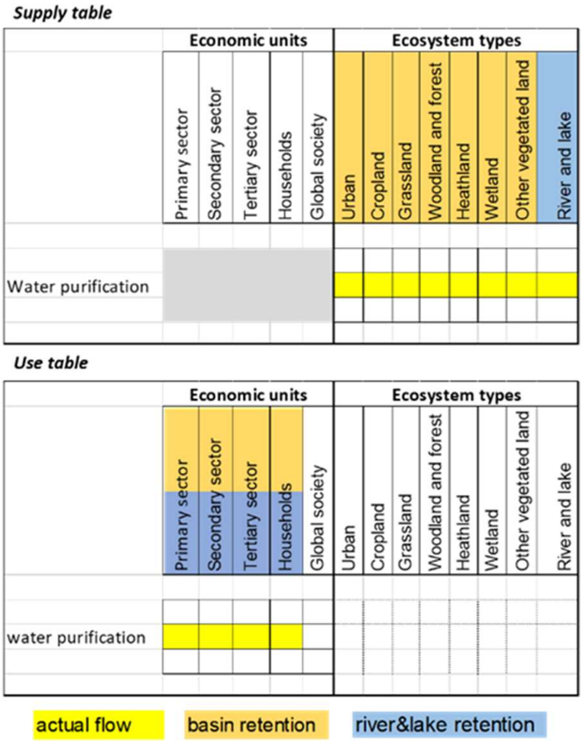
Equation 5.7 illustrates how nitrogen retention weights (w_N) are used:

$$WPflow_{LC} = \frac{ha_i \times w_{Ni}}{\sum_{i=1}^{7}(ha_i \times w_{Ni})} \times ret_{basin} \qquad \text{(Equation 5.7)}$$

where *WPflow$_{LC}$* is the basin retention flow allocated to each of the seven identified land cover classes (*i* = 1,2,...,7) of the overall denitrification computed as basin retention (*ret$_{basin}$*).

Regarding the use table, we base the allocation on the logic that the service is about 'cleaning' rather than 'provisioning', as explained in Chapter 2 (see Section 2.3.2). The metric used for water purification is the amount of the pollutant removed, in this case tonnes of nitrogen removed, rather than cubic metres of water provided for multiple uses. Water supply and water purification are different services meant to carry out different purposes. As shown in La Notte and Marques (2017), the allocation of sink services to polluters allows a variety of policy analysis that otherwise would not be possible, because the cleaning service would become hidden in the provisioning service. Figure 5.6 summarises the structure of SUTs for the water purification service.

Figure 5.6. Water purification flow allocation to SUTs



Specifically, for basin retention all nitrogen emitted by the agricultural sector has been allocated to the primary sector. For river and lake retention, point sources (i.e. WWTPs) are assigned to the secondary and tertiary sectors plus households.

5.4. Results

In this section, we present the results concerning water purification accounts. Biophysical assessment mostly considers the outcomes from the GREEN model (briefly explained in Section 5.1.1) and monetary valuation shows their translation into monetary terms. However, additional analysis is necessary when considering sustainability issues, as explained in this section.

5.4.1. Biophysical assessment of water purification

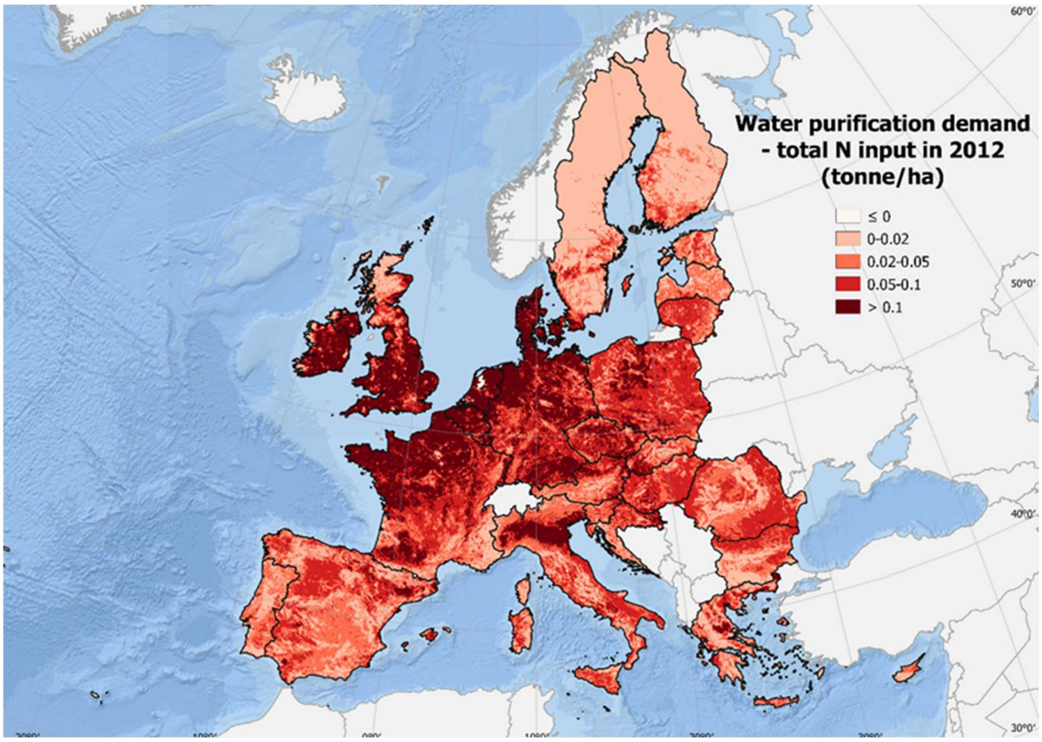
Water purification is a sink service (i.e. its role is to remove pollutants). The demand that generates the flow is thus represented by nitrogen emissions, the proxy we use in this application to estimate this service. As explained in the section dedicated to the GREEN model, sources of nitrogen emissions can be diffuse or point sources. Overall, for Europe, diffuse sources represent the major pressure (about 97 %, compared with 3 % for point sources). Among diffuse sources, those concerning agricultural activities dominate, constituting about 81 % of diffuse sources (Table 5.3).

Table 5.3. Nitrogen input from a variety of sources in the EU-28, year 2012 (tonnes)

Sources	**Agriculture**					**Dwll**	**Atm**	**WWTPs**
	Min N	Man N	Soil N	Fix N	Total			
Total	10 863 684	6 114 040	718 701	1 071 646	18 768 071	84 697	3 766 509	680 744

Figure 5.7 maps the spatial distribution of nitrogen input sources to soil and water (both diffuse and point sources), which represents the ES D for water purification. Countries such as Denmark and the Netherlands, and the north of Italy and considerable areas in Hungary and Poland remain the most polluted areas due to nitrogen pressure.

Figure 5.7. Total nitrogen input in the EU-28, year 2012 (tonnes/ha)



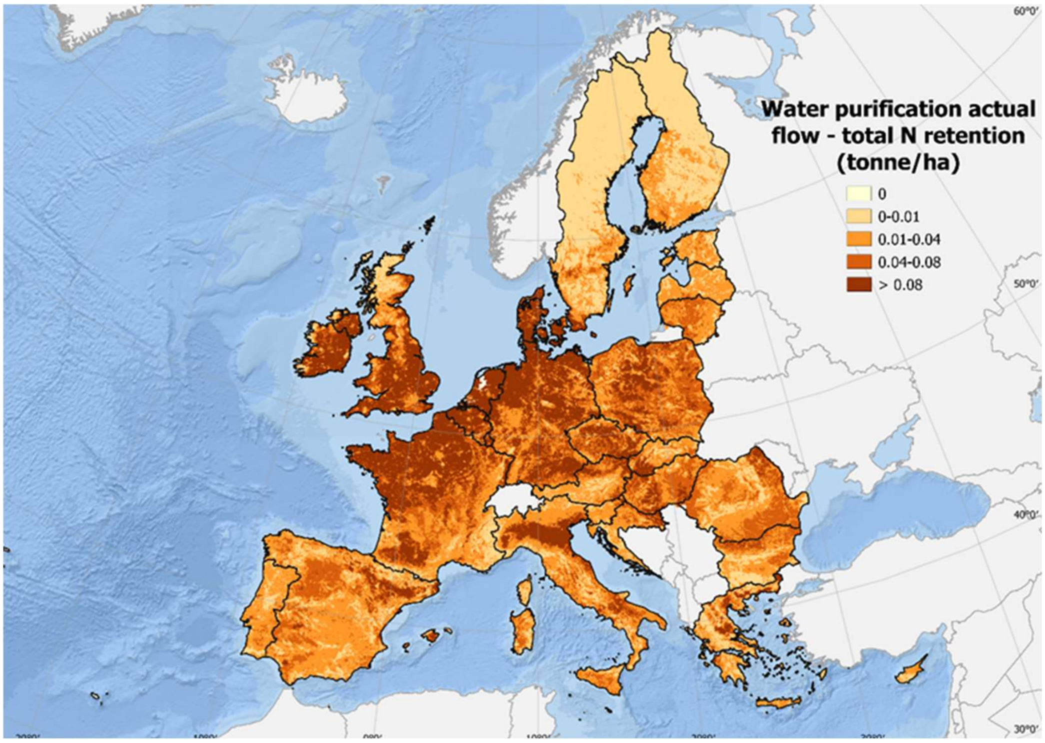
Nitrogen input from most of the diffuse sources is removed through basin retention (about 89 %), which includes crop uptake. Of the total nitrogen that enters rivers and lakes from each sub catchment, 20 % is from point sources (i.e. WWTPs), 53 % is from the agricultural sector and the remainder is from atmospheric deposition and scattered dwellings (Table 5.4). When processing data on rivers and lakes, there is also a flow from upstream sub catchments (i.e. all the nitrogen that was not removed).

Table 5.4. From the basin to the water bodies in the EU-28, year 2012 (tonnes)

Sources	Nitrogen input from basin to river			Nitrogen retained in basin	Nitrogen input from WWTPs	Nitrogen retained in water	
	Agriculture	Other	Dwellings			Rivers	Lakes
Total	1 769 366	842 946	56 464	19 950 501	680 744	131 145	94 801

Figure 5.8 maps total nitrogen retention, which represents the actual flow of water purification, in the EU in 2012. Comparing total nitrogen input with total nitrogen retention shows that, where there is high nitrogen input, there is high nitrogen retention. In fact, we record high nitrogen retention in countries such as Denmark, Hungary, the Netherlands and Poland, and in northern Italy.

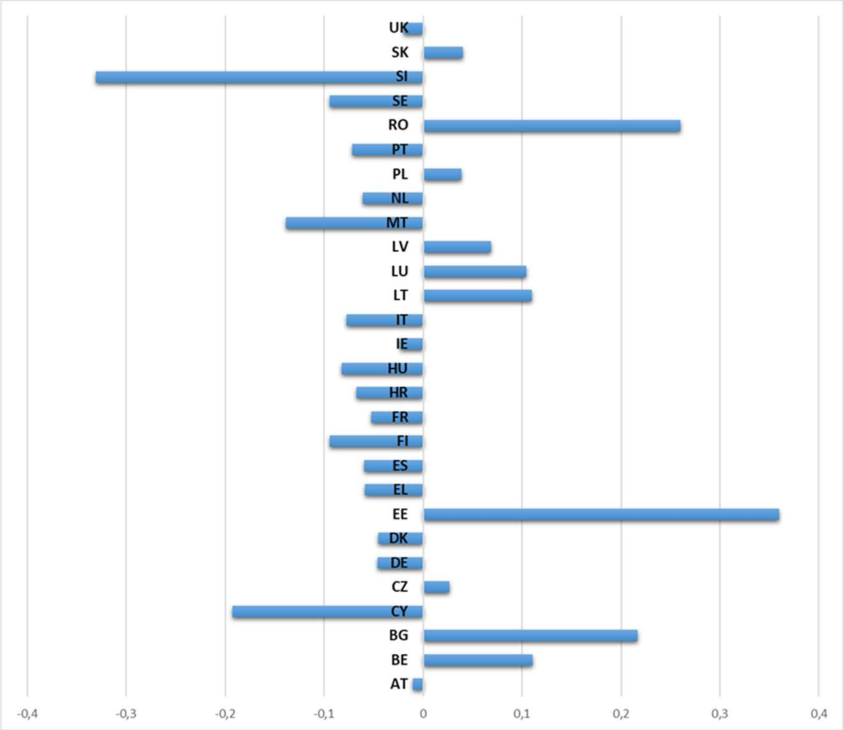
Figure 5.8. Water purification actual flow in the EU-28, year 2012 (tonnes/ha)



Since nitrogen input decreased from 2006 to 2012 by about 2 % across the EU-28, the recorded water purification actual flow also changed, but the changes were not in the same direction in all countries.

Figure 5.9 shows where the actual flow of water purification increased when comparing 2006 and 2012. Positive bars means that nitrogen retention (in absolute terms) increased. Nitrogen input, and in turn the actual flow of water purification, increased mostly in Eastern European countries, such as Bulgaria, Estonia, Poland and Romania.

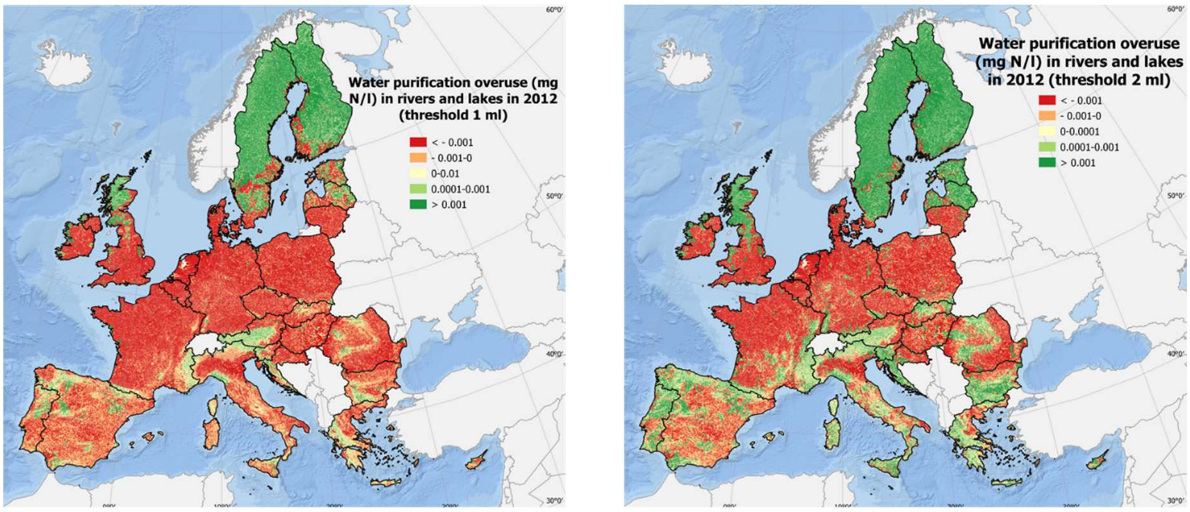
Figure 5.9. Changes in the actual flow of water purification between 2006 and 2012 in the EU-28 (%)



5.4.2. Overuse of water purification with two threshold levels

Comparing Figure 5.7 and Figure 5.8 shows that, the greater the amount of nitrogen input, the greater the water purification service provided. The ES actual flow measures how much ecosystems are working to satisfy human demand, but does not measure whether this workload is sustainable. To provide this information, we attempt to propose sustainability thresholds (i.e. the critical nitrogen concentration) as described in Section 5.1.2. Specifically, we refer to Grizzetti et al. (2017), in which, with reference to the nitrogen pressure in European rivers, the correlation with 'good ecological status' refers to an average concentration of 2 mg N/l and the correlation with 'high ecological status' refers to an average concentration of 1 mg N/l.

Figure 5.10. Water purification overuse in rivers and lakes with different sustainability thresholds



(a) (b)

Figure 5.10 shows water purification overuse for rivers and lakes. As previously explained, overuse is calculated as the difference between the sustainable and actual flows; the sustainable flow depends on the sustainability thresholds applied. In fact, overuse differs according to the threshold used: when referring to 'good ecological status' (Figure 5.10(b)), some countries, such as Bulgaria, Estonia, Croatia, Latvia and Slovenia, do not exceed the sustainability threshold (i.e. 2 mg N/l); when referring to 'high ecological status' (Figure 5.10(a)), only a few countries, such as Finland and Sweden, do not exceed the sustainability threshold (i.e. 1 mg N/l).

Table 5.5 shows an aggregation of water purification overload for all EU Member States except Finland and Sweden (in those countries, we can see there is not an issue regarding sustainability; see Figure 5.10).

Table 5.5. Water purification overuse with respect to nitrogen emissions in physical terms in the EU-26 ([a])

Nitrogen emissions			**Water purification overuse**													
Economic unit			**Economic unit**						**Ecosystem type**							
	Total			Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Woodland and	Grassland	Heathland	Vegetated land	Wetland	Rivers and lakes
(tonnes)			*(tonnes)*													
1 mg N/l																
2006	23.867		2006													135.293
2012	23.338		2012													124.357
2 mg N/l																
2006	23.867		2006													63.562
2012	23.338		2012													52.627

([a]) EU-28 minus Finland and Sweden.

It is very clear that the overuse is much larger when the target is to enhance environmental condition (1 mg N/l, i.e. reach high ecological status), rather than keeping closer to good ecological status (i.e. 2 mg N/l). Considering a sustainability threshold of 1 mg N/l (from 2 mg N/l) generates a change in the ES overuse of about 52 % (from 22 %). It is also very clear that, the lower the nitrogen input, the smaller the gap between a sustainable situation and the current situation: by decreasing the nitrogen input (and thus the actual flow of water purification), it is possible for an area to be placed on a sustainability path. Building an analytical basis that enables policymakers to undertake this kind of analysis is not possible if only the official accounting metric is reported for water purification actual flow. Quantifying the amount of service overuse is necessary and this needs to be appropriately structured.

5.4.3. Monetary valuation of water purification

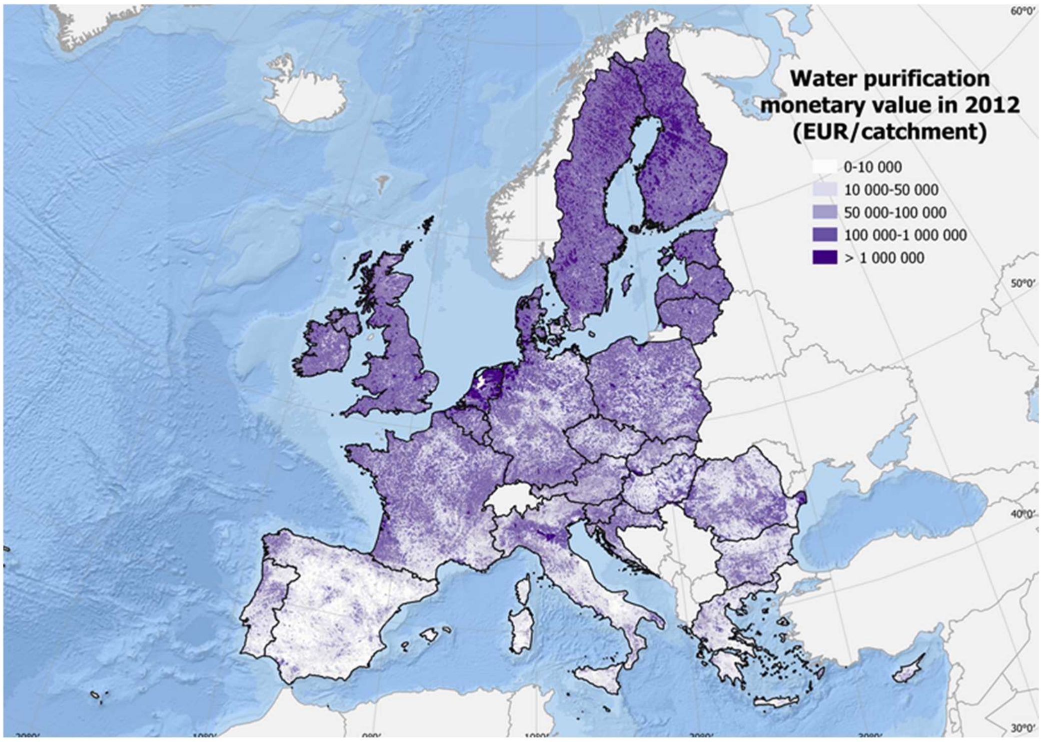
The biophysical assessment of water purification actual flow is translated into monetary terms by applying the replacement cost technique. The results mapped in Figure 5.11 show that the highest values occur where there is a significant amount of nitrogen input and, in turn, a significant amount of nitrogen removal.

These results are not surprising because the valuation technique translates into monetary terms the biophysical outcome. However, in the application of the valuation technique we differentiate the replacement treatments according to their sources and this generates some differences in the estimated values.

It is important to consider that, when translating tonnes of nitrogen into hectares of CW, there is an efficiency coefficient that ensures that more value is attributed to catchments that are able to remove more nitrogen because they are in good condition. This explains why northern European countries have a high value in monetary terms. There are thus two elements that affect monetary valuation: nitrogen input and basin efficiency in removing nitrogen.

Moreover, the application of the replacement cost embedding the economy of scale principle further highlights that, in the monetary valuation, there are several variables that play a role and that cannot be generalised with a single price tag. Examples of such variables are the amount of nitrogen input in relation to the size of the country, rainfall and relative presence of point sources.

Figure 5.11. Value of the actual flow of water purification in the EU-28, year 2012 (EUR)[39]



5.4.4. Accounting for basin and river retention

In this section, water purification accounts are presented in SUTs in physical and monetary terms, aggregated at EU-28 level. SUTs disaggregated by individual country are available in Annexes AA17–AA24.

The use tables show that basin retention plays a very important role, and the supply tables show that, within the basin, cropland is the major land use, where a large part of basin retention takes place. This result is consistent with the fact that cropland is where most fertiliser is used. Based on previous studies comparing land nitrogen budgets in Europe using various modelling approaches (de Vries et al., 2011), about two thirds of basin retention is crop uptake, which does not constitute pollution.

Table 5.6. Supply (a) and use (b) tables for water purification in the EU-28 in physical terms

(a)

	Economic unit					Ecosystem type								
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Woodland and forest	Grassland	Heathland	Vegetated land	Wetland	Rivers and lakes	**Total**
(1 000 tonnes)														
						Basin retention								
2006						517	13 962	3 171	2 431	168	50	75	239	20 614
2012						510	13 822	3 032	2 314	154	45	73	216	20 166

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[39] For a more representative visualization, values are mapped as €/catchment rather than €/km^2

(b)

	Economic unit					Ecosystem type								
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Heathland	Wetland	Other vegetated land	Rivers and lakes	**Total**
(1 000 tonnes)														
2006														
Basin retention	17 066	3 309												
Rivers and lakes retention	236	3.38												
Total	17 302	3 312												20 614
2012														
Basin retention	15 931	4 018												
Rivers and lakes retention	213	3.08												
Total	16 144	4 021												20 166

When considering SUTs in monetary terms, the roles of basin retention and river and lake retention do not change remarkably. A slight difference is recorded for river and lake retention: the change between 2006 and 2012 is about 1 % in physical terms, and is about 5 % in monetary terms. As previously explained, different replacement techniques were applied according to the source of pressure: while diffuse sources (for which the replacement cost of free water systems was used) are more extensive but less demanding in terms of replacement devices, point sources (for which the replacement cost of HF CW was used) are more spatially compressed but more expensive and have higher O&M costs. The importance of point sources risks being hidden in the large numbers involved in basin retention in physical terms, but comes more to light when considering monetary terms.

Table 5.7. Supply (a) and use (b) tables for water purification in the EU-28 in monetary terms

(a)

	Economic unit					Ecosystem type								
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Woodland and forest	Grassland	Heathland	Vegetated land	Wetland	Rivers and lakes	**Total**
(million EUR)														
						Basin retention								
2006						1 094	30 686	15 650	4 242	343	183	349	3 114	55 662
2012						1 105	31 041	15 374	4 128	312	170	330	3 114	55 576

(b)

	Economic unit					Ecosystem type								
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Heathland	Wetland	Other vegetated land	Rivers and lakes	**Total**
(million EUR)														
2006														
Basin retention	35.595	16.953												
Rivers and lakes retention	3.100	14.56												
Total	38.695	16.967												55.662
2012														
Basin retention	35.516	16.946												
Rivers and lakes retention	3.100	14.81												
Total	38.615	16.960												55.576

5.5. Discussion, limitations and future developments

Water purification is an ES that presents many issues in accounting terms.

- It is a sink service characterised by an absorption rate, which can be exceeded; there is a need to confront current service use with a hypothetical sustainable use and eventually assess whether there is overuse. The threshold level will affect the results considerably.
- The critical variable is nitrogen input, which represents the demand for the service; economic sectors and households responsible for nitrogen emissions will thus be considered users of the service (as explained in Chapter 2, Section 2.3.2).
- Basin retention is an additional component of water purification. If appropriately addressed, there is no double counting (as explained in Chapter 2, Section 2.4.2).

Regarding the third point above, we need to consider that basin retention includes crop uptake, which provides nitrogen removal, but is not a source of pollution. It is important to include this measurement because it consistently frames the full nitrogen budget; however, future developments may aim to disentangle crop uptake from what remains as soil denitrification, and thus identify what constitutes ‘pollution’ only.

Considering the complexity of the water purification service, we have to make a lot of assumptions when moving from assessment to valuation to accounting. It is important to be transparent in these assumptions to be aware of the meaning of these data and their limitations.

First, we used only nitrogen retention as a proxy for water purification. However, the water purification service involves different sources of pollution, involves several chemical, physical and biological processes of removal, and can take place in both aquatic and terrestrial ecosystems. These aspects explain the complexity of assessing the service. In addition, the relevance of the pollution and the types of pollution depend on the world regions and different uses of water being considered. For example, nitrogen pollution and aquatic eutrophication are of concern in industrialised countries, where agriculture is intensive and domestic waste and drinking water generally receive adequate treatments, whereas pathogens and coliforms are of major concern in countries with poor access to clean water, because of the lack of sanitation infrastructures and drinking water treatment, and contamination from metals and specific chemicals can be relevant in urban and industrial areas.

Second, when allocating basin retention flow to terrestrial ecosystem types, one of the main reference sources was the national capital project database, that is mainly for European studies, even though these estimates reflect various local-level factors. Nitrogen cycling and storage in soils and vegetation varies considerably depending on ecosystem type and land use. In agricultural systems, processes are dominated by fertiliser use and crop removal. In natural and semi-natural systems, processes are largely affected by climatic, soil and landscape conditions and the sum of nitrogen inputs through deposition and biological fixation (Butterbach-Bahl and Dannenmann, 2011). Some of the main limitations are caused by local factors, such as:

- pre-existing nitrogen saturation of ecosystems (Jones et al., 2011),
- nitrogen and sulfur deposition – affects nitrogen cycling by lowering soil pH (Jones et al., 2011),
- ozone – affects nitrogen cycling (Jones et al., 2011),
- physiographical region (Sutton et al., 2011; Van Dobben et al., 2013; Sharp et al., 2018),
- land use change (Sutton et al., 2011; Sharp et al., 2018),
- slope (Sharp et al., 2018),
- intra-annual variation (i.e. seasons) (Sharp et al., 2018),
- vegetation roughness (Van Dobben et al., 2013),
- temperature, soil wetness, phosphorus limitation and management intensity (Hicks et al., 2011); climatic, edaphic and landscape conditions, climate, soil properties and management activities (Sutton et al., 2011); and phosphorus limitation and management intensity (sod cutting versus low-intensity management) (Achermann and Bobbink, 2003),
- plant community composition (Van Dobben et al., 2013),
- balance of inorganic nitrogen immobilisation by microbes and (autotrophic) nitrification (Sutton et al., 2011),
- level of precipitation (Achermann and Bobbink, 2003).

The allocation based on the weights reported in Table 5.2 is thus subject to high levels of uncertainty, which future applications will need to address.

Third, when setting the sustainability threshold, we applied the same thresholds across the EU-28. A more sophisticated application of sustainability thresholds should consider several features. The threshold depends on the water body type. Shallow lakes are more vulnerable than estuaries. Lentic systems (lakes) in general are more vulnerable than lotic systems (rivers and flowing water). Ideally, one would use the reports of the Member States (which are provided in national languages) and map the typology of freshwaters and then attach a spatially explicit threshold concentration. Although upstream catchments are more vulnerable than downstream catchments, there is less pressure upstream because all the nitrogen that is not removed upstream flows downstream, making the catchments close to the sea the most pressured.. It is also important to differentiate between countries by considering ecosystems: in terms of nitrogen inputs, cropland is of course more pressured than mountainous areas or other ecosystems.

Fourth, regarding the discount rate used for the yearly flow calculation, although a 3 % discount rate may reflect society's time preference, it is unlikely to reflect the opportunity costs for the agricultural and utility sectors, which will bear the costs of nitrogen removal measures.

Fifth, the cost of land purchase is a key part of the opportunity cost associated with CW, and improved data and estimates should be included in the analysis for river retention and basin retention replacement cost options if feasible.

Key messages

- The critical variable for assessing the water purification service is nitrogen input. Two components are accounted for in this ES: basin retention and river and lake retention. Part of basin retention is crop uptake, which should not be considered pollution.
- Nitrogen input represents the ES D of water purification. The higher the nitrogen input, the higher the ES actual flow. Nitrogen input decreased between 2006 and 2012 by about 2 % across the EU-28, and the water purification flow showed a similar decrease in physical terms: from 20.6 million tonnes/year to 20.1 million tonnes/year.
- The value of water purification is about EUR 55 billion/year. The cost of building and maintaining CW is used to translate into monetary terms the outcomes of the GREEN biophysical model.
- Sustainability analysis requires the assessment of not only the ES actual flow, but also the ES overuse. For river and lake retention in the EU-26 (EU-28 minus Finland and Sweden), changing the sustainability threshold from 2 mgN/l (representing the average for good ecological status) to 1 mgN/l (representing the average for high ecological status) generates in turn a change in the ES overuse from about 22 % to 52 %, respectively.
- Water purification is a key ES for the agricultural sector and information about it can inform policies supporting sustainable practices.

6. Updates of previous ecosystem services accounts

Initial applications of ES accounting are experimental by nature. The more applications become available, the more it is possible for the assessment and valuation techniques to evolve. In previous Joint Research Centre reports (Vallecillo et al., 2018, 2019b), six ESs have been described, quantified and mapped. Ongoing research and the addition of other ES flows, forced us to rethink the way some of these services were assessed, valued and framed in the accounting context. Flexibility is a necessity in complex and multidisciplinary exercises such as ES accounting, but it is also an intrinsic property of the accounts in the broad sense. The purpose of this chapter is to explain all the modifications undertaken for the ES accounts already reported in INCA. Modifications are focused on:

- crop provision – to solve the double counting issue with soil retention;
- timber provision – to harmonise with environmental accounts already set out in the SEEA central framework (CF);
- carbon sequestration – to distinguish between the flow provided by ecosystems and the flow that effectively reaches the users;
- nature-based recreation – to clarify the previous application of monetary data;
- crop pollination – to attempt to set some basic rules when using existing data sets.

6.1. Crop provision

The crop provision service is defined as the ecological contribution to the growth of cultivated crops that can be harvested and used as raw material to produce food, animal feed, fibre and fuel. The ecosystem contribution needs to be separated from human inputs, otherwise the outcomes can be misleading (i.e. intensive agricultural systems (characterised by high use of external inputs, such as fertilisers, plant protection products and machinery) generate a higher yield than extensive agricultural systems or organic farming). The quantity of the yield itself does not represent the crop provision service: the ecosystem contribution to yield needs to be disentangled. In Chapter 3 of Vallecillo et al. (2019), the biophysical assessment is based on an emergy-based approach, in which the emergy (from 'embodied energy') of a product is defined as the total solar energy needed, directly and indirectly, to make that product. In the emergy calculation, the following flows are included:

- human (purchased) inputs, which include fertilisers, irrigation, plant protection products, seeds, fuel, use of machinery, electricity and labour;
- natural inputs, which include:
    - flows generated by renewable resources (i.e. solar radiation energy, wind, rainfall, flowing water and groundwater, all ultimately deriving from solar energy);
    - flows generated by non-renewable resources (NRs) or only partly renewable resources, represented in this case by topsoil depletion (40).

In particular, the emergy flow here called 'NRs' is calculated as the depletion of soil organic matter (SOM) by multiplying the estimated quantity of SOM consumed by the emergetic transformity of SOM (i.e. the emergy embedded in a unit of SOM, taken from the literature). Figure 6.1 visualises the ecosystem inputs provided by soil according to the emergy approach (Pérez-Soba et al., 2019), specifically 'topsoil', shown in grey. Two arrows originate from 'SOM': one flow is to 'ecosystem production' (plant uptake) and the other is to 'erosion' caused by run-off. The flow that goes to 'ecosystem production' is also accounted for in this report as 'on-site soil retention', which would result in a double counting issue if corrections were not applied. Flows generated by NRs include both flows: 'on-site soil retention' (yellow label) and 'erosion' (blue label). To avoid double counting, it is necessary to disentangle these two flows to exclude on-site soil retention from crop provision when both accounts (crop provision and soil retention) are presented together.

Figure 6.1 is a generic figure showing how such flows are commonly schematised in the emergy literature. Concerning the specific application used to assess the ecosystem contribution as 'crop provision', for the NR component, the study by Pérez-Soba et al. (2019) does not explicitly further distinguish between the two patterns of SOM depletion. For the purposes of this report, if the NR flow embedded only the residual component of superficial run-off by rainfall, then there would not be a double counting issue, as by definition this would not be 'soil retained'. However, a more conservative (from an accounting perspective) approach suggests considering the NR flow as corresponding to the total SOM depletion (i.e. both soil retained and superficial run-

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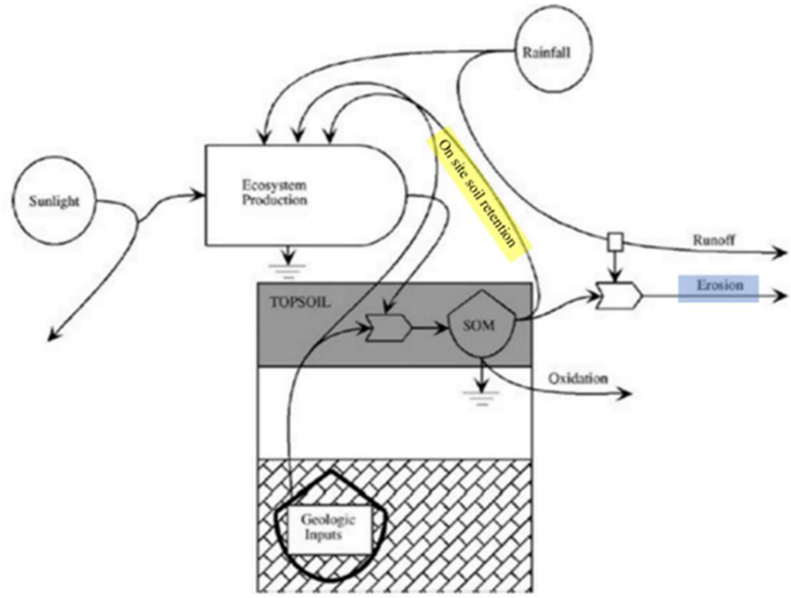
(40) Soil depletion here is used as an input for agricultural production since it is used as a proxy for soil consumption by plants.

off) and subdividing this flux into two subfluxes through an assumption that minimises the potential double counting error.

Figure 6.1. Visual simplification of the emergy flows contributing to ecosystem production



Source: Adapted from Ridolfi and Bastianoni (2008).

To extract the component of NR flow at risk of double counting, the soil retention model is used. When assessing the soil retention service (see Chapter 4), the biophysical model requires first an assessment of soil erosion caused by rain. For each land reference unit (41), it is thus possible to calculate the proportion of soil retained compared with the proportion of soil eroded. Since the NR flow is proportional to SOM according to a fixed coefficient, to estimate the two subflows of NR (soil erosion and retention), it is assumed that the two proportions of SOM (hence, emergy) – (i) depleted through run-off and (ii) depleted as a result of plant uptake – are the same as the proportions of topsoil eroded and retained. This means that if, in a spatial unit, the quantity of soil eroded is equal to the quantity of soil retained, the two NR subflows are equal, and 50 % of the original NR value is considered to have been already accounted for in the 'soil retained' service. If no run-off erosion occurred in a spatial unit, then all the NR flow therein is attributable to soil retained. If the quantity of soil retained is double the quantity of soil eroded, then one third of the flow is attributed to run-off and the rest to soil retained and so on.

In this way, the share of emergy associated with SOM depleted as a result of run-off is subtracted from the total NR flow, and only the remaining part is considered already counted in the soil retention service. This represents a first approximation, which was the best option, given the available data and their structure, to minimise potential inaccuracies related to double counting. More generally, this exercise is also used to highlight the problem and signal how biophysical approaches such as the emergy approach and accounting techniques should be developed jointly to take into account the needs of different – but interrelated – research domains.

Figure 6.2 maps both (a) the crop provision ecosystem contribution coefficient embedding soil retention and (b) the crop provision ecosystem contribution with a corrected coefficient not including soil retention. As shown in Figure 6.2, the updated ecosystem contribution to crop provision (b) is significantly reduced, while keeping the same geographical distribution when compared with the initial assessment of the ecosystem contribution to crop provision (a). In fact, compared with the previous account for crop provision (Vallecillo et al., 2018), the results show that about 43 % of 'flows generated by non-renewable or only partly renewable resources' risk being double counted, whether considered by country or by crop type, and, for this reason, the whole ES is reprocessed excluding this proportion of the flow. Table 6.1 reports the updated ecosystem contribution ratio to be used for calculating crop provision.

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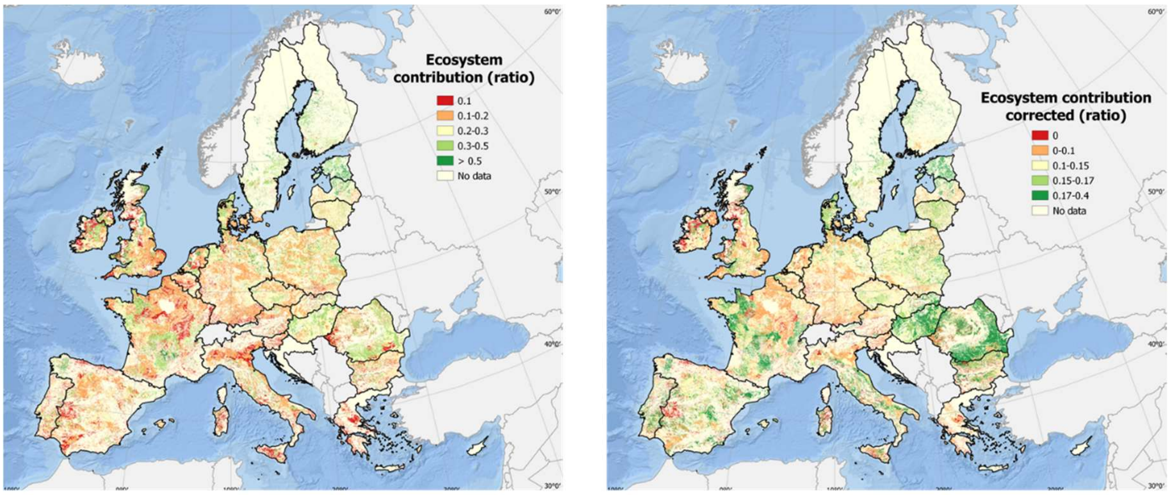
(41) For consistency with previous work (Vallecillo et al., 2019), calculations have been undertaken per homogeneous spatial mapping unit.

Table 6.1. Ecosystem contribution ratio to crop provision after extracting the soil retention share at risk of double counting

Country	Soft wheat	Durum wheat	Barley	Oats	Maize	Other cereals	Rape	Sunflower	Fodder maize	Other fodder	Pulse	Potato	Sugar beat	Country average
AT	0.13	0.12	0.16	0.15	0.05	0.13	0.14	0.16	0.14	0.03	0.01	0.01	0.05	0.10
BE	0.08		0.10	0.11	0.04	0.01	0.09		0.17	0.05	0.11	0.08	0.07	0.08
BG	0.15	0.01	0.14	0.10	0.13	0.01	0.01	0.22	0.17		0.01	0.06		0.09
CZ	0.12		0.15	0.20	0.07	0.15	0.20	0.20	0.18	0.01	0.02	0.01	0.10	0.12
DE	0.10	0.08	0.12	0.13	0.06	0.09	0.11	0.15	0.15	0.03	0.13	0.09	0.10	0.10
DK	0.13		0.17	0.16		0.14	0.14		0.00	0.12	0.10	0.11	0.15	0.12
EE	0.17		0.18	0.18		0.19	0.22			0.25		0.05		0.18
EL	0.10	0.05	0.12	0.02	0.05	0.04		0.10	0.10	0.11	0.12	0.05	0.07	0.08
ES	0.11	0.06	0.14	0.17	0.12	0.11	0.15	0.15	0.10	0.19	0.21	0.06	0.11	0.13
FI	0.15		0.15	0.13		0.02	0.13			0.21				0.13
FR	0.10		0.12	0.14	0.06		0.10	0.19	0.18	0.17	0.14	0.08	0.07	0.12
HR	0.13	0.09	0.16	0.16	0.09	0.10	0.15	0.17	0.13	0.11	0.11	0.05	0.10	0.12
HU	0.20	0.16	0.23	0.27	0.09	0.22	0.25	0.24	0.27	0.05		0.09	0.09	0.18
IE	0.10		0.12	0.11	0.02		0.15		0.00	0.13	0.15	0.06		0.09
IT	0.09	0.08	0.13	0.13	0.10	0.07	0.11	0.15	0.10	0.19	0.14	0.06	0.11	0.11
LT	0.16		0.18	0.21	0.01	0.20	0.24		0.02			0.01	0.07	0.12
LU	0.08		0.10	0.11	0.04	0.01	0.09		0.17	0.05	0.11	0.08	0.07	0.08
LV	0.18		0.21	0.20		0.22	0.22			0.05		0.06	0.09	0.15
NL	0.09		0.15	0.15	0.05	0.03	0.11	0.01	0.15	0.02	0.18	0.06	0.11	0.09
PL	0.12		0.19	0.16	0.08	0.13	0.14	0.15	0.22		0.01	0.06	0.09	0.12
PT	0.16		0.19	0.17	0.14	0.01		0.18	0.11	0.22	0.09	0.05	0.12	0.13
RO	0.22		0.20	0.18	0.22	0.00	0.09	0.27	0.22			0.03	0.13	0.16
SE	0.12		0.15	0.17		0.10	0.18			0.17		0.01	0.02	0.12
SI	0.08		0.09	0.11	0.09	0.00	0.09	0.09	0.08	0.02		0.04		0.07
SK	0.18	0.12	0.20	0.23	0.08	0.15	0.22	0.22	0.17	0.01		0.03	0.14	0.15
UK	0.09		0.11	0.14	0.22		0.18		0.11	0.11	0.17	0.05	0.13	0.13
EU average	0.13	0.09	0.15	0.15	0.09	0.09	0.15	0.17	0.13	0.10	0.11	0.05	0.10	

Figure 6.2. Crop provision and soil retention contribution: embedded and disentangled coefficients



(a) (b)

Table 6.2 shows the accounting results and Annexes AA25–AA36 report SUTs by Member State. Please note that, in contrast to the previous application, the euro per tonne values applied for crop provision have been applied following the same procedure as for crop pollination (see Section 6.5).

Table 6.2. Updated supply (a) and use (b) tables for crop provision

(a)

	Economic unit						**Ecosystem type**										
	Primary sector									Woodland and forest							
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Available for wood supply	Other	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
2000							0	87 518	0	0	0	0	0	0	0	0	87 518
2006							0	83 876	0	0	0	0	0	0	0	0	83 876
2012							0	93 936	0	0	0	0	0	0	0	0	93 936
(million EUR)																	
2000							0	8 365	0	0	0	0	0	0	0	0	8 365
2006							0	8 119	0	0	0	0	0	0	0	0	8 119
2012							0	11 407	0	0	0	0	0	0	0	0	11 407

(b)

	Economic unit							Ecosystem type									
	Primary sector										Woodland and forest						
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Available for wood supply	Other	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(1 000 tonnes)																	
2000	87 518	0	0	0	0	0	87 518										
2006	83 875	0	0	0	0	0	83 875										
2012	93 936	0	0	0	0	0	93 936										
(million EUR)																	
2000	8 365	0	0	0	0	0	8 365										
2006	8 119	0	0	0	0	0	8 119										
2012	11 407	0	0	0	0	0	11 407										

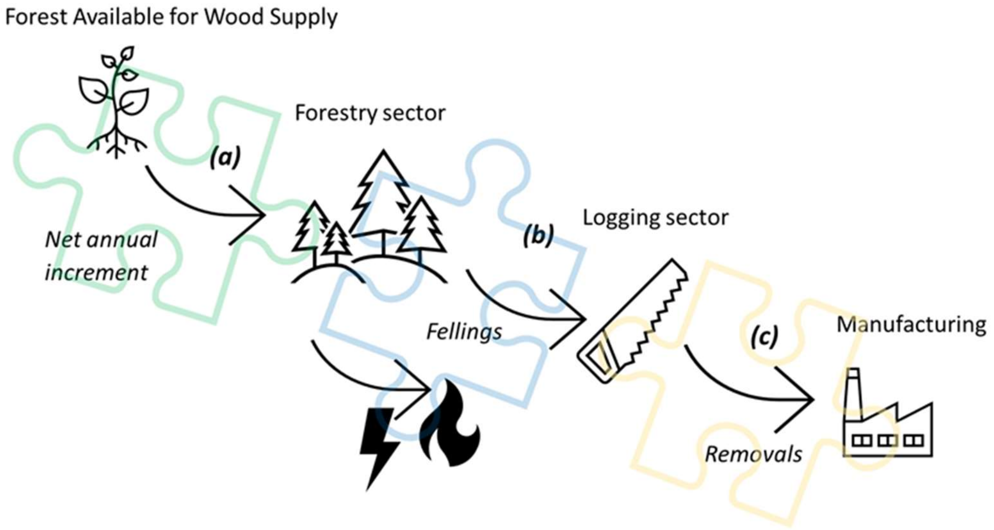
6.2. Timber provision

The timber provision service is defined as the ecological contribution to the production of timber that can be harvested and used as a raw material. In terms of the ecological process, we need to refer to natural growth of a biotic resource; this in turn implies that the service flow for accounting purposes is the net annual increment (NAI) of standing timber in forests that is available for wood supply.

In contrast to what was assessed in Chapter 4 of Vallecillo et al. (2019), the timber provision is in fact reported as the whole NAI flow in physical terms: no human input is disentangled from the NAI. This choice is underpinned by accounting and ecological justifications.

Regarding the accounting justification, natural growth of biotic resources is already part of the SEEA CF: natural assets, such as forests, wild fish and subsoil resources, are recorded in national accounts, and the SEEA CF develops specific satellite accounts to also cover what is already recorded on the purely economic accounting side. In forest asset accounts, the opening stock can be increased annually through the 'addition to stock due to natural causes', which is a flow and basically represents the ecosystem contribution. This may be an issue in the interpretation of what is an actual flow in ecosystem accounting. Forests and timber provision are considered in more detail here with the support of Figure 6.3. The NAI of woody biomass is the contribution of woodland ecosystems to the forestry sector (a). The forestry sector manages forests, but it is the logging sector that extracts the timber (b) that flows into economic activities as intermediate and final consumption (c). Therefore, depending on the kind of analysis to be undertaken, the actual flow can be understood as the flow from woodland to forestry (NAI (a)), or as the flow from woodland to the logging sector (felling/logging (b)). For the sake of consistency between the CF and EA components of the SEEA accounting framework, it is appropriate to consider the NAI as the actual flow of timber provision (a). However, for ecological consistency and for further sustainability analysis, it would be worthwhile considering logging as actual flow (b), as it is usually considered in the field of ES assessment (Maes et al., 2020). Logging will, in turn, affect the NAI in the future. Forest asset accounts report all three flows, which can be accounted as appropriate in SUTs.

Figure 6.3. Service flows along the chain of timber management, extraction and transformation



Regarding the ecological justification, we need to consider Eichhorn's rule (1904), whose general notion is that forest management does not influence stand volume growth significantly for a range of thinning grades or stocking densities, whereas heavier thinning beyond this range reduces volume growth (Skovsgaard, 2008). Clearly other forest management practices, such as the selection of tree species, can affect volume growth; however, the volume of a stand of monospecific regular forest in a closed state is a function of the stand age, the species and the site (including radiation and soil condition). Thus, there would be no need to disentangle from the biomass growth the role of human inputs. The law is not confirmed in every stand or every situation, but it gives a first-order idea of what can be produced in a forest. This reveals that it is the selection of species and the level of thinnings that can actually result in different levels of production. Eichhorn's rule has been challenged by several authors, and reformulated or better specified over time (e.g. Pretzsch, 2009).

Additional work to consolidate timber provision accounts concerns the issue of filling data gaps. Although forest accounts regularly reported by Eurostat should explicitly provide measurements concerning NAIs both in physical and in monetary terms for woodland and forest available for wood supply, there are still many missing data.

Regarding the physical assessment, timber provision data were provided by Eurostat under the code [for_vol_efa] (42). The data on forest resources were obtained from the following sources: European Forest Accounts (i.e. Eurostat's annual data collection on forest resources and economic activity in the forestry and logging industry), the Food and Agriculture Organization of the United Nations Global Forest Resources Assessment (5-yearly data collection) and Forest Europe's reports on the state of Europe's forests (5-yearly data collection). Due to the number of missing data, the approach suggested is to use estimates from the carbon budget model (43); this was the data source used (Pilli et al., 2021), with the purpose of using the model output to gap-fill missing data.

Regarding the monetary assessment, the NAI values for forest available for wood supply in monetary terms are estimated using data provided by Eurostat (44). Using these values, we can calculate the unit value of the NAI. However, there are still countries that report only some values throughout the time series and countries that report no values at all. To fill this gap, we suggest the use of 'export data' (45). Export data comprise monetary as well as physical data on the exports of roundwood products. It is thus possible to estimate the unit

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(42) The main data source for timber accounts is provided by Eurostat in 'Volume of timber over bark' [for_vol_efa] (https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=for_vol_efa&lang=en).

(43) https://data.jrc.ec.europa.eu/dataset/d4be2da6-54a1-4767-a262-dcebf66bf10b

(44) These data refer to economic data on forestry and logging in physical and monetary terms: 'Supply and use of products within forestry' [for_sup_cp] (https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do).

(45) Physical and monetary data on exports for roundwood primary products, provided by Eurostat: 'Roundwood, fuelwood and other basic products' [for_basic] (https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=for_basic&lang=en).

value (in euro per m^3) of roundwood. However, this value contains the added value of human components through the logic chain of timber production and, as such, it cannot represent a good proxy for NAI monetary value. To assess this proxy given the unit value of exports, we used a ratio of the unit value of exports to the unit value of NAI (hereafter referred to as 'Ratio_export_NAI').

There are still some data gaps for Ratio_export_NAI due to data gaps in the NAI unit value. We use the country average for Ratio_export_NAI to fill the gaps if a country is partly missing data across the time series and we use the EU average for Ratio_export_NAI if a country is missing data for the whole time period. Hence, this addresses the data gaps and we obtain estimates of Ratio_export_NAI for all countries and across all years. Finally, we divide the unit value of exports by the updated (i.e. after data gaps are filled) Ratio_export_NAI to estimate the proxy for NAI monetary value.

Table 6.3 shows the updated SUTs for timber provision in physical and monetary terms and Annexes AA37–AA48 report SUTs by Member State.

Table 6.3. Updated supply (a) and use (b) tables for timber provision

(a)

	Economic unit						**Ecosystem type**									
	Primary sector									Woodland and forest						
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Available for wood supply	Other	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(1 000 m^3)																
2000							0	0	0	955	0	0	0	0	0	0
2006							0	0	0	897	0	0	0	0	0	0
2012							0	0	0	885	0	0	0	0	0	0
(million EUR)																
2000							0	0	0	23 745	0	0	0	0	0	0
2006							0	0	0	21 623	0	0	0	0	0	0
2012							0	0	0	22 714	0	0	0	0	0	0

(b)

	Economic unit						**Ecosystem type**									
	Primary sector									Woodland and forest						
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Available for wood supply	Other	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(1 000 m^3)																
2000	0	955	0	0	0	0										
2006	0	897	0	0	0	0										
2012	0	885	0	0	0	0										
(million EUR)																
2000	0	23 745	0	0	0	0										
2006	0	21 623	0	0	0	0										
2012	0	22 714	0	0	0	0										

6.3. Carbon sequestration

Carbon sequestration as an ES is considered to be the net sequestration by ecosystems of CO_2 from the atmosphere, therefore contributing to mitigating climate change. In the previous assessment of this service (Chapter 5 in Vallecillo et al., 2019), carbon sequestration (referring to Global Climate Regulation) was assessed as the uptake of CO_2 by ecosystems of various types (Table 6.4(a)). On the one hand, ecosystems remove CO_2 from the atmosphere, as reported by the negative net emissions in land use, land use change and forestry (LULUCF) data. However, ecosystems may also emit CO_2 (Table 6.5(b)), as reported by the positive net emissions in LULUCF data, but this was not originally accounted within the carbon sequestration service in Vallecillo et al. (2019), completely ignoring the role of ecosystems in the increasing CO_2 concentration in the atmosphere.

Table 6.4. CO_2 removals (a) and emissions (b) in physical terms, year 2012

(a)

	Economic unit					Ecosystem type						
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Other ecosystem types	**Total**
(1 000 tonnes)												
EU						648	5 008	28 429	444 429	33	1 530	**480 078**

(b)

	Economic unit					Ecosystem type						
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Other ecosystem types	**Total**
(1 000 tonnes)												
EU						47 033	68 354	38 026	0	18 333	2 024	**173 770**

If we calculate the difference between removals and emissions by ecosystem type, the only ecosystem that provides net CO_2 sequestration is woodland and forest: for this ecosystem, removals are larger than emissions (Table 6.5). Table 6.5(a) reports the net CO_2 sequestration that woodland and forest provides (see also Vallecillo et al., 2019). However, other ecosystem types are still contributing to increasing CO_2 levels in the atmosphere through net emissions (where the differences between removals and emissions are negative) (Table 6.5(b)).

Table 6.5. CO_2 removals by woodland and forest (a) and CO_2 emissions by other ecosystem types (b) in physical terms, year 2012

(a)

	Economic unit					Ecosystem type						
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Other ecosystem types	**Total**
(1 000 tonnes)												
EU									444 429			**444 429**

(b)

	Economic unit					Ecosystem type						
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Other ecosystem types	**Total**
(1 000 tonnes)												
EU						46 385	63 346	9 597	0	18 299	494	**138 121**

The emissions from all ecosystems except woodland and forest contribute to increasing CO_2 levels in the atmosphere. This will have important consequences when estimating the actual flow of carbon sequestration by ecosystems. In other words, if we consider carbon sequestration aimed at the mitigation of CO_2 emissions to the atmosphere, we should consider the assessment of net CO_2 sequestration jointly for all ecosystem types. In this way, ecosystems effectively contribute to the reduction of CO_2 levels in the atmosphere, therefore benefiting global society. This implies that if CO_2 removals by woodland and forest are not large enough to compensate for emissions from other ecosystem types, then the service of carbon sequestration to reduce CO_2 levels in the atmosphere would not be provided to global society. Therefore, the actual flow of carbon sequestration is calculated as the balance between total removals and emissions provided in Table 6.5, considering all ecosystem types (Table 6.6).

Table 6.6. Supply (a) and use (b) tables of the carbon sequestration ecosystem contribution to global society, year 2012

(a)

	Economic unit					Ecosystem type						
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Other ecosystem types	**Total**
(1 000 tonnes)												
EU									306 308			**306 308**

(b)

	Economic unit						Ecosystem type					
	Primary sector	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Other ecosystem types
(1 000 tonnes)												
EU					306 308	**306 308**						

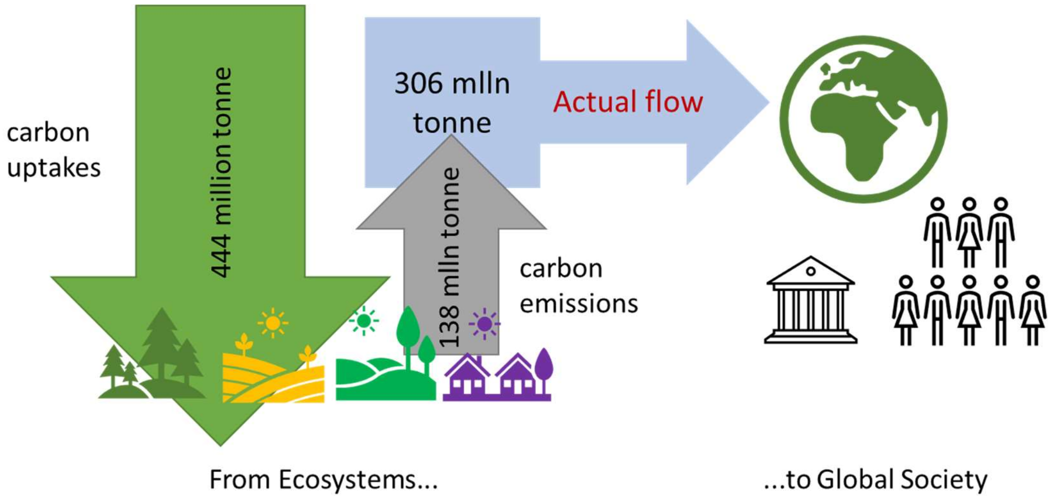
The assessment of the actual flow under the current approach takes into account the amount of service that reaches society: although forests remove 444 million tonnes of CO_2, only 306 million tonnes is of benefit to society (through mitigating climate change) because forests compensate for the emissions of other ecosystem types (Figure 6.4). The issue of establishing a positive net annual carbon balance has been raised by other carbon accounting contributions (Keith et al., 2019). Importantly, if ecosystems are responsible for more emissions than removals, then they would not provide any service, since they would not contribute to the reduction of CO_2 in the atmosphere.

Practitioners interested in measuring the role of forests should look at the removal table (Table 6.5(a)) rather than at the actual flow table (Table 6.6(a)), where this ecosystem's role appears to be underestimated. The two tables address slightly different questions.

- What is the role of forests in climate change mitigation? This is shown by CO_2 removals (Table 6.5(a)).
- What is the ecosystem contribution to global society of mitigating climate change? This is shown by carbon sequestration actual flow (Table 6.6).

The procedure for calculating and allocating carbon sequestration to Member States is not straightforward. Data extracted from the LULUCF database (see Chapter 5 in Vallecillo et al., 2019) refer to removals and emissions as reported in Table 6.5. In Table 6.6, we can clearly see that the only ecosystem type that is able to provide a positive uptake (after considering ecosystem emissions) is woodland and forest.

Figure 6.4. Visual simplification of carbon sequestration as an ecosystem contribution to global society



To appropriately allocate to each Member State the carbon sequestration contribution by the woodland and forest ecosystem type to global society, we cannot subtract the ecosystem's CO_2 uptake (Table 6.4(a)) from the ecosystem's CO_2 emissions (Table 6.4(b)). This allocation is undertaken by calculating the proportion of CO_2 removed by woodland and forest as follows:

$$Actual\ flow_{MS} = \frac{Woodland\ and\ forest\ carbon\ removal_{MS}}{Woodland\ and\ forest\ carbon\ removal_{EU-28}} \times [Total\ carbon\ removal_{EU-} \quad - Total\ carbon\ emission_{EU-28}]$$

(Equation 6.1)

Equation 6.1 allows us to allocate to each Member State the carbon sequestration by woodland and forest that, aggregated at European level (EU-28), is in line with the actual flow quantification (i.e. 303 million tonnes rather than 444 million tonnes (2012)). Table 6.7 shows the updated accounting results for the three years assessed in INCA. Annexes AA49–AA60 report SUTs by Member State.

Table 6.7. Updated supply (a) and use (b) tables for carbon sequestration

(a)

	Economic unit						Ecosystem type										
	Primary sector									Woodland and forest							
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Available for wood supply	Other	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
2000							0	0	0	290 358		0	0	1 195	0	0	291 554
2006							0	0	0	292 213		0	0	0	0	0	292 213
2012							0	0	0	306 308		0	0	0	0	0	306 308
(million EUR)																	
2000							0	0	0	8 710		0	0	35	0	0	8 746
2006							0	0	0	8 766		0	0	0	0	0	8 766
2012							0	0	0	9 189		0	0	0	0	0	9 189

(b)

	Economic unit							Ecosystem type									
	Primary sector										Woodland and forest						
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Available for wood supply	Other	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal
(1 000 tonnes)																	
2000	0	0	0	0	0	291 554	291 554										
2006	0	0	0	0	0	292 213	292 213										
2012	0	0	0	0	0	306 308	306 308										
(million EUR)																	
2000	0	0	0	0	0	8 747	8 747										
2006	0	0	0	0	0	8 766	8 766										
2012	0	0	0	0	0	9 189	9 189										

6.4. Nature-based recreation

The nature-based recreation assessment and accounting combine biophysical and economic modelling to capture the value of visits to local ‘high-quality’ sites (see Chapter 3 of Vallecillo et al., 2018). The input data for the economic models are related to the output of the biophysical model to provide site-specific nature-based recreation estimates. Some caveats and clarifications are necessary.

The first clarification is that the biophysical model classifies all recreational sites according to their quality/attractiveness, and the economic model just refers to high-quality sites; therefore, the estimates are not representative of every natural area in Europe. This results in a ‘conservative’ estimated value of the ES provided.

The actual recreational usage in 2012 was 40 million visits per year. A 'back of envelope' calculation gives the result that fewer than 1 in 10 EU citizens (46) visit a recreational site within 4 km of where they live once per year. This value may appear too low or unrealistic. However, the nature-based model refers to a small subset of high-quality sites used for daily nature-based recreation. The actual number of sites considered ranged from 63 sites in Malta to 39 292 sites in France (Table 6.8).

The second clarification refers to the fact that the economic analysis is site specific. For every single recreation site, a separate zonal travel cost analysis is applied. This method assumes that the recreational value (price) is represented by the travel cost to the specific site incurred by all individual users. The biophysical model provides the distance and visitation rate by zones around each individual high-quality recreational site (Figure 6.5). The zonal cost model (Willis and Garrod, 1991; Poor and Smith, 2004) is then used to calculate a value derived from a user demand curve. The demand curve shows the relationship between the number of visits and the price (i.e. travel cost incurred). The demand curve is site specific and therefore relates only to the overall benefit that the visitors experience from visiting each site individually. In other words, if that specific site is lost or protected, the welfare loss or gain for the site depends on the slope of the demand curve.

Table 6.8. Number of high-quality sites considered for the assessment of nature-based recreation

Country	**Sites**
Austria	2 351
Belgium	589
Bulgaria	4 025
Croatia	556
Cyprus	556
Czechia	6 171
Denmark	2 124
Germany	11 214
Estonia	225
Finland	318
France	36 292
Greece	1 031
Hungary	3 153
Ireland	3 228
Italy	8 068
Latvia	119
Lithuania	527
Luxembourg	106
Malta	63
Netherlands	408
Poland	2 479
Portugal	4 000
Romania	3 181
Slovakia	2 660
Slovenia	211
Spain	7 953
Sweden	290
United Kingdom	9 203
Total EU high-quality recreational sites	111 100

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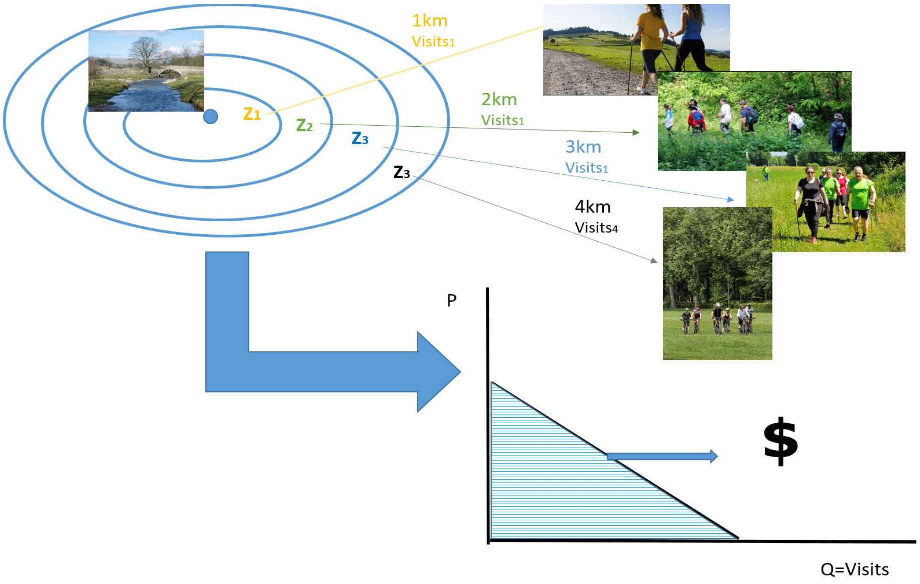
(46) A UK study found that 58 % of survey respondents claimed to visit the outdoors at least once a week. However, in this survey every type of outdoor space was considered, which is quite different from the INCA biophysical model. In addition, 42 % made no visits a year. The distribution is thus skewed towards zero (*Monitor of Engagement with the Natural Environment* annual report from the 2013–2014 survey).

Figure 6.5. Visual simplification of the distance approach applied for zonal travel costs



NB: Price is the proxy for the travel cost, which depends on the distance, and numbers of visits are influenced by this (note that in economics the demand curve inverts the *x*- and *y*-axes used in statistics).

Each site will have a specific sloping demand curve. Therefore, the 50 billion estimate for 2012 (Vallecillo et al., 2018) refers to an aggregate loss of over 100 000 high-quality recreational sites, or the benefit if sites remain intact and open access (Table 6.9).

The relationship between recreational quantity demanded and economic value is site specific. The value per visit is calculated individually at site level and averaged across different Member States. For the year 2012, the EU median value for a visit to an average high-quality recreation site is EUR 2.23. Table 6.9 shows individual estimates for Member State, reporting the quartile distribution.

The quartile distribution shows the spread of values above and below the median. The median is a measure of central tendency that, for an almost symmetrical distribution, is close to the mean but not affected by the effect of outliers, which can inflate the mean (Table 6.9). The median value varies across countries and the variance across countries also differs. For example, Denmark has the highest median access value of EUR 65 and a 75th percentile of more than EUR 461. Only Belgium had a 75th percentile value of over EUR 600. Italy, on the other hand, had a median value of EUR 4 and a 75th percentile value of EUR 104. This suggests that the variability of site visitation rates and values is greater in Denmark than in Italy. The individual Member State nature-based recreation welfare measures (Table 6.9) could be used as reference points in national accounting assessments, as in these estimates the extent and condition of sites is captured by the biophysical model, albeit confined to high-quality sites in the economic model. For example, Lankia et al. (2020) report that the average value of state-owned sites per visit is EUR 3.30, which equates to the EUR 3 of our 25th percentile. The Lankia et al. study includes sites of all quality levels, whereas Table 6.9 refers only to high-quality sites

Table 6.9. Reference value per visit across Member States (EUR/visit)

	2012		
	25th percentile	Median	75th percentile
	0	**2.23**	**66.32**
Austria	1	4	80
Belgium	0	15	691
Bulgaria	0	2	55
Croatia	0	3	149
Cyprus	0	1	8
Czechia	0	1	4
Denmark	3	65	461
Estonia	—	—	—
Finland	3	25	593
France	0	1	5
Germany	1	5	226
Greece	2	13	327
Hungary	1	4	152
Ireland	0	1	4
Italy	0	4	104
Latvia	—	—	—
Lithuania	1	5	177
Luxembourg	—	—	—
Malta	2	12	55
Netherlands	—	—	—
Northern Ireland	0	4	14
Poland	5	17	65
Portugal	0	0	5
Romania	0	4	131
Slovakia	—	—	—
Slovenia	0	3	70
Spain	0	1	11
Sweden	—	—	—
United Kingdom	0	5	16

NB: For some Member States, we could not produce estimates due to missing information on the distribution of the population or very skewed distributions of values around the site.

6.5. Crop pollination

For the monetary valuation of the crop pollination ESs, we use market prices drawn from an official statistics website (Eurostat). In the first version of the application (see Chapter 4 of Vallecillo et al., 2018), the pollination ecosystem contribution ratio is applied directly to economic accounts (47) that for each pollinator-dependent crop are expressed in monetary terms. For the sake of consistency with other ESs, in the second version (see Vallecillo et al., 2019) the pollination ecosystem contribution ratio is first applied to pollinator-dependent crops in physical terms, and then multiplied by price per tonne. However, when using the data set available, some modifications are needed:

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(47) The data source for crop yield is Eurostat: ‘Crop production in EU standard humidity [apro_cpsh1]’. The data source for per-unit price is Eurostat: ‘Unit values at basic prices [aact_uv01]’.

- some countries, such as Belgium, report per-unit values that are considerably higher than those of all the other countries (outliers);
- some countries report quantities in physical terms, but no price per tonne in monetary terms (missing data);
- prices change over time due to market conditions (current versus constant prices).

Table 6.10 shows the updated accounting results and Annexes AA61–AA72 report SUTs by Member State.

To address the outlier issue, the EU average value is calculated and substituted for the price per tonne recorded in individual Member States. To address the missing data issue, the same EU average value is multiplied by the actual flow in physical terms calculated for individual Member States. To address the changing value over time, the average value for 2000–2012 is calculated and applied to all the years for which accounting tables are reported. In fact, for all the other accounts a change towards using the constant price has been adopted: the change to be tracked over time is the change in ES flows not changes driven by the market system, which are outside the assessment.

Table 6.10. Updated supply (a) and use (b) tables for crop pollination

(a)

	Economic unit						Ecosystem type									
	Primary sector									Woodland and forest						
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Available for wood supply	Other	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(1 000 tonnes)																
2000							0	9 308	0		0	0	0	0	0	0
2006							0	10 775	0		0	0	0	0	0	0
2012							0	10 477	0		0	0	0	0	0	0
(million EUR)																
2000							0	4 085	0		0	0	0	0	0	0
2006							0	4 333	0		0	0	0	0	0	0
2012							0	4 517	0		0	0	0	0	0	0

(b)

	Economic unit						Ecosystem type									
	Primary sector									Woodland and forest						
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Available for wood supply	Other	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(1 000 tonnes)																
2000	9 308	0	0	0	0	0										
2006	10 775	0	0	0	0	0										
2012	10 477	0	0	0	0	0										
(million EUR)																
2000	4 085	0	0	0	0	0										
2006	4 333	0	0	0	0	0										
2012	4 517	0	0	0	0	0										

Key messages

- The assessment, valuation and accounting of soil retention required the reprocessing of the crop provision service to avoid double counting. The conservative approach applied shows that the ecosystem contribution ratio decreased by about 43 % (EU average).
- The timber provision service has been updated in physical terms to be consistent with the SEEA CF forest accounts from an accounting perspective, and to respect Eichhorn's rule from an ecological perspective. By applying a more rigorous gap-filling procedure, the ES actual flow increased (for 2012) from EUR 14 billion/year to EUR 22 billion/year.
- Carbon sequestration represents the CO_2 mitigation service operated by ecosystems with respect to climate change. The ES flow that reaches global society should consider the offset of CO_2 emissions from other ecosystem types at EU level. From the previous 444 million tonnes/year of carbon removals (not including CO_2 emissions), we now account for 306 million tonnes/year of carbon removals (including CO_2 emissions).
- The monetary valuation of nature-based recreation was EUR 50 billion/year for 2012 in absolute terms; the value per visit is calculated individually at site level and averaged across Member States. For 2012, the EU median value for a daily visit to an average high-quality recreation site was EUR 2.23.
- Adjusting for outliers and filling data gaps increased the yearly value of the crop pollination service from EUR 3.3 billion/year to EUR 4.5 billion/year in 2012.

7. Accounts aggregation and INCA indicators

From ES SUTs, it is possible to directly extract information that can be used to build descriptive indicators without any further processing. Extracted data can be in physical or monetary terms. If we consider ESs in monetary terms, we can aggregate all ES flows using a common unit and provide relevant information about the overall flow provided by ecosystems to the socioeconomic system by analysing the role played by different ecosystem types and economic units (Section 7.1). If we consider ESs in physical terms, we can consider in detail the sustainability issues according to the features of different ESs (Section 7.2), and additional features that can be useful from a policy perspective (Section 7.3). Overall, different types of indicators can be extracted from SUTs according to the type of information, the level of complexity, the type of use and managing needs (Section 7.4). In this chapter, we address only the very first stage of the descriptive analysis. Finally, one of the possible uses of indicators concerns their support for international reference frameworks. In this chapter, we start exploring how INCA indicators can support the sustainable development goals and the post-2020 global biodiversity framework (Section 7.5).

7.1. Aggregation of supply and use tables in monetary terms

At EU scale, it is possible to aggregate nine ESs in monetary terms for the year 2012. From the supply table (Table 7.1), the aggregation by ecosystem type enables us to rank ecosystems by the value of the services they provide.

Table 7.1. Supply table in monetary terms for the EU-28, year 2012

	Ecosystem type										
	Urban	Cropland	Grassland	Woodland and forest		Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/ intertidal area	**Total**
				Available for wood supply	Other						
(million EUR)											
Crop provision		11 407									11 407
Timber provision				22 714							22 714
Crop pollination		4 517									4 517
Soil retention		11 512									11 512
Carbon sequestration	—	—	—	9 189		—	—	—	NA	NA	9 189
Flood control	89	1 015	3 129	11 388		333	357	1	NA	NA	16 312
Water purification	1 105	31 041	4 128	15 374		330	312	170	3 114	NA	55 576
Habitat and species maintenance (a)	NA	5 516	985	20 416		1 689	1 176	369	2 363	NA	32 515
Nature-based recreation	77	4 073	7 482	30 723		2 296	3 097	1 351	1 015	279	50 393
Total value	1 272	69 081	15 724	109 805		4 649	4 941	1 891	6 493	279	214 134
EUR/km^2	6 026	42 972	31 014	69 051		47 525	27 361	32 202	59 586	14 531	48 877
% ecosystem type	0.6 %	32.39 %	7.3 %	51.3 %		2.2 %	2.3 %	0.9 %	3.0 %	0.1 %	

(a) Welfare value is reported for this ES.
NA: Not Available

Table 7.1 shows that, in absolute terms, woodland and forest provides 51 % of the total ES yearly monetary flow. It is worthwhile mentioning that the timber provision service is only 21 % of the value of services generated by **woodland and forest**, and this statement endorses the important role of this ecosystem type, which **goes far beyond its conventional categorisation of 'supplying wood'**.

In analysing data from the supply table, it is important to consider two elements.

- The total extent of the ecosystem type can be misleading when interpreting the importance of some ecosystem types in generating services. Ecosystem types that in Europe do not cover a large extent, such as rivers and lakes, sparsely vegetated land and wetland, considerably increase their weight and importance when considered in relative terms (euro per km^2) rather than in absolute terms (euro).
- The importance of some ecosystem types compared with others is based on the ESs that are assessed: cropland is one of the ecosystem types providing most of the ES flows (about 32 %) because we assessed services such as crop provision, crop pollination, on-site soil retention and water purification, in which the role of cropland is absolutely leading. It is thus not surprising that its importance is so great.

From the use table (Table 7.2), the aggregation by economic units enables us to rank which human activities receive most ES flows.

Table 7.2. Use table in monetary terms for the EU-28, year 2012

	Economic units					
	Primary sector		Secondary and tertiary sectors	Households	Global society	**Total**
(million EUR)	Agriculture	Forestry				
Crop provision	11 407					11 407
Timber provision		22 714				22 714
Crop pollination	4 517					4 517
Soil retention	11 512					11 512
Carbon sequestration					9 189	9 189
Flood control	799		3 786	11 726		16 312
Water purification	38 615		11 307	5 653		55 576
Habitat and species maintenance ([a])					32 515	32 515
Nature-based recreation				50 393		50 393
Total value	66 851	22 714	15 093	67 773	41 704	214 314
% economic units	31.2 %	10.6 %	7.0 %	31.6 %	19.5 %	100 %

([a]) Welfare value is reported for this ES.
NA: Not Available

Table 7.2 shows that the agricultural sector uses about 31.2 % of the total ESs provided yearly. The same argument explained with reference to cropland also applies for agriculture (i.e. the choice of ES largely determines which ecosystem types become the most important providers and which economic units become the most important users). Since we assessed services such as crop provision, crop pollination, on-site soil retention and water purification, it is expected that cropland provides a large flow of ESs to agriculture. On the other hand, we also need to acknowledge that **agriculture is one of the main activities through which the territory is actively managed and is key for the entire food system**. The choice of such ESs is thus sensible and justified.

Another important economic unit that stands out is households (which use 31.6 % of the total ESs provided yearly). The ES that contributes more than others to provide households with such an important service is nature-based recreation. With an actual flow of EUR 50 billion/year, nature-based recreation records one of the highest monetary estimates with regard to other ESs. This outcome is not as unusual as it may appear at first sight: nature-based recreation (as currently classed in INCA) is the opportunity for residents to enjoy natural attractions that are nearby. This service does not pass through the market: there is no transformation, no value added and no selling or trading. This service is generated by ecosystem types and **households are its final user**. As is the case for other services (e.g. crop and timber provision, crop pollination), the provision from this ecosystem type is only the first step of a long value chain: at each step of the value chain, the transformed product increases its market value. The very final user of the final product is not agriculture or forestry, as recorded in our use table.

Finally, as explained in Chapter 2, there is a difference between ‘domestic’ and ‘global’ services: whereas the former serve economic sectors and activities that are physically located within countries, the users of the latter are located beyond national boundaries. Global services are relevant to overarching environmental targets such as climate change (addressed by carbon sequestration) and biodiversity loss (addressed by habitat and species maintenance), whose beneficiary is global society. Table 7.2 shows that 19.5 % of yearly ES flows in the EU-28 serve global society: this represents one point of reference to analyse over time to acknowledge whether and **how much Europe is contributing to internationally acknowledged targets**.

7.2. (Un)sustainability indicators

Additional useful indicators can be calculated with reference to cases where ES P and ES D match and to cases where ES P and ES D do not match. Based on the range of available ES accounts, three kinds of mismatches can occur:

- ES unmet demand,
- ES overuse,
- ES missed flows.

In the case of ES unmet demand, there is no possibility of providing ESs because there is no presence of service-providing areas for the service delivery, even if demand for those services is there. This is the case for source suitability (e.g. crop pollination), buffer (e.g. flood control) and cultural (e.g. nature-based recreation) services (see Section 3 of La Notte et al., 2019).

Table 7.3. The issue of sustainability: ES unmet demand

	ES D covered by ES P			**ES D uncovered by ES P**		
	2000	2006	2012	2000	2006	2012
Flood control (area, km^2)		41 880	41 696		95 169	95 111
Soil retention (million tonnes/year)	7 246	7 281	7 270	798	765	771
Pollination (area, km^2)	71 695	80 796	78 512	81 447	81 230	83 514
Nature-based recreation (1 000 inhabitants)	232 926		284 581	209 565		172 578

Ideally, the ES D covered by ES P and the ES D uncovered by ES P should have opposite signs: the higher the match between ES P and ES D, the lower their mismatch. Table 7.3 confirms this trend for soil retention, but not for pollination. In the case of crop pollination, a higher-covered area is explained by an increase in ES D that is not counterbalanced by an adequate increase in the ES P. In fact, when looking at changes over a long period (2000–2012) we record an increase of 9.5 % in pollination actual flow, but also an increase in the pollination unmet demand (+ 2.5 %). In the case of nature-based recreation, on the one hand, we record a + 22 % change (considering 2000–2012) in the population covered by nature-based recreation opportunities; on the other hand, we record a – 17 % change in the population uncovered by nature-based recreation opportunities. This implies that changes occurring on the ES D side may be partly but not fully covered by changes in ES P: ES D grows more than ES P (therefore, the ES unmet demand remains). A similar trend applies to flood control: on the one hand, we record a – 0.44 % change (between 2006 and 2012) in the area protected from the risk of flooding; on the other hand, we record a – 0.06 % change in the areas unprotected by the risk of flooding. In this case, the slight decrease (considering we are considering only 6 years) in the match and the almost no change in the mismatch suggests that modifications mainly occurred on the ES D side: more areas that need protection are not counterweighted by more areas that provide protection.

For those ESs in which the actual flow can exceed regeneration and absorption rates, ES overuse can take place: this is the case for resource extraction (e.g. timber provision) and pollution emissions (e.g. water purification). Table 7.4 reports the example of water purification.

Table 7.4. The issue of sustainability: ES overuse

	ES current use		ES use ≤ sustainability threshold	
	2006	2012	2006	2012
Water purification inland water (tonnes N/year)	239 378	215 900	135 293	124 357

We considered the sustainability threshold of 1 mg/l, which in the literature (Camargo and Alonso, 2006) is commonly reported with reference to the eutrophication issue. Table 7.4 clearly shows that a decrease (– 9.8 %) in the actual flow (less nitrogen input requires less nitrogen removal) corresponds to a decrease in water purification overuse (– 8.1 %).

Finally, as described in Chapter 2, there are ESs that refer to overarching environmental issues such as climate change and biodiversity loss. In this case, users of those ESs are not only the people living in a specific place at a specific time, but rather are present and future societies, from a global perspective. What can be measured and reported in these cases are the two sides of the total ES potential flow: the part that is provided (i.e. the actual flow) and the part that is missed.

Table 7.5. The issue of sustainability: ES missed flow

	ESs reaching global society		ESs missed by global society	
	2000	2012	2000	2012
Carbon sequestration (million tonnes/year)	291 554	306 308	180 678	173 770
Habitat and species maintenance (million EUR/year)	31 238	32 515	53 383	56 011

Table 7.5 shows for carbon sequestration (which addresses the issue of climate change mitigation) the expected trend of an increase in ES actual flow (+ 5.1 %) and a decrease in ES missed flow (– 3.2 %). However, trends work differently for habitat and species maintenance (which address the issue of biodiversity loss): although we record an increase in the ES actual flow (+ 4.09 %), we also record an even higher increase in the ES missed flow (+ 4.92 %). This is explained by the increase in one of the variables (i.e. population) that has no impact on the ecological side. Both indications are useful for policymakers: on the one hand, it is possible to keep track of changes over time; on the other hand, it is possible to measure the gap with regard to what could actually be achievable but is not achieved.

7.3. Additional indicators in physical terms

To deal with the issue of food system resilience, the ecosystem contribution to agricultural production is an interesting indicator to monitor. Table 7.6 shows the differences between European countries and the EU average for the ecosystem contribution ratio in crop provision. Only those countries in which the difference is < – 0.05 and > + 0.05 are reported.

Table 7.6. Ecosystem contribution ratio in crop provision: difference from the EU average, year 2012

	High ecosystem contribution		Medium ecosystem contribution		Low ecosystem contribution	
	Oilseed crops	Fodder crops	Cereal crops	Pulses	Tuber crops	Sugar crops
Belgium	0.11	0.01	0.06	0.11	– 0.03	0.01
Denmark	0.09	0.06	0.02	0.09	– 0.06	0.06
Estonia	0.04	– 0.07	0.00	0.04	0.00	– 0.07
Ireland	0.08	0.05	0.06	0.08	– 0.01	0.05
Greece	0.03	0.01	0.06	0.03	0.01	0.01
France	0.01	– 0.06	0.03	0.01	– 0.02	– 0.06
Lithuania	0.04	0.06	– 0.01	0.04	0.05	0.06
Hungary	– 0.09	– 0.04	– 0.08	– 0.09	– 0.04	– 0.04
Netherlands	0.10	0.03	0.04	0.10	– 0.01	0.03
Portugal	0.06	– 0.05	– 0.01	0.06	0.00	– 0.05
Slovenia	0.07	0.07	0.06	0.07	0.02	0.07
Slovakia	– 0.07	0.03	– 0.04	– 0.07	0.02	0.03
Sweden	0.07	– 0.03	0.01	0.07	0.04	– 0.03

Table 7.6 shows that Hungary has, for all crops, an ecosystem contribution ratio that is lower than the EU average; on the other hand, Greece and Slovenia have ecosystem contributions that are higher than the EU average for all crop types. Countries such as Denmark, Ireland and the Netherlands record contributions that are higher than the EU average for those crops that have higher and medium ecosystem contributions. Not all crops have the same level of ecosystem contribution: one the one hand, Belgium has a higher than the EU average (+ 0.11) ecosystem contribution ratio for oilseed crops (a high ecosystem contribution crop) and a lower than average (– 0.03) ecosystem contribution ratio for tuber crops (a low ecosystem contribution crop. In the analysis of the overall ecological contribution, the role of Belgium and Slovenia will be different.

Climate change is an overarching environmental issue. The ES that relates most to this issue is carbon sequestration.

Table 7.7. Carbon sequestration allocation to polluting sectors

	Economic unit						
	Primary sector	Manufacturing and construction	Electricity, gas supply	Transport	Waste management	Other tertiary sector	Households
Allocation of CO_2 to polluting sectors							
2000	5 979	67 630	95 566	56 335	154	11 617	54 271
2006	5 254	64 457	95 036	61 241	190	11 638	54 397
2012	5 766	61 272	98 732	68 297	181	11 727	60 334
Allocation coefficients							
2000	0.021	0.232	0.328	0.1932	0.001	0.040	0.1861
2006	0.018	0.221	0.325	0.2096	0.001	0.040	0.1862
2012	0.019	0.200	0.322	0.2230	0.001	0.038	0.1970

The atmospheric CO_2 mitigation by ecosystems considers ecosystem uptake and ecosystem emissions, but does not consider anthropogenic emissions (i.e. emissions by economic sectors and households). However, by combining air emission accounts (from the SEEA CF) with carbon sequestration accounts (by ecosystems), it is possible to 'allocate' the mitigation action to the most polluting economic units. The 'allocation' is not ecologically real, but it is policy relevant; in fact, it is not possible to establish which anthropogenic emissions are sequestered by what ecosystems in which countries. However, the most polluting (in terms of CO_2 emissions) sectors may be the ones responsible for the most offsetting (e.g. in terms of woodland and forest restoration and tree planting).

Table 7.7 shows that electricity remains the most polluting sector (with a coefficient of about 0.32), followed by transport (with a coefficient of about 0.22, which increased from 2000 to 2012) and manufacturing (with a coefficient of about 0.20, which decreased from 2000 to 2012). To interpret the (policy rather than ecological) meaning of allocation, ecosystems (mostly woodland and forest) are working to mitigate atmospheric CO_2, whose main anthropogenic emitters are electricity, transport and manufacturing sectors.

Halting biodiversity loss is another overarching environmental target. To find out whether species are at risk, it is important to compare the presence of habitats in good condition with the presence of target species (species hotspots). Where the presence of target species is not supported by suitable habitats, species may be at risk of extinction in the medium or long term.

Table 7.8 shows that suitable habitats declined from 2000 to 2012 (– 0.4 %). The presence of species supported by suitable habitats also declined (– 1.1 %), and the species at risk (in the medium and long run) increased (+ 0.3 %). Although the magnitude of changes at EU level is almost insignificant (although locally may be greater), the sign of the changes can be relevant as an early warning of the need for ecosystem restoration measures.

Table 7.8. Presence of habitats suitable for species hotspots

	2000	2012	Absolute changes	Relative changes
Suitable habitats (1 000 km^2)	1 705	1 698	– 7	– 0.4 %
Species hotspots (1 000 km^2)	2 282			—
Species supported by suitable habitats (1 000 km^2)	812	803	– 9	– 1.1 %
Species not supported by suitable habitats (1 000 km^2)	1 476	1 480	+ 4	+ 0.3 %

7.4. From descriptive statistics to policy analysis

There are many ways of processing information provided by ES SUTs. We can identify three main groups (Table 7.9).

- **Indicators that are derived from descriptive statistical data.** These indicators are characterised by the fact that any practitioner can use the data without any further processing. A range of information can be extracted from the tables as they are.
- **Indicators that are derived through combining and processing descriptive statistical data (non-parametric estimates).** Data extracted by SUTs need to be further processed to obtain the desired outcome. The degree of complexity of each indicator can vary greatly. The outcome obtained is 'final'.
- **Indicators that are derived through analytical work based on statistical data and methods (parametric estimates).** Data extracted by SUTs need to be further processed to obtain the desired outcome. In this case, the outcome is not an indicator per se, but it represents an input for further computation. Skills in the tools/models that will be used for the ES accounting input are a precondition.

Regarding descriptive statistics, downloading ES SUTs needs to be undertaken and the only management need lies in the systematic replication of these accounts to report and monitor data over time. Typically, this task is undertaken by national statistical institutes. However, being a service of public utility, any institution could ideally use and spread this kind of information. In this chapter, we considered indicators that belong to this group.

Table 7.9. Possible ways to build indicators based on SUTs

Type of information	Level of complexity	Type of use	Management needs	Examples
Descriptive statistics	No further processing (low)	Basic	Replicability	• Total values • Relative values • Percentages
Processed indicators (non-parametric estimates)	Additional processing (medium)	Advanced	Replicability and cross scaling	• Ratios • Ranking • Composite indices
Processed variables (parametric estimates)	Additional processing (high)	Expert	Replicability, cross scaling, skills in the target model to be bridged	• Extended input–output matrix • 'Shock' variable in (economic) equilibrium models

Regarding processed indicators, the downloading of accounting tables and maps is only the first step in processing information to address a specific topic / policy question. The indicator can be very simple or very complex depending on a variety of features, such as the amount of quantitative information that is jointly combined and the role of spatial explicitness. Since further processing is needed, the format in which SUTs are officially provided may not fit for the purpose different users may have: disaggregation (per sector, per area, etc.) plus (geographical) upscaling and downscaling operations may be needed. The range of possible users in this case is wide: from public authorities, to consulting institutes, to academia.

Regarding processed variables, the downloading of accounting tables and maps is only the first step in processing information to create the variable to be used as the input for another model. Analysts able to use other existing tools and models will extract and process from SUTs the data needed with the specificity and format required for the next processing step; the information processed from SUTs is not 'final' but 'propaedeutic'. In this case, users are ad hoc field analysts (e.g. from economic and financial sectors) able to work with tools that are already generally accepted and widely used.

7.5. Possible linkages with reference frameworks

The SEEA EA addresses the issue of indicators in Chapter 14 of the handbook (UN, 2021). The work on this topic is still in progress; however, it is possible to identify some sensitive areas on which to focus attention and drive applications based on INCA available experience. An important and sensitive issue in SEEA EA concerns the 'links to reporting framework', such as the sustainable development goals and the post-2020 biodiversity, climate change (United Nations Framework Convention on Climate Change) and land degradation (United Nations Convention to Combat Desertification) frameworks. Special emphasis is paid to the post-2020 global biodiversity framework and sustainable development goal indicators. This is indeed an important link to be established because those frameworks are increasingly becoming the common ground of international policy discussion, agreements and compelling initiatives. We now attempt to find out how the INCA indicators can contribute to these two international reference frameworks.

Table 7.10 shows a first proposal for using indicators extracted from INCA to support the post-2020 global biodiversity framework. The EU biodiversity strategy is largely aligned to the post-2020 global biodiversity framework: if INCA indicators can support the post-2020 global biodiversity framework, they can also support the EU biodiversity strategy. The table is divided into two parts: the first part refers to the descriptive statistics indicators reported in this chapter, and the second part refers to what could be done with further processed information.

Table 7.10. INCA indicators for the post-2020 global biodiversity framework

INCA indicators already available	Post-2020 global biodiversity framework
Habitat and species maintenance: ES actual flow to monitor changes regarding species supported by suitable habitats (see Table 7.8)	Target 3. By 2030, ensure active management actions to enable wild species of fauna and flora recovery and conservation, and reduce human–wildlife conflict by X %
Water purification: ES overuse with respect to sustainability thresholds (see Table 7.4)	Target 6. By 2030, reduce pollution from all sources, including reducing excess nutrients (by X %), biocides (by X %) and plastic waste (by X %) to levels that are not harmful to biodiversity and ecosystem functions and human health
Carbon sequestration: ES actual flow and missed flow by ecosystems considering the role of uptake and emissions (see Table 7.5)	Target 7. By 2030, increase contributions to climate change mitigation adaption and disaster risk reduction from nature-based solutions and ecosystems-based approaches, ensuring resilience and minimising any negative impacts on biodiversity
Crop provision: ES actual flow with respect to ecosystem contribution ratio (see Table 7.6)	Target 9. By 2030, support the productivity, sustainability and resilience of biodiversity in agricultural and other managed ecosystems through conservation and sustainable use of such ecosystems, reducing productivity gaps by at least (50 %)
Flood control: ES actual flow regarding ecosystem potential to monitor the increase of nature-based solutions (see Table 7.3)	Target 10. By 2030, ensure that nature-based solutions and ecosystem approaches contribute to regulation of air quality, hazards and extreme events and quality and quantity of water for at least (X million) people
Nature-based recreation: ES actual flow regarding ecosystem demand (i.e. resident households) (see Table 7.3)	Target 11. By 2030, increase benefits from biodiversity and green/blue spaces for human health and well-being, including the proportion of people with access to such spaces, by at least (100 %), especially for urban dwellers
INCA indicators potentially available	**Post-2020 global biodiversity framework**
Bridging ES accounts and economic models to assess economic impacts of changes in ES flows (**processed variable** (a))	Target 5. By 2030, manage, and where possible control, pathways for the introduction of invasive alien species, achieving (50 %) reduction in the rate of new introductions, and control or eradicate invasive alien species to eliminate or reduce their impacts, including in at least (50 %) of priority sites
Urban accounts: ES accounts for functional urban areas	Target 10. By 2030, ensure that nature-based solutions and ecosystem approaches contribute to regulation of air quality, hazards and extreme events and quality and quantity of water for at least (X million) people
Urban accounts: ES accounts for functional urban areas	Target 11. By 2030, increase benefits from biodiversity and green/blue spaces for human health and well-being, including the proportion of people with access to such spaces, by at least (100 %), especially for urban dwellers
Bridging ES accounts and economic models to assess economic impacts of changes in ES flows (**processed variable** (a))	Target 13. By 2030, integrate biodiversity values into policies, regulations, planning, development processes, poverty reduction strategies and accounts at all levels, ensuring that biodiversity values are mainstreamed across all sectors and integrated into assessments of environmental impacts
Scenario analysis on ES accounts regarding bridged ES accounts and economic models to assess economic impacts of changes in ES flows (**processed variable** (a))	Target 17. By 2030, redirect, repurpose, reform or eliminate incentives harmful for biodiversity, including (X) reduction in the most harmful subsidies, ensuring that incentives, including public and private economic and regulatory incentives, are either positive or neutral for biodiversity
ES accounts linked to the EU taxonomy	Target 18. By 2030, increase by (X %) financial resources from all international and domestic sources, through new, additional and effective financial resources commensurate with the ambition of the goals and targets of the framework and implement the strategy for capacity building and technology transfer and scientific cooperation to meet the needs for implementing the post-2020 global biodiversity framework

(a) Examples available in https://publications.jrc.ec.europa.eu/repository/handle/JRC120571.

Table 7.11 shows a first proposal for using indicators extracted from INCA to support the sustainable development goals. Table 7.11 is divided into two parts: the first part refers to the descriptive statistics indicators reported in this chapter, and the second part refers to what could be done with further processed information.

Table 7.11. INCA indicators for the sustainable development goals

INCA indicators already available	Sustainable development goals
Crop provision: ES actual flow (regarding ecosystem contribution ratio) (see Table 7.6) Synergies (trends over time) between crop provision and other ESs (see Table 7.1)	2.4. By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters, and that progressively improve land and soil quality
Water purification accounts: ES overuse (regarding specific sustainability thresholds) (see Table 7.4)	6.3. By 2030, improve water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and increasing recycling and safe reuse by X % globally
Water purification by the urban ecosystem type (see Table 7.1)	11.6. By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality, municipal and other waste management
Nature-based recreation by the urban ecosystem type (see Table 7.2)	11.7. By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities
Carbon sequestration: Combined presentation with CO_2 emission by economic units (see Table 7.7)	13.2. Integrate climate change measures into national policies, strategies, and planning
Monitor over time the supply table by ecosystem type (see Table 7.1)	15.1. By 2020, ensure conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetland, mountains and dryland, in line with obligations under international agreements
Monitor over time the ecosystem type 'woodland and forest' on the supply table (see Table 7.1)	15.2. By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests, and increase afforestation and reforestation by X % globally
ES unmet demand for flood control and soil retention (see Table 7.3)	15.3. By 2020, combat desertification, and restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land-degradation neutral world
Habitat and species maintenance: ES potential flow regarding species not supported by suitable habitats (see Table 7.8) Synergies between habitat and species maintenance and other ESs (see Table 7.1)	15.5. Take urgent and significant action to reduce degradation of natural habitat, halt the loss of biodiversity, and by 2020 protect and prevent the extinction of threatened species
INCA indicators potentially available	**Sustainable development goals**
Crop and timber provision: ES overuse (regarding specific sustainability thresholds) Sustainability scoreboard (**processed indicator** ([a]))	12.2. By 2030, achieve sustainable management and efficient use of natural resources
Processed variables from INCA to be bridged with multiregional input–output tables (**processed variable** ([a]))	8.4. Improve progressively through 2030 global resource efficiency in consumption and production, and endeavour to decouple economic growth from environmental degradation in accordance with the 10-year framework of programmes on sustainable consumption and production with developed countries taking the lead
ES accounts linked to the EU taxonomy	8.10. Strengthen the capacity of domestic financial institutions to encourage and to expand access to banking, insurance and financial services for all
Urban accounts: ES accounts for functional urban areas	11.a. Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning
Urban accounts:	11.b. By 2020, increase by X % the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource

ES accounts for functional urban areas	efficiency, mitigation and adaptation to climate change, resilience to disasters, develop and implement in line with the forthcoming Hyogo framework holistic disaster risk management at all levels
Ranking Member States' value/km^2 with respect to EU average (**processed indicator**)	15.1. By 2020, ensure conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetland, mountains and dryland, in line with obligations under international agreements
Crop pollination: Processed variables from INCA to bridge economic models (**processed variable** (a))	15.8. By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems, and control or eradicate the priority species
Vulnerability accounts: Monetary unmet demand	15.a. Mobilise and significantly increase from all sources financial resources to conserve and sustainably use biodiversity and ecosystems
Vulnerability accounts: Monetary unmet demand	15.b. Mobilise significantly resources from all sources and at all levels to finance sustainable forest management, and provide adequate incentives to developing countries to advance sustainable forest management, including for conservation and reforestation
Bridging ES accounts and economic models to assess economic impacts of changes in ES flows (**processed variable** (a))	17.14. Enhance policy coherence for sustainable development
Environmentally adjusted net value added (**processed indicator** (b))	17.19. By 2030, build on existing initiatives to develop measurements of progress on sustainable development that complement gross domestic product, and support statistical capacity building in developing countries

(a) Examples available in https://publications.jrc.ec.europa.eu/repository/handle/JRC120571.

(b) Example available in https://www.tandfonline.com/doi/full/10.1080/20964129.2019.1634979.

INCA indicators summary

a. 'Woodland and forest' is the ecosystem type that provided about 51.3 % of the total service flow in 2012. The 'timber provision' service constituted only 21 % of the quantity of services generated by woodland and forest, whose important role goes far beyond 'supplying wood'.

- 'Agriculture' is one of the main activities through which the territory is actively managed and is key for the entire food system. This sector used 31.2 % of the total ESs provided in 2012.
- 'Households' used 31.6 % of the total services provided in 2012. The ESs allocated to 'households' do not pass by the market; in contrast to other economic units, there is no value chain involving transformation, value added, selling and trading. 'Households' are the final user.
- There are overarching environmental targets such as climate change and biodiversity loss whose beneficiary is global society. Europe contributed 19.5 % of ESs to these international targets in 2012.
- An increase in ES D cannot be counterbalanced by an adequate increase in the ES P. This is observed for the following ESs.
    - **Crop pollination.** We recorded (2000–2012) an increase of 9.5 % in pollination actual flow, but also an increase in the pollination unmet demand (+ 2.5 %).
    - **Nature-based recreation.** We recorded (2000–2012) a + 22 % change in the population 'covered' by nature-based recreation opportunities, but also a – 17 % change in the population 'uncovered' by nature-based recreation opportunities.
    - **Flood control.** We recorded (2006–2012) a – 0.44 % change in the area 'protected' from the risk of flooding, but almost no change in the areas 'unprotected' by the risk of flooding. In this case, the slight decrease (only 6 years considered) suggests that changes mainly occurred on the ES D side (i.e. more areas that need protection are not counterweighted by more areas that provide protection).
- Water purification is a service whose absorption rate can be exceeded by the overload of nitrogen pollutants. We recorded (2006–2012) that a decrease (– 9.8 %) in the actual flow (i.e. less nitrogen input requires less nitrogen removal) corresponds to a decrease in water purification overuse (– 8.1 %). This policy message supports the effectiveness of the nitrates directive.

- ESs contributing to overarching environmental issues such as climate change and biodiversity loss are not only for the people living in a specific place at a specific time, but rather are for present and future societies, from a global perspective. The overall ES potential flow results from the service provided (i.e. the actual flow) and the services that are missed:
    - For carbon sequestration (which contributes to climate change mitigation), we recorded (2000–2012) an increase in the ES actual flow (+ 5.1 %) and a decrease in ES missed flow (– 3.2 %).
    - For habitat and species maintenance (which contributes to addressing biodiversity loss), we recorded (2000–2012) an increase in the ES actual flow (+ 4.09 %) and an even higher increase in the ES missed flow (+ 4.92 %). The increase in the actual flow is explained by the increase in the population variable, which has no impact on the ecological side. However, both indications are policy relevant: on the one hand, changes are tracked over time; on the other hand, the ecological gap represented by the missed flow is measured.
- The issue of food system resilience can be supported by the ecosystem contribution to agricultural production. The difference between European countries and the EU average regarding ecosystem contribution ratios in crop provision could be a potential indicator. Hungary has, for all crops, an ecosystem contribution ratio that is lower than the EU average; on the other hand, Greece and Slovenia have ecosystem contributions that are higher than the EU average for all crops.
- By combining air emission accounts (by economic sector) with carbon sequestration accounts (by ecosystem type), it is possible to 'allocate' the mitigation action to the most polluting economic units. The allocation is not ecologically real but could be policy relevant: for which sectors are ecosystems working to mitigate atmospheric CO_2? Electricity remains the most polluting sector (allocation coefficient: 0.32), followed by transport (allocation coefficient: 0.22, which increased from 2000 to 2012) and manufacturing (allocation coefficient: 0.20, which decreased from 2000 to 2012).
- Where the presence of target species is not supported by suitable habitats, species may be at risk in the medium and long term: we recorded (2000–2012) a decrease in suitable habitats (– 0.4 %) and in the presence of species supported by suitable habitats (– 1.1 %), and an increase in the species at risk (in the medium and long run) (+ 0.3 %).
- In this chapter, we considered only descriptive analysis indicators. However, INCA offers the possibility of calculating processed indicators (non-parametric estimates) and processed variables (parametric estimates) to serve a large variety of users and uses.
- INCA indicators can contribute to the post-2020 global biodiversity framework with indicators that are already available and indicators that can be available in the near future (see Table 7.10).
- INCA indicators can contribute to the sustainable development goals with indicators that are already available and indicators that can be available in the near future (see Table 7.11).

8. Conclusions

ES accounts represent a simplification of an extremely complex network of socioecological processes, meant to quantify the transactions from ecosystems to the society and the economy in a way that is consistent with traditional economic accounting.

The SEEA EA is the statistical framework proposed and developed by the United Nations Statistics Division that describes ecosystems and the services they provide to the economy and society, in a way that is consistent with the SNA. In March 2021, the United Nations Statistical Commission officially adopted the SEEA EA (UN et al., 2021). Among the many applications based on the SEEA EA that have been used worldwide (Hein et al., 2020; La Notte et al., 2021), the INCA initiative, led by the European Commission (Vysna et al., 2021), at the same time (i) is compliant with the SEEA EA and (ii) further develops structural elements to consistently mainstream ecological content (the complexity) in accounting mechanisms (the simplification process). This simplification of complex processes (as undertaken in INCA) implies, **first from a conceptual perspective**, that there is a structure behind the quantification of ES actual flow that is reported in SUTs. In INCA, the actual flow is determined by the interaction between an ecosystem side (called ES P) and a socioeconomic side (called ES D). The interaction between ES P and ES D is not working against the accounting notion of an ES transaction but is working to explain the nature of this transaction and analyse whether changes occurring are the result of sustainable (where the ES P ≥ ES D) or unsustainable (where ES P < ES D) practices.

This is an important piece of information since it helps policymakers to address questions such as '**How good was the ecological performance of past policies?**' For example, crop pollination actual flow increased from 2000 to 2012 by 9.5 %, which seems to be good news; however, since no adequate increase occurred in the ES P, pollination unmet demand also increased, by + 2.5 %.

When looking at the socioeconomic side, we need to acknowledge that there are ES flows that cannot be allocated to specific users in specific countries because they are meant to target overarching environmental issues that go beyond national boundaries, such as climate change and biodiversity loss. This is the case when ESs represent a global public good, which in turn needs to be allocated to global society and implies the impossibility of geographically mapping the demand in a specific place, within specific national boundaries, because public goods are non-rivalrous and non-excludable. These statements concerning the accounting of ecological global public goods (and services) are not meant to be a final conclusion but insights for the beginning of a discussion that is urgently needed.

Such an approach would allow the assessment of questions such as '**How much is Europe contributing to global issues such as climate change mitigation and halting biodiversity loss?**' The answer, estimated according to our approach, is 44.8 billion/year in 2012, which represents 20.6 % of the nine ESs so far accounted.

Ecosystem accounts (as proposed by the SEEA EA) specify a set of modules: (i) extent accounts describing the size of ecosystem assets in terms of area aggregated by ecosystem types, (ii) condition accounts describing the integrity of ecosystems in terms of their main characteristics, and (iii) ES flow accounts describing which ESs are provided by which ecosystem type to which economic units in physical and/or monetary terms. The **second** step in simplifying complexity, **from an accounting perspective** in INCA, attempts to find a link between the ecosystem accounting modules. Although practitioners do not need to measure ecosystem condition before measuring ESs, it may be important to clearly track the causality nexus between condition variables and input data in ES assessment. The causality nexus can in fact make the overall accounting system more consistent because each module is connected to the others rather than being independent modules that run in parallel. This first proposal needs to be further validated by a hopefully growing number of applications.

Establishing this causality nexus could help address questions such as '**What is the environmental–economic impact of conservation measures?**' For example, between 2000 and 2006 soil conservation generated changes in vegetation density, crop type and management practices, which are all biotic variables included to model soil retention potential. This in turn caused (between 2000 and 2012) an increase in soil retention by ecosystems of nearly 24 million tonnes, especially in arable land, and thus is of benefit to the agricultural sector.

Establishing this causality nexus could also help address questions such as '**Is it possible to measure sustainability improvements of policies?**' For example, a reduction of nitrogen input (a pressure variable) between 2006 and 2012 of about 2 % across the EU generated a decrease in nitrogen overuse in rivers and lakes of 124 360 tonnes.

Finally, simplifying complexity needs to bring together a variety of disciplines, ranging from natural sciences (including subjects such as ecology, biology, hydrology and forestry) to geography and economics. It is very difficult to collect all the knowledge you need when you need it, especially for statistical offices. For this reason, the availability of plug-in tools that enable practitioners to replicate (tested and validated) modelling procedures could help greatly. The **third** and final contribution of INCA to systematic ES accounting is the **transfer of the knowledge** behind physical assessment and monetary valuation of all nine services to create the tools ultimately needed by statistical offices to apply ES SUTs at national (and subnational) level(s) and replicate them over time to create time series and to implement socioeconomic–environmental analyses, as appropriate. The creation of geographical information system plug-ins is currently work in progress (48), which may relatively soon generate concrete tools to be used in an open-source environment.

Systematically filling SUTs over time will enable Member States to address questions such as '**What is the estimated value of natural capital?**', '**Which are the ecosystem types that provide most of this value?**' and '**Who is benefiting the most from ES delivery?**' Based on our applications for the year 2012, we can provide these answers for nine ESs: Europe provides a yearly flow of EUR 217 billion/year; woodland and forest is the ecosystem type that provides most of these services (48.7 %), followed by cropland (37.9 %); and agriculture is the economic sector that uses most of these services (30.8 %), together with households (31.2 %).

To conclude, the contribution of INCA phase II (2016–2020) is both theoretical and practical. Through a series of concrete case studies, we (i) tested and developed comprehensive and consistent concepts and (ii) set empirical step-by-step procedures that, we hope, may be of help to all interested ES accounting practitioners.

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(48) See the call for tender launched by Eurostat (https://etendering.ted.europa.eu/cft/cft-display.html?cftId=6577).

9. References

Adhikari, K. and Hartemink, A. E. (2016), ‘Linking soils to ecosystem services – A global review’, *Geoderma*, Vol. 262, pp. 101–111, doi:10.1016/j.geoderma.2015.08.009.

Achermann, B. and R. Bobbink (eds.). (2003), ‘Empirical critical loads for nitrogen.. Proceedings of an Expert Workshop, 11-13 November 2002, Berne. Environmental Documentation No. 164.Bern: Swiss Agency for the Environment, Forest and Landscape.

Aukema, J. E., Pricope, N. G., Husak, G. J. and Lopez-Carr, D. (2017), ‘Biodiversity areas under threat: overlap of climate change and population pressures on the world’s biodiversity priorities’, *PloS ONE*, Vol. 12, No 1, e0170615, doi:10.1371/journal.pone.0170615.

Berg, C. E., Mineau, M. M., & Rogers, S. H. (2016), .Examining the ecosystem service of nutrient removal in a coastal watershed’. Ecosystem Services, 20, 104–112. https://doi.org/https://doi.org/10.1016/j.ecoser.2016.06.007

Billen, G., Garnier, J., Thieu, V., Silvestre, M., Barles, S. and Chatzimpiros, P. (2012), ‘Localising the nitrogen imprint of the Paris food supply: the potential of organic farming and changes in human diet’, *Biogeosciences*, Vol. 9, No 1, pp. 607–616, doi:10.5194/bgd-8-10979-2011.

Borrego-Marín, M. M., Gutiérrez-Martín, C. and Berbel, J. (2016), ‘Water productivity under drought conditions estimated using SEEA-Water’, *Water*, Vol. 8, No 4, doi:10.3390/w8040138.

Borrelli, P., Robinson, D. A., Fleischer, L. R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt B., Ferro, V., Bagarello, B., Van Oost, K., Montanarella, L. and Panagos, P. (2017), ‘An assessment of the global impact of 21st century land use change on soil erosion’, *Nature Communications*, Vol. 8, No 1, 2013, doi:10.1038/s41467-017-02142-7.

Brauman, K. A., Daily, G. C., Duarte, T. K. and Mooney, H. A. (2007), ‘The nature and value of ecosystem services: an overview highlighting hydrologic services’, *Annual Review of Environment and Resources*, Vol. 32, No 1, pp. 67–98, doi:10.1146/annurev.energy.32.031306.102758.

Britz, W., & Witzke, P. (2012), ‘CAPRI model documentation’. Institute for Food and Resource Economics. Bonn: University of Bonn.

Bugge, M. M., Hansen, T., & Klitkou, A. (2016), ‘What Is the Bioeconomy? A Review of the Literature’. Sustainability, 8(7). https://doi.org/10.3390/su8070691

Burkhard, B., Kroll, F., Nedkov, S. and Müller, F. (2012), ‘Mapping ecosystem service supply, demand and budgets’, *Ecological Indicators*, Vol 21, pp. 17–29, doi:10.1016/j.ecolind.2011.06.019.

Butterbach-Bahl, K. and Dannenmann, M. (2011), ‘Denitrification and associated soil N_2O emissions due to agricultural activities in a changing climate’, *Current Opinion in Environmental Sustainability*, Vol. 3, No 5, pp. 389–395, doi:10.1016/j.cosust.2011.08.004.

Camargo, J. A. and Alonso, Á. (2006), ‘Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment’, *Environment International*, Vol. 32, No 6, pp. 831–849, doi:10.1016/j.envint.2006.05.002.

Caparrós, A., Campos, P. and Montero, G. (2003), ‘An operative framework for total Hicksian income measurement: application to a multiple-use forest’, *Environmental and Resource Economics*, Vol. 26, No 2, pp. 173–198, doi:10.1023/A:1026306832349.

Caparrós, A., Oviedo, J. L., Álvarez, A. and Campos, P. (2017), ‘Simulated exchange values and ecosystem accounting: theory and application to free access recreation’, *Ecological Economics*, Vol. 139, No 140–149, doi:10.1016/j.ecolecon.2017.04.011.

Collins, M., Minobe, S., Barreiro, M., Bordoni, S., Kaspi, Y., Kuwano-Yoshida, A., Keenlyside, N., Manzini, E., O’Reilly, C. H., Sutton, R., Xie, S.-P. and Zolina, O. (2018), ‘Challenges and opportunities for improved understanding of regional climate dynamics’, *Nature Climate Change*, Vol. 8, No 2, pp. 101–108, doi:10.1038/s41558-017-0059-8.

Czúcz, B., Keith, H., Driver, A., Jackson, B., Nicholson, E. and Maes, J. (2021), ‘A common typology for ecosystem characteristics and ecosystem condition variables’, *One Ecosystem*, Vol. 6, No e58218.

Czúcz, B., Arany, I., Potschin-Young, M., Bereczki, K., Kertész, M., Kiss, M., Aszalós, R., & Haines-Young, R. (2018), 'Where concepts meet the real world: A systematic review of ecosystem service indicators and their classification using CICES'. Ecosystem Services, 29, 145–157. https://doi.org/10.1016/j.ecoser.2017.11.018

Dasgupta, P. (2021), *The Economics of Biodiversity: The Dasgupta Review*, HM Treasury, London.

Desmet, P. J. J., & Govers, G. (1996), 'A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units'. Journal of Soil and Water Conservation, 51(5), 427. http://www.jswconline.org/content/51/5/427

de Vries, W., Leip, A., Reinds, G. J., Kros, J., Lesschen, J. P. and Bouwman, A. F. (2011), 'Comparison of land nitrogen budgets for European agriculture by various modeling approaches', *Environmental Pollution*, Vol. 159, No 11, pp. 3254–3268, doi:10.1016/j.envpol.2011.03.038.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., Hill, R., Chan, K. M. A., Baste, I. A., Brauman, K. A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P. W., Van Oudenhoven, A. P. E., Van Der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Denissew, S., Erpul, G., Failler, P., Guerra, C. A., Hewitt, C. L., Keune, H., Lindley, S. and Shirayama, Y. (2018), 'Assessing nature's contributions to people', *Science*, Vol. 359, No 6373, pp. 270–272, doi:10.1126/science.aap8826.

Duku, C., Rathjens, H., Zwart, S. J. and Hein, L. (2015), 'Towards ecosystem accounting: a comprehensive approach to modelling multiple hydrological ecosystem services', *Hydrology and Earth System Sciences*, Vol. 19, No 10, pp. 4377–4396, doi:10.5194/hess-19-4377-2015.

Dusenbery, B. (1992). Sensory Ecology: How Organisms Acquire and Respond to Information. W H Freeman & Co. ISBN-10: 0716723336

Edson, M. M., Foin, T. C., & Knapp, C. M. (1981), ' "Emergent Properties" and Ecological Research'. The American Naturalist, 118(4), 593–596. http://www.jstor.org/stable/2460792

Eichhorn F. (1904). 'Beziehungen zwischen bestandeshohe und bestandesmasse', *Ailgemeine Forst und Jagdzeitung*, Vol. 80, pp. 45–49.

Elmqvist, T., Folke, C., Nyström, M., Peterson, G., Bengtsson, J., Walker, B. and Norberg, J. (2003), 'Response diversity, ecosystem change, and resilience', *Frontiers in Ecology and the Environment*, Vol. 1, No 9, pp. 488–494, doi:10.1890/1540-9295(2003)001[0488:RDECAR]2.0.CO;2.

Faivre, N., Fritz, M., Freitas, T., de Boissezon, B., & Vandewoestijne, S. (2017), 'Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges'. Environmental Research, 159, 509–518. https://doi.org/10.1016/j.envres.2017.08.032

Fleishman, E., Noss, R. F. and Noon, B. R. (2006), 'Utility and limitations of species richness metrics for conservation planning', *Ecological Indicators*, Vol. 6, No 3, pp. 543–553, doi:10.1016/j.ecolind.2005.07.005.

Godfray, H. C. J. (2011), 'Food for thought'. Proceedings of the National Academy of Sciences, 108(50), 19845. https://doi.org/10.1073/pnas.1118568109

Graves, A. R., Morris, J., Deeks, L. K., Rickson, R. J., Kibblewhite, M. G., Harris, J. A., Farewell, T. S., & Truckle, I. (2015), 'The total costs of soil degradation in England and Wales'. Ecological Economics, 119, 399–413. https://doi.org/https://doi.org/10.1016/j.ecolecon.2015.07.026

Graves, A., Morris, J., Deeks, L.K., Rickson, J., Kibblewhite, M.G., Harris, J.A., Farewell, T.S. (2011), *The total costs of soils degradation in England and Wales*. Defra Project: CTE0946: Final report available at: http://sciencesearch.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=16992

Grizzetti, B., Liquete, C., Pistocchi, A., Vigiak, O., Zulian, G., Bouraoui, F., De Roo, A. and Cardoso, A. C. (2019), 'Relationship between ecological condition and ecosystem services in European rivers, lakes and coastal waters', *Science of The Total Environment*, Vol. 671, pp. 452–465, doi:10.1016/j.scitotenv.2019.03.155.

Grizzetti, B., Vigiak, O., Udias, A., Aloe, A., Zanni, M., Bouraoui, F., Pistocchi, A., Dorati, C., Friedland, R., De Roo, A., Benitez Sanz, C., Leip, A. and Bielza, M. (2021), 'How EU policies could reduce nutrient pollution in European inland and coastal waters', *Global Environmental Change*, Vol. 69, No 102281, doi:10.1016/j.gloenvcha.2021.102281.

Guerra, C. A., Heintz-Buschart, A., Sikorski, J., Chatzinotas, A., Guerrero-Ramírez, N., Cesarz, S., Beaumelle, L., Rillig, M. C., Maestre, F. T., Delgado-Baquerizo, M., Buscot, F., Overmann, J., Patoine, G., Phillips, H. R. P., Winter, M., Wubet, T., Küsel, K., Bardgett, R. D., Cameron, E. K., Cowan, D., Grebenc, T., Marín, C., Orgiazzi, A., Singh, B. K., Wall, D. H. and Eisenhauer, N. (2020), 'Blind spots in global soil biodiversity and ecosystem function research', *Nature Communications*, Vol. 11, No 1, pp. 3870, doi:10.1038/s41467-020-17688-2.

Guilford, T., & Dawkins, M. S. (1991), 'Receiver psychology and the evolution of animal signals'. Animal Behaviour, 42(1), 1–14. https://doi.org/https://doi.org/10.1016/S0003-3472(05)80600-1

Guswa, A. J., Brauman, K. A., Brown, C., Hamel, P., Keeler, B. L. and Sayre, S. S. (2014), 'Ecosystem services: challenges and opportunities for hydrologic modeling to support decision-making', *Water Resources Research*, Vol. 50, No 5, pp. 4535–4544, doi:10.1002/2014WR015497.

Haines-Young, R. and Potschin, M. (2012), 'The links between biodiversity, ecosystem services and human well-being', in Rafaelli, D. G. and Frid, C. L. J. (eds), *Ecosystem Ecology: A new synthesis*, Cambridge University Press, Cambridge.

Haines-Young, R. and M.B. Potschin (2018), *Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure*. Available from www.cices.eu

Hawkins, B. A., Field, R., Cornell, H. V., Currie, D. J., Guégan, J.-F., Kaufman, D. M., Kerr, J. T., Mittelbach, G. G., Oberdorff, T., O'Brien, E. M., Porter, E. E. and Turner, J. R. G. (2003), 'Energy, water, and broad-scale geographic patterns of species richness', *Ecology*, Vol. 84, No 12, pp. 3105–3117, doi:10.1890/03-8006.

Hein, L., Bagstad, K. J., Obst, C., Edens, B., Schenau, S., Castillo, G., Soulard, F., Brown, C., Driver, A., Bordt, M., Steurer, A., Harris, R. and Caparrós, A. (2020), 'Progress in natural capital accounting for ecosystems', *Science*, Vol. 367, No 6477, pp. 514–515, doi:10.1126/science.aaz8901.

Heinrichs, J. A., Bender, D. J. and Schumaker, N. H. (2016), 'Habitat degradation and loss as key drivers of regional population extinction', *Ecological Modelling*, Vol. 335, pp. 64–73, doi:10.1016/j.ecolmodel.2016.05.009.

Herrando S., Villero, D., Brotons, L. and S, V. (2020), 'Development of a biodiversity indicator from EBBA2 modelled maps to model habitat maintenance as ecosystem service'.

Hicks, W.K., C.P. Whitfield, W.J. Bealey en M.A. Sutton (eds.) (2011), 'Nitrogen Deposition and Natura 2000: Science and Practice in Determining Environmental Impacts'. COST729/Nine/ESF/CCW/JNCC/SEI Workshop Proceedings, published by COST. Available at: http://cost729.ceh.ac.uk/n2kworkshop

Holland, B. M., & Johnston, R. J. (2017), 'Optimized quantity-within-distance models of spatial welfare heterogeneity'. Journal of Environmental Economics and Management, 85, 110–129. https://doi.org/10.1016/j.jeem.2017.04.006

Howarth, R., Chan, F., Conley, D. J., Garnier, J., Doney, S. C., Marino, R. and Billen, G. (2011), 'Coupled biogeochemical cycles: eutrophication and hypoxia in temperate estuaries and coastal marine ecosystems', *Frontiers in Ecology and the Environment*, Vol. 9, No 1, pp. 18–26, doi:10.1890/100008.

Howarth, R. W., Billen, G., Swaney, D., Townsend, A., Jaworski, N., Lajtha, K., Downing, J. A., Elmgren, R., Caraco, N., Jordan, T., Berendse, F., Freney, J., Kudeyarov, V., Murdoch, P. and Zhao-Liang, Z. (1996), 'Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: natural and human influences', *Biogeochemistry*, Vol. 35, No 1, pp. 75–139, doi:10.1007/BF02179825.

IPBES (2019), *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, IPBES secretariat, Bonn.

IPBES (2017) Update on the classification of nature's contributions to people by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Note by the Secretariat. IPBES/5/INF/24, available at https://ipbes.net/sites/default/files/downloads/pdf/ipbes-5-inf-24.pdf

Jakobsson, S., Töpper, J. P., Evju, M., Framstad, E., Lyngstad, A., Pedersen, B., Sickel, H., Sverdrup-Thygeson, A., Vandvik, V., Velle, G. L., Aarrestad, A. Nybø, S. (2020), 'Setting reference levels and limits for good ecological condition in terrestrial ecosystems – Insights from a case study based on the IBECA approach', *Ecological Indicators*, Vol. 116, No 106492, doi:10.1016/j.ecolind.2020.106492.

Jones, M.L.M., Provins, A., Harper-Simmonds, L., Holland, M., Mills, G., Hayes, F., Emmett, B.A., Hall, J., Sheppard, L.J., Smith, R., Sutton, M., Hicks, K., Ashmore, M., Haines-Young, R. (2011), 'Using the Ecosystems Services Approach to value air quality'. Annex 1: Review of available evidence and outline methodology. Full technical report to Defra, project NE0117.

Jørgensen, S. (2012), *Introduction to Systems Ecology*, CRC Press, Boca Raton.

Kadlec, R. H. and Wallace, S. (2009), *Treatment Wetlands*, CRC Press, Boca Raton.

Karydas, C. G., Panagos, P. and Gitas, I. Z. (2014), 'A classification of water erosion models according to their geospatial characteristics', *International Journal of Digital Earth*, Vol. 7, No 3, pp. 229–250, doi:10.1080/17538947.2012.671380.

Keith, H., Vardon, M., Stein, J. A. and Lindenmayer, D. (2019), 'Contribution of native forests to climate change mitigation – A common approach to carbon accounting that aligns results from environmental-economic accounting with rules for emissions reduction', *Environmental Science & Policy*, Vol. 93, pp. 189–199, doi:10.1016/j.envsci.2018.11.001.

Keith, H., Czúcz, B., Jackson, B., Driver, A., Nicholson, E. and Maes, J. (2020), 'A conceptual framework and practical structure for implementing ecosystem condition accounts', *One Ecosystem*, Vol. 5, No e58216.

King, S., Vardon, M., Grantham, H. S., Eigenraam, M., Ferrier, S., Juhn, D., Larsen, T., Brown, C. and Turner, K. (2021), 'Linking biodiversity into national economic accounting', *Environmental Science & Policy*, Vol. 116, pp. 20–29, doi:10.1016/j.envsci.2020.10.020.

Kronvang B., Hezlar J., Boers P., Jensen J. P., Behrendt H., Anderson T., Arheimer, B., Venohr, M., Hoffman, C. C. and Nielsen, C. B. (2004), *Nutrient Retention Handbook – Software manual for EUROHARP-NUTRET and scientific review on nutrient retention*, Norwegian Institute for Water Research, Oslo.

Lal, R. (2010), 'Managing Soils and Ecosystems for Mitigating Anthropogenic Carbon Emissions and Advancing Global Food Security'. BioScience, 60(9), 708–721. https://doi.org/10.1525/bio.2010.60.9.8

La Notte, A. and Dalmazzone, S. (2018), 'Sustainability assessment and causality nexus through ecosystem service accounting: the case of water purification in Europe', *Journal of Environmental Management*, Vol. 223, pp. 964–974, doi:10.1016/j.jenvman.2018.06.072.

La Notte, A. and Marques, A. (2017), 'The role of enabling actors in ecosystem service accounting', *One Ecosystem*, Vol. 2, No. e20834.

La Notte, A. and Marques, A. (2019), 'Adjusted macroeconomic indicators to account for ecosystem degradation: an illustrative example', *Ecosystem Health and Sustainability*, Vol. 5, No 1, pp. 133–143, doi:10.1080/20964129.2019.1634979.

La Notte A., Maes, J., Thieu, V., Bouraoui, F. and Masi, F. (2012), *Biophysical Assessment and Monetary Valuation of Ecosystem Services: Scenario analysis for the case of water purification in Europe*, Publications Office of the European Union, Luxembourg.

La Notte, A., Liquete, C., Grizzetti, B., Maes, J., Egoh, B. N. and Paracchini, M. L. (2015), 'An ecological-economic approach to the valuation of ecosystem services to support biodiversity policy. A case study for nitrogen retention by Mediterranean rivers and lakes', *Ecological Indicators*, Vol. 48, pp. 292–302, doi:10.1016/j.ecolind.2014.08.006.

La Notte, A., D'Amato, D., Mäkinen, H., Paracchini, M. L., Liquete, C., Egoh, B., Geneletti, D. and Crossman, N. D. (2017), 'Ecosystem services classification: a systems ecology perspective of the cascade framework', *Ecological Indicators*, Vol. 74, pp. 392–402, doi:10.1016/j.ecolind.2016.11.030.

La Notte, A., Maes, J., Dalmazzone, S., Crossman, N. D., Grizzetti, B. and Bidoglio, G. (2017), 'Physical and monetary ecosystem service accounts for Europe: a case study for in-stream nitrogen retention', *Ecosystem Services*, Vol. 23, pp. 18–29, doi:10.1016/j.ecoser.2016.11.002.

La Notte, A., Vallecillo, S., Marques, A. and Maes, J. (2019), 'Beyond the economic boundaries to account for ecosystem services', *Ecosystem Services*, Vol. 35, pp. 116–129, doi:10.1016/j.ecoser.2018.12.007.

La Notte, A., Grammatikopoulou, I., Grunewald, K., Barton, D. and Ekinci, B. (2021a), *Ecosystem and Ecosystem Services Accounts: Time for applications*, Publications Office of the European Union, Luxembourg.

La Notte, A., Ferrini, S., Pisani, D, Grilli, G., Grammatikopoulou, I., Badura, T, Vallecillo, S, Turner, K., and Maes, J. (2021b), *How much do Europeans value biodiversity? A choice experiment exercise to estimate the "habitat and species maintenance" ecosystem service*, Publications Office of the European Union, Luxembourg

Lamb, E. G., Bayne, E., Holloway, G., Schieck, J., Boutin, S., Herbers, J. and Haughland, D. L. (2009), 'Indices for monitoring biodiversity change: are some more effective than others?', Ecological Indicators, Vol. 9, No 3, pp. 432–444, doi:10.1016/j.ecolind.2008.06.001.

Lankia, T., Neuvonen, M., Pouta, E., Sievänen, T. and Torvelainen, J. (2020), 'Outdoor recreation in ecosystem service accounting: pilot accounts from Finland', *Scandinavian Journal of Forest Research*, Vol. 35, No 3-4, pp. 186–197, doi:10.1080/02827581.2020.1760342.

Leip, A., Britz, W., Weiss, F., & de Vries, W. (2011), 'Farm, land, and soil nitrogen budgets for agriculture in Europe calculated with CAPRI'. Environmental Pollution, 159(11), 3243–3253. https://doi.org/10.1016/j.envpol.2011.01.040

Lennon, J. J., Koleff, P., Greenwood, J. J. D. and Gaston, K. J. (2004), 'Contribution of rarity and commonness to patterns of species richness', *Ecology Letters*, Vol. 7, No 2, pp. 81–87, doi:10.1046/j.1461-0248.2004.00548.x.

Lewis, R. J., Pakeman, R. J., Angus, S. and Marrs, R. H. (2014), 'Using compositional and functional indicators for biodiversity conservation monitoring of semi-natural grasslands in Scotland', *Biological Conservation*, Vol. 175, pp. 82–93, doi:10.1016/j.biocon.2014.04.018.

Liquete, C., Kleeschulte, S., Dige, G., Maes, J., Grizzetti, B., Olah, B. and Zulian, G. (2015), 'Mapping green infrastructure based on ecosystem services and ecological networks: a pan-European case study', *Environmental Science & Policy*, Vol. 54, pp. 268–280, doi:10.1016/j.envsci.2015.07.009.

Logar, I., & Brouwer, R. (2018), 'Substitution Effects and Spatial Preference Heterogeneity in Single- and Multiple-Site Choice Experiments'. Land Economics, 94(2), 302–322.

Mace, G. M., Norris, K. and Fitter, A. H. (2012), 'Biodiversity and ecosystem services: a multilayered relationship', *Trends in Ecology & Evolution*, Vol. 27, No 1, pp. 19–26, doi:10.1016/j.tree.2011.08.006.

Maes J. (2013), 'A model for the assessment of habitat conservation status in the EU' (Issue LB-NA-26186-EN-N). Publications Office of the European Union. https://doi.org/10.2788/27866

Maes J., Teller A., Erhard M., Conde S., & al., et. (2020), 'Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment'. Publications Office of the European Union. https://doi.org/10.2760/757183

Martínez-Jauregui, M., Touza, J., White, P. C. L. and Soliño, M. (2021), 'Choice of biodiversity indicators may affect societal support for conservation programs', *Ecological Indicators*, Vol. 121, No 107203, doi:10.1016/j.ecolind.2020.107203.

McKerrow, A. J., Tarr, N. M., Rubino, M. J. and Williams, S. G. (2018), 'Patterns of species richness hotspots and estimates of their protection are sensitive to spatial resolution', *Diversity and Distributions*, Vol. 24, No 10, pp. 1464–1477, doi:10.1111/ddi.12779.

Methorst, J., Rehdanz, K., Mueller, T., Hansjürgens, B., Bonn, A. and Böhning-Gaese, K. (2021), 'The importance of species diversity for human well-being in Europe', *Ecological Economics*, Vol. 181, No 106917, doi:10.1016/j.ecolecon.2020.106917.

Millennium Ecosystem Assessment (2005), *Ecosystems and Human Well-being*, Island Press, Washington DC.

Morse-Jones, S., Bateman, I. J., Kontoleon, A., Ferrini, S., Burgess, N. D. and Turner, R. K. (2012), 'Stated preferences for tropical wildlife conservation amongst distant beneficiaries: charisma, endemism, scope and substitution effects', *Ecological Economics*, Vol. 78, pp. 9–18, doi:10.1016/j.ecolecon.2011.11.002.

Odum, E. P. (1977), 'The Emergence of Ecology as a New Integrative Discipline'. Science, 195(4284), 1289–1293. https://doi.org/10.1126/science.195.4284.1289

OECD (2009), "Sample Weights", in PISA Data Analysis Manual: SPSS, Second Edition, OECD Publishing, Paris. DOI: https://doi.org/10.1787/9789264056275-4-en

Onofri, L., Lange, G. M., Portela, R. and Nunes, P. A. L. D. (2017), 'Valuing ecosystem services for improved national accounting: a pilot study from Madagascar', Ecosystem Services, Vol. 23, pp. 116–126, doi:10.1016/j.ecoser.2016.11.016.

Orme, C. D. L., Davies, R. G., Burgess, M., Eigenbrod, F., Pickup, N., Olson, V. A., Webster, A. J., Ding, T.-S., Rasmussen, P. C., Ridgely, R. S., Stattersfield, A. J., Bennett, P. M., Blackburn, T. M., Gaston, K. J. and Owens, I. P. F.

(2005), ‘Global hotspots of species richness are not congruent with endemism or threat’, *Nature*, Vol. 436, No 7053, pp. 1016–1019, doi:10.1038/nature03850.

Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E. and Montanarella, L. (2015), ‘Estimating the soil erosion cover-management factor at the European scale’, *Land Use Policy*, Vol. 48, pp. 38–50, doi:10.1016/j.landusepol.2015.05.021.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. and Alewell, C. (2015), ‘The new assessment of soil loss by water erosion in Europe’, *Environmental Science & Policy*, Vol. 54, pp. 438–447, doi:10.1016/j.envsci.2015.08.012.

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G. P. and Smith, P. (2016), ‘Climate-smart soils’, *Nature*, Vol. 532, No 7597, pp. 49–57, doi:10.1038/nature17174.

Parikh, S. J. & James, B. R. (2012), *Soil: The Foundation of Agriculture. Nature Education Knowledge* 3(10):2 available at https://www.nature.com/scitable/knowledge/library/soil-the-foundation-of-agriculture-84224268/

Pearman, P. B. and Weber, D. (2007), ‘Common species determine richness patterns in biodiversity indicator taxa’, *Biological Conservation*, Vol. 138, No 1, pp. 109–119, doi:10.1016/j.biocon.2007.04.005.

Pedro-Monzonís, M., Solera, A., Ferrer, J., Andreu, J. and Estrela, T. (2016), ‘Water accounting for stressed river basins based on water resources management models’, *Science of The Total Environment*, Vol. 565, pp. 181–190, doi:10.1016/j.scitotenv.2016.04.161.

Pérez-Soba, M., Elbersen, B., Braat, L., Kempen, M., Van Der Wijngaart, R., Staritsky I., Rega, C. and Paracchini, M. (2019), *The Emergy Perspective: Natural and anthropic energy flows in agricultural biomass production*, Publications Office of the European Union, Luxembourg.

Perrings, C., Naeem, S., Ahrestani, F., Bunker, D. E., Burkill, P., Canziani, G., Elmqvist, T., Ferrati, R., Fuhrman, J., Jaksic, F., Kawabata, Z., Kinzig, A., Mace, G. M., Milano, F., Mooney, H., Prieur-Richard, A.-H., Tschirhart, J. and Weisser, W. (2010), ‘Ecosystem services for 2020’, *Science*, Vol. 330, No 6002, pp. 323, doi:10.1126/science.1196431

Pilli, R. and Grassi, G. (2021), *Provision of technical and scientific support to DG ESTAT in relation to EU land footprint estimates and gap-filling techniques for European forest accounts (LAFO)*, Publications Office of the European Union, Luxembourg.

Poor, P. J. and Smith, J. M. (2004), ‘Travel cost analysis of a cultural heritage site: the case of historic St. Mary’s City of Maryland’, *Journal of Cultural Economics*, Vol. 28, No 3, pp. 217–229, doi:10.1023/B:JCEC.0000038020.51631.55.

Potschin-Young, M., Haines-Young, R., Görg, C., Heink, U., Jax, K. and Schleyer, C. (2018), ‘Understanding the role of conceptual frameworks: reading the ecosystem service cascade’, *Ecosystem Services*, Vol. 29, pp. 428–440, doi:10.1016/j.ecoser.2017.05.015.

Pretzsch H. (2009), Forest Dynamics, Growth and Yield – From measurement to model, Springer-Verlag, Berlin, Heidelberg.

Rebetez, M., Mayer, H., Dupont, O., Schindler, D., Gartner, K., Kropp, J. P., & Menzel, A. (2006), ‘Heat and drought 2003 in Europe: a climate synthesis’. Ann. For. Sci., 63(6), 569–577. https://doi.org/10.1051/forest:2006043

Redman, G. (2018), ‘The John Nix Pocketbook for Farm Management 2019’. 49th Edition. Melton Mowbray: Agro Business Consultants.

Reed, S. C. and Brown, D. (1995), ‘Subsurface flow wetlands – A performance evaluation’, *Water Environment Research*, Vol. 67, No 2, pp. 244–248, doi:10.2175/106143095X131420.

Renard, K. G., Foster, G. R., Weesies, G. A. and Porter, J. P. (1991), ‘RUSLE: revised universal soil loss equation’, *Journal of Soil and Water Conservation*, Vol. 46, No 1, pp. 30.

Ridolfi, R. and Bastianoni, S. (2008), ‘Emergy’, in Jørgensen, S. E. and Fath, B. D. (eds), *Encyclopedia of Ecology: Ecological indicator*s, pp. 1218–1228.

Saunders, D. L. and Kalff, J. (2001), ‘Nitrogen retention in wetlands, lakes and rivers’, *Hydrobiologia*, Vol. 443, No 1, pp. 205–212, doi:10.1023/A:1017506914063.

Seitzinger, S., Harrison, J. A., Böhlke, J. K., Bouwman, A. F., Lowrance, R., Peterson, B., Tobias, C. and Van Drecht, G. (2006), ‘Denitrification across landscapes and waterscapes: a synthesis’, *Ecological Applications*, Vol. 16, No 6, pp. 2064–2090, doi:10.1890/1051-0761(2006)016[2064:DALAWA]2.0.CO;2.

Sekercioglu, C. H. (2006), ‘Increasing awareness of avian ecological function’, *Trends in Ecology & Evolution*, Vol. 21, No 8, pp. 464–471, doi:10.1016/j.tree.2006.05.007.

Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E. et al. (2018), ‘Retention efficiency’, in: InVEST 3.6.0 User’s Guide. The Natural Capital Project, http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/ndr.html#retention-efficiency.

Shrestha, P., Hurley, S. E. and Wemple, B. C. (2018), ‘Effects of different soil media, vegetation, and hydrologic treatments on nutrient and sediment removal in roadside bioretention systems’, *Ecological Engineering*, Vol. 112, pp. 116–131, doi:10.1016/j.ecoleng.2017.12.004.

Skovsgaard, J. P. and Vanclay, J. K. (2007), ‘Forest site productivity: a review of the evolution of dendrometric concepts for even-aged stands’, *Forestry: An International Journal of Forest Research*, Vol. 81, No 1, pp. 13–31, doi:10.1093/forestry/cpm041.

Sutton, M. A., Howard, C. M., Erisman, J. W., Billen, G., Bleeker, A., Grennfelt, P., van Grinsven, H. and Grizzetti, B. (eds) (2011), *The European Nitrogen Assessment: Sources, effects and policy perspectives*, Cambridge University Press, Cambridge.

Syrbe, R.-U., Schorcht, M., Grunewald, K. and Meinel, G. (2018), ‘Indicators for a nationwide monitoring of ecosystem services in Germany exemplified by the mitigation of soil erosion by water’, *Ecological Indicators*, Vol. 94, pp. 46–54, doi:10.1016/j.ecolind.2017.05.035.

TEEB (2010), *Ecological and Economic Foundations*, Earthscan, London, Washington.

ten Brink, B. J. E. (2000), ‘Biodiversity indicators for the OECD environmental outlook and strategy’, in *Biodiversiteitsindicatoren voor de OESOmilieuverkenning en -strategies*, Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven.

The Natural Capital Project (2016), *NatCap nutrient parameter database*.
https://www.naturalcapitalproject.org/wp-content/uploads/2016/04/Nutrient_DB_0212.xlsx

Török, P., Vida, E., Deák, B., Lengyel, S., & Tóthmérész, B. (2011), ‘Grassland restoration on former croplands in Europe: an assessment of applicability of techniques and costs’. Biodiversity and Conservation, 20(11), 2311–2332. https://doi.org/10.1007/s10531-011-9992-4

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., Eckley, N., Kasperson, J. X., Luers, A., Martello, M. L., Polsky, C., Pulsipher, A. and Schiller, A. (2003), ‘A framework for vulnerability analysis in sustainability science’, *Proceedings of the National Academy of Sciences*, Vol. 100, No 14, pp. 8074, doi:10.1073/pnas.1231335100.

UN (2019), *Technical recommendations in support of the system of environmental-economic accounting 2012 – Experimental ecosystem accounting*, United Nations, New York.

UN (2021), *System of Environmental-Economic Accounting – Ecosystem accounting: Final draft*, United Nations, New York.

UN, European Union, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development and World Bank (2014), *System of Environmental Economic Accounting 2012 – Central framework*, United Nations, New York.

US EPA (2015). National Ecosystem Services Classification System (NESCS): Framework Design and Policy Application. EPA-800-R-15-002. United States Environmental Protection Agency, Washington, DC. available at https://www.epa.gov/sites/default/files/2015-12/documents/110915_nescs_final_report_-_compliant_1.pdf

Vallecillo S., La Notte A., Polce C., Zulian G., Alexandris N., Ferrini S. and Maes, J. (2018), *Ecosystem Services Accounting – Part I: Outdoor recreation and crop pollination*, Publications Office of the European Union, Luxembourg.

Vallecillo, S., La Notte, A., Ferrini, S. and Maes, J. (2019a), ‘How ecosystem services are changing: an accounting application at the EU level’, *Ecosystem Services*, Vol. 40, No 101044, doi:10.1016/j.ecoser.2019.101044.

Vallecillo S., La Notte A., Kakoulaki G., Kamberaj J., Robert N., Dottori F., Feyen, L., Rega, C. and Maes, J. (2019b), *Ecosystem Services Accounting – Part II: Pilot accounts for crop and timber provision, global climate regulation and flood control*, Publications Office of the European Union, Luxembourg.

Vallecillo, S., Maes, J., Polce, C., & Lavalle, C. (2016), 'A habitat quality indicator for common birds in Europe based on species distribution models'. Ecological Indicators, 69, 488–499. https://doi.org/10.1016/j.ecolind.2016.05.008

Van Dobben, H.; Bobbink, R.; Bal, D. and A. van Hinsberg. (2013), 'Overview of critical loads for nitrogen deposition for Natura 2000 habitat types occurring in The Netherlands', Alterra Report 2488.

Vigerstol, K. and Aukema, J. E. (2011), 'A comparison of tools for modeling freshwater ecosystem services', *Journal of Environmental Management*, Vol. 92, No 10, pp. 2403–2409.

Vigiak, O., Grizzetti, B., Zanni, M., Aloe, A., Dorati, C., Bouraoui, F., & Pistocchi, A. (2020), 'Domestic waste emissions to European waters in the 2010s'. Scientific Data, 7(1), 33. https://doi.org/10.1038/s41597-020-0367-0

Vysna, V., Maes, J., Petersen, J.-E., La Notte, A., Vallecillo, S., Aizpurua, N. Ivits, E. and Teller, A. (2021), *Accounting for ecosystems and their services in the European Union – Final report from phase II of the INCA project aiming to develop a pilot for an integrated system of ecosystem accounts for the EU*, Publications Office of the European Union, Luxembourg.

Warnell, K. J. D., Russell, M., Rhodes, C., Bagstad, K. J., Olander, L. P., Nowak, D. J., Poudel, R., Glynn, P. D., Hass, J. L., Hirabayashi, S., Ingram, J. C., Matuszak, J., Oleson, K. L. L., Posner, S. M. and Villa, F. (2020), 'Testing ecosystem accounting in the United States: a case study for the southeast', *Ecosystem Services*, Vol. 43, No 101099, doi:10.1016/j.ecoser.2020.101099.

Willis, K. and Garrod, G. (1991), 'An individual travel-cost method of evaluating forest recreation', *Journal of Agricultural Economics*, Vol. 42, pp. 33–42.

Whittaker, R. J., Willis, K. J., & Field, R. (2001), 'Scale and species richness: towards a general, hierarchical theory of species diversity'. Journal of Biogeography, 28(4), 453–470. https://doi.org/https://doi.org/10.1046/j.1365-2699.2001.00563.x

Wolff, S., Schulp, C. J. E. and Verburg, P. H. (2015), 'Mapping ecosystem services demand: a review of current research and future perspectives', *Ecological Indicators*, Vol. 55, pp. 159–171, doi:10.1016/j.ecolind.2015.03.016.

Yang, G., Best, E. P. H., Whiteaker, T., Teklitz, A., & Yeghiazarian, L. (2014), 'A screening-level modeling approach to estimate nitrogen loading and standard exceedance risk, with application to the Tippecanoe River watershed, Indiana'. Journal of Environmental Management, 135, 1–10. https://doi.org/10.1016/j.jenvman.2014.01.003

10. Abbreviations

CAPRI	common agricultural policy regionalised impact
CF	central framework
CICES	Common International Classification of Ecosystem Services
CLC	Corine land cover
Corine	coordination of information on the environment in Europe
CW	constructed wetland
EA	ecosystem accounting
EBBA2	*European Breeding Bird Atlas 2*
EEA	experimental ecosystem accounting
EMEP	European monitoring and evaluation programme
ES	ecosystem service
ES D	ecosystem service demand
ES P	ecosystem service potential
FWS	free water surface
GREEN	geospatial regression equation for European nutrient losses
HF	horizontal subsurface flow
INCA	Integrated system for Natural Capital Accounting
IPBES	Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services
LULUCF	land use, land use change and forestry
MAES	Mapping and Assessment of Ecosystems and their Services
NAI	net annual increment
NR	non-renewable resource
NUTS	nomenclature of territorial units for statistics (Eurostat)
O&M	operation and maintenance
RUSLE	revised universal soil loss equation
SEEA	system of environmental economic accounting
SEV	simulated exchange value
SNA	system of national accounts
SOC	soil organic carbon
SOM	soil organic matter
SUT	supply and use table
TEEB	the economics of ecosystems and biodiversity
WTP	willingness to pay

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13. Accounting annexes

AA1. Supply table of habitat and species maintenance in monetary terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector		Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/int. area	**Total**
	Agriculture	Forestry														
(million EUR)																
AT								2.69	1.65	4.79	0.02	0.27	0.71	0.09		10.22
BE								0.64	0.15	0.26	0.00	0.01	0.00	0.01		1.07
BG								228.4	33.78	174.54	0.51	1.26	2.38	4.28		445.15
CY								8.06	0.53	3.11	0.01	2.60	0.45	0.04		14.80
CZ								3.94	0.70	2.80	0.01	0.00	0.00	0.06		7.52
DE								12.93	6.08	10.11	0.10	0.09	0.05	0.39		29.74
DK								4.75	0.13	0.70	0.09	0.07	0.01	0.06		5.81
EE								7.95	2.43	17.59	1.49	0.05	0.02	0.93		30.45
EL								58.62	13.02	41.32	0.28	26.83	3.05	1.26		144.40
ES								1,018	213	581	2	300	37	12		2,162
FI								1,301	10	10,737	956	294	85	1,427		14,811
FR								50.05	19.95	31.57	0.19	2.03	1.80	0.81		106.40
HR								19.64	5.22	25.60	0.18	1.09	0.46	0.51		52.70
HU								14.07	2.34	5.03	0.22	0.00	0.01	0.47		22.13
IE								2.46	10.44	1.65	2.76	0.23	0.19	0.32		18.05
IT								25.62	2.88	14.42	0.03	1.82	1.45	0.37		46.59
LT								999.9	114.2	611.97	17.1	0.38	0.32	36.32		1,779
LU								0.07	0.03	0.07	0.00	0.00	0.00	0.00		0.18
LV								860.2	342.4	1,466	72.8	0.00	2.90	62.93		2,807
MT								0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
NL								0.33	0.25	0.08	0.01	0.01	0.00	0.05		0.73
PL								88.77	15.74	55.63	0.59	0.02	0.08	2.60		163.42
PT								20.09	0.90	16.76	0.01	2.77	0.63	0.30		41.46
RO								301.9	81.82	198.59	8.56	1.88	0.62	9.26		602.62
SE								676.1	79.28	5,259	511.4	478.82	198	667		7,870
SI								0.28	0.06	0.56	0.00	0.01	0.01	0.00		0.93
SK								1.27	0.18	1.32	0.00	0.01	0.01	0.02		2.81
UK								18.73	22.29	6.21	5.59	4.51	0.81	0.63		58.77
EU								5,726	979	19,269	1,58	1,119	337	2,229	0	31,238

AA2. Use table of habitat and species maintenance in monetary terms, year 2000

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT						10.22	10.22									
BE						1.07	1.07									
BG						445.15	445.15									
CY						14.80	14.80									
CZ						7.52	7.52									
DE						29.74	29.74									
DK						5.81	5.81									
EE						30.45	30.45									
EL						144.40	144.40									
ES						2,162.86	2,163									
FI						14,811.44	14,811									
FR						106.40	106.40									
HR						52.70	52.70									
HU						22.13	22.13									
IE						18.05	18.05									
IT						46.59	46.59									
LT						1,779.50	1,779									
LU						0.18	0.18									
LV						2,807.79	2,808									
MT						0.00	0.002									
NL						0.73	0.73									
PL						163.42	163.42									
PT						41.46	41.46									
RO						602.62	603									
SE						7,870.78	7,871									
SI						0.93	0.93									
SK						2.81	2.81									
UK						58.77	58.77									
EU	0	0	0	0	0	31,238	31,238									

AA3. Supply table of habitat and species maintenance in monetary terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT								5.04	3.10	8.99	0.05	0.51	1.34	0.18		19.20
BE								0.67	0.16	0.27	0.00	0.01	0.00	0.01		1.13
BG								170.6	25.01	130.31	0.39	0.93	1.76	3.20		332.17
CY								9.31	0.59	3.76	0.01	2.99	0.40	0.05		17.10
CZ								4.33	0.95	3.21	0.01	0.00	0.00	0.07		8.57
DE								16.73	7.81	13.10	0.13	0.11	0.05	0.52		38.46
DK								5.75	0.15	0.86	0.10	0.08	0.01	0.08		7.03
EE								14.09	4.14	31.11	2.64	0.08	0.04	1.64		53.74
EL								52.96	11.80	37.24	0.25	24.14	3.14	1.22		130.76
ES								935.1	195.3	534.56	1.93	273.64	31.74	12.60		1,984
FI								1,325	9.89	10,755	954.9	295.36	85.61	1,432		14,859
FR								47.37	18.84	29.96	0.18	1.91	1.70	0.78		100.75
HR								16.15	4.20	20.89	0.15	0.88	0.39	0.42		43.07
HU								12.97	2.16	4.93	0.21	0.00	0.01	0.45		20.73
IE								0.62	2.71	0.48	0.70	0.06	0.05	0.08		4.70
IT								25.34	2.84	14.27	0.03	1.80	1.44	0.38		46.10
LT								555.5	60.48	343.22	9.54	0.19	0.13	20.2		989.24
LU								0.06	0.03	0.06	0.00	0.00	0.00	0.00		0.15
LV								1,220	462.8	2,059	102.2	0.00	4.07	88.5		3,937
MT								0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
NL								0.35	0.27	0.08	0.01	0.01	0.00	0.06		0.79
PL								142.1	25.05	89.91	0.95	0.02	0.12	4.24		262.37
PT								10.11	0.44	8.64	0.01	1.35	0.29	0.20		21.03
RO								127	34.34	83.61	3.64	0.79	0.26	3.91		253.57
SE								801.1	94.34	6,235	606.4	567.69	235.52	791		9,331
SI								0.19	0.04	0.39	0.00	0.01	0.01	0.00		0.65
SK								1.73	0.24	1.80	0.00	0.01	0.01	0.03		3.82
UK								14.83	17.63	4.95	4.43	3.57	0.64	0.50		46.55
EU								5,516	985	20,416	1,689	1,176	369	2,363	0	32,515

AA4. Use table of habitat and species maintenance in monetary terms, year 2012

	Economic unit							**Ecosystem type**								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT						19.20	19.20									
BE						1.13	1.13									
BG						332.17	332.17									
CY						17.10	17.10									
CZ						8.57	8.57									
DE						38.46	38.46									
DK						7.03	7.03									
EE						53.74	53.74									
EL						130.76	130.76									
ES						1,984.76	1,985									
FI						14,859.28	14,859									
FR						100.75	100.75									
HR						43.07	43.07									
HU						20.73	20.73									
IE						4.70	4.70									
IT						46.10	46.10									
LT						989.24	989.24									
LU						0.15	0.15									
LV						3,937.43	3,937									
MT						0.00	0.00									
NL						0.79	0.79									
PL						262.37	262.37									
PT						21.03	21.03									
RO						253.57	253.57									
SE						9,331.57	9,332									
SI						0.65	0.65									
SK						3.82	3.82									
UK						46.55	46.55									
EU	0	0	0	0	0	32,515	32,515									

AA5. Supply table of soil retention in physical terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT							55	24 160	132 421	364 789		31 345	24 854			577 623
BE							33	5 801	2 558	9 966		70	0			18 427
BG							31	33 583	14 040	137 008		1 408	669			186 740
CY							4	2 586	337	8 075		3 039	132			14 172
CZ							62	20 177	7 593	53 717		52	2			81 601
DE							330	39 838	55 321	201 884		2 081	402			299 856
DK							19	2 873	62	1 066		31	0			4 050
EE							6	1 531	458	5 063		3	0			7 060
EL							21	55 550	36 307	191 632		87 025	4 283			374 819
ES							193	174 163	124 717	574 013		241 173	12 156			1 126 416
FI							10	2 334	83	37 122		1 908	49			41 507
FR							189	116 343	173 146	470 169		39 757	23 782			823 386
HR							32	21 939	16 699	147 481		4 968	1 012			192 131
HU							30	14 410	4 175	34 273		0	2			52 891
IE							8	3 960	18 662	8 832		3 815	1 979			37 256
IT							262	358 506	178 141	1 169 384		83 025	24 342			1 813 661
LT							40	5 658	816	7 218		2	1			13 735
LU							7	1 130	415	2 707		0	0			4 258
LV							15	3 344	1 735	10 267		0	1			15 362
MT							3	137	0	2		32	0			174
NL							22	1 160	766	600		45	0			2 592
PL							75	38 516	6 550	65 033		276	15			110 465
PT							30	25 930	2 620	62 315		11 642	1 571			104 108
RO							31	62 472	67 176	336 401		6 173	178			472 431
SE							90	6 149	6 435	158 809		36 265	4 256			212 003
SI							23	28 645	11 977	200 193		8 201	2 297			251 335
SK							12	14 025	6 661	77 021		1 193	195			99 106
UK							229	11 942	145 622	63 063		74 270	13 499			308 625
EU							1 861	1 076 861	1 015 492	4 398 103	0	637 798	115 676	0	0	7 245 791

AA6. Use table of soil retention in physical terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT	24 160						55		132 421	364 789		31 345	24 854			577 623
BE	5 801						33		2 558	9 966		70	0			18 427
BG	33 583						31		14 040	137 008		1 408	669			186 740
CY	2 586						4		337	8 075		3 039	132			14 172
CZ	20 177						62		7 593	53 717		52	2			81 601
DE	39 838						330		55 321	201 884		2 081	402			299 856
DK	2 873						19		62	1 066		31	0			4 050
EE	1 531						6		458	5 063		3	0			7 060
EL	55 550						21		36 307	191 632		87 025	4 283			374 819
ES	174 163						193		124 717	574 013		241 173	12 156			1 126 416
FI	2 334						10		83	37 122		1 908	49			41 507
FR	116 343						189		173 146	470 169		39 757	23 782			823 386
HR	21 939						32		16 699	147 481		4 968	1 012			192 131
HU	14 410						30		4 175	34 273		0	2			52 891
IE	3 960						8		18 662	8 832		3 815	1 979			37 256
IT	358 506						262		178 141	1 169 384		83 025	24 342			1 813 661
LT	5 658						40		816	7 218		2	1			13 735
LU	1 130						7		415	2 707		0	0			4 258
LV	3 344						15		1 735	10 267		0	1			15 362
MT	137						3		0	2		32	0			174
NL	1 160						22		766	600		45	0			2 592
PL	38 516						75		6 550	65 033		276	15			110 465
PT	25 930						30		2 620	62 315		11 642	1 571			104 108
RO	62 472						31		67 176	336 401		6 173	178			472 431
SE	6 149						90		6 435	158 809		36 265	4 256			212 003
SI	28 645						23		11 977	200 193		8 201	2 297			251 335
SK	14 025						12		6 661	77 021		1 193	195			99 106
UK	11 942						229		145 622	63 063		74 270	13 499			308 625
EU	1 076 861						1 861		1 015 492	4 398 103		637 798	115 676			7 245 791

AA7. Supply table of soil retention in monetary terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT								250								250
BE								61								61
BG								344								344
CY								26								26
CZ								210								210
DE								413								413
DK								30								30
EE								16								16
EL								574								574
ES								1 794								1 794
FI								24								24
FR								1 205								1 205
HR								220								220
HU								148								148
IE								42								42
IT								3 697								3 697
LT								58								58
LU								12								12
LV								34								34
MT								1								1
NL								12								12
PL								395								395
PT								266								266
RO								645								645
SE								64								64
SI								301								301
SK								146								146
UK								125								125
EU								11 114								11 114

AA8. Use table of soil retention in monetary terms, year 2000

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	250						250									
BE	61						61									
BG	344						344									
CY	26						26									
CZ	210						210									
DE	413						413									
DK	30						30									
EE	16						16									
EL	574						574									
ES	1 794						1 794									
FI	24						24									
FR	1 205						1 205									
HR	220						220									
HU	148						148									
IE	42						42									
IT	3 697						3 697									
LT	58						58									
LU	12						12									
LV	34						34									
MT	1						1									
NL	12						12									
PL	395						395									
PT	266						266									
RO	645						645									
SE	64						64									
SI	301						301									
SK	146						146									
UK	125						125									
EU	11 114						11 114									

AA9. Supply table of soil retention in physical terms, year 2006

	Economic unit						Ecosystem type									Total
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	
(1 000 tonnes)																
AT							54	24 953	131 555	364 443		31 146	24 021			576 172
BE							33	5 966	2 523	9 959		68	0			18 549
BG							31	37 897	14 015	136 968		1 385	676			190 972
CY							3	2 805	329	8 320		3 012	69			14 537
CZ							61	22 172	7 981	53 741		51	2			84 008
DE							329	49 165	54 674	201 804		2 070	382			308 424
DK							19	3 031	60	1 066		31	0			4 207
EE							6	1 637	438	5 053		3	0			7 136
EL							21	54 209	36 316	191 382		86 922	4 316			373 166
ES							193	186 566	124 370	574 061		240 116	11 323			1 136 629
FI							10	2 505	83	37 078		1 910	50			41 637
FR							186	121 567	171 708	469 964		39 349	22 588			825 363
HR							32	21 946	16 490	147 173		4 943	972			191 556
HU							30	15 416	4 064	34 389		0	2			53 902
IE							8	3 913	18 371	9 380		3 784	1 948			37 404
IT							260	366 182	177 150	1 168 948		82 851	23 149			1 818 540
LT							40	5 714	799	7 216		2	1			13 772
LU							6	1 148	406	2 710		0	0			4 271
LV							15	3 351	1 705	10 233		0	1			15 304
MT							3	138	0	2		32	0			175
NL							23	1 140	746	599		45	0			2 553
PL							75	40 189	6 463	65 072		275	14			112 087
PT							30	26 194	2 560	61 282		11 062	1 753			102 881
RO							31	67 080	67 147	336 220		6 167	176			476 820
SE							89	6 534	6 426	158 498		36 260	4 261			212 067
SI							23	28 154	11 851	200 056		8 145	2 213			250 442
SK							12	14 773	6 527	77 026		1 187	190			99 715
UK							227	14 385	144 101	63 214		73 717	12 922			308 566
EU							1 849	1 128 730	1 008 860	4 395 854		634 532	111 027			7 280 853

AA10. Use table of soil retention in physical terms, year 2006

	Economic unit						**Ecosystem type**									**Total**
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	
(1 000 tonnes)																
AT	24 953						54		131 555	364 443		31 146	24 021			576 172
BE	5 966						33		2 523	9 959		68	0			18 549
BG	37 897						31		14 015	136 968		1 385	676			190 972
CY	2 805						3		329	8 320		3 012	69			14 537
CZ	22 172						61		7 981	53 741		51	2			84 008
DE	49 165						329		54 674	201 804		2 070	382			308 424
DK	3 031						19		60	1 066		31	0			4 207
EE	1 637						6		438	5 053		3	0			7 136
EL	54 209						21		36 316	191 382		86 922	4 316			373 166
ES	186 566						193		124 370	574 061		240 116	11 323			1 136 629
FI	2 505						10		83	37 078		1 910	50			41 637
FR	121 567						186		171 708	469 964		39 349	22 588			825 363
HR	21 946						32		16 490	147 173		4 943	972			191 556
HU	15 416						30		4 064	34 389		0	2			53 902
IE	3 913						8		18 371	9 380		3 784	1 948			37 404
IT	366 182						260		177 150	1 168 948		82 851	23 149			1 818 540
LT	5 714						40		799	7 216		2	1			13 772
LU	1 148						6		406	2 710		0	0			4 271
LV	3 351						15		1 705	10 233		0	1			15 304
MT	138						3		0	2		32	0			175
NL	1 140						23		746	599		45	0			2 553
PL	40 189						75		6 463	65 072		275	14			112 087
PT	26 194						30		2 560	61 282		11 062	1 753			102 881
RO	67 080						31		67 147	336 220		6 167	176			476 820
SE	6 534						89		6 426	158 498		36 260	4 261			212 067
SI	28 154						23		11 851	200 056		8 145	2 213			250 442
SK	14 773						12		6 527	77 026		1 187	190			99 715
UK	14 385						227		144 101	63 214		73 717	12 922			308 566
EU	1 128 730						1 849		1 008 860	4 395 854		634 532	111 027			7 280 853

AA11. Supply table of soil retention in monetary terms, year 2006

	Economic unit						**Ecosystem type**									**Total**
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	
(million EUR)																
AT								258								258
BE								63								63
BG								388								388
CY								28								28
CZ								231								231
DE								510								510
DK								31								31
EE								17								17
EL								560								560
ES								1 921								1 921
FI								26								26
FR								1 259								1 259
HR								220								220
HU								159								159
IE								41								41
IT								3 775								3 775
LT								59								59
LU								12								12
LV								34								34
MT								1								1
NL								12								12
PL								412								412
PT								269								269
RO								693								693
SE								68								68
SI								296								296
SK								154								154
UK								151								151
EU								11 648								11 648

AA12. Use table of soil retention in monetary terms, year 2006

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	258						258									
BE	63						63									
BG	388						388									
CY	28						28									
CZ	231						231									
DE	510						510									
DK	31						31									
EE	17						17									
EL	560						560									
ES	1 921						1 921									
FI	26						26									
FR	1 259						1 259									
HR	220						220									
HU	159						159									
IE	41						41									
IT	3 775						3 775									
LT	59						59									
LU	12						12									
LV	34						34									
MT	1						1									
NL	12						12									
PL	412						412									
PT	269						269									
RO	693						693									
SE	68						68									
SI	296						296									
SK	154						154									
UK	151						151									
EU	11 648						11 648									

AA13. Supply table of soil retention in physical terms, year 2012

	Economic unit						**Ecosystem type**									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT							55	24 006	132 005	363 732		31 134	24 230			575 163
BE							32	5 611	2 530	9 950		68	0			18 192
BG							30	37 002	13 921	136 878		1 384	655			189 869
CY							3	2 839	330	8 319		3 009	86			14 587
CZ							61	21 421	8 652	53 786		52	2			83 974
DE							330	47 311	54 645	201 781		2 075	385			306 528
DK							19	3 041	60	1 066		31	0			4 217
EE							6	1 602	435	5 063		3	0			7 109
EL							21	54 550	36 436	191 054		86 708	4 699			373 468
ES							212	183 822	124 244	574 250		239 418	11 458			1 133 404
FI							10	2 471	82	37 061		1 905	49			41 578
FR							186	123 828	171 837	470 176		39 570	22 971			828 567
HR							32	21 768	16 397	146 786		4 906	1 021			190 910
HU							30	13 767	4 060	34 570		0	2			52 429
IE							8	3 846	18 429	9 520		3 781	1 953			37 537
IT							263	362 790	177 348	1 168 457		82 871	24 017			1 815 747
LT							40	5 608	778	7 260		1	0			13 687
LU							6	1 148	405	2 708		0	0			4 267
LV							15	3 366	1 674	10 220		0	1			15 276
MT							3	139	0	2		32	0			176
NL							24	1 008	747	598		47	0			2 423
PL							75	39 185	6 420	65 205		275	14			111 174
PT							30	25 979	2 552	61 902		11 293	1 592			103 349
RO							31	66 113	66 465	336 117		6 146	172			475 045
SE							89	6 487	6 429	158 887		36 226	4 201			212 319
SI							23	28 055	11 857	200 027		8 139	2 214			250 315
SK							12	14 090	6 516	77 004		1 191	195			99 007
UK							228	14 541	144 934	63 061		73 924	13 192			309 878
EU							1 873	1 115 392	1 010 190	4 395 439		634 189	113 109			7 270 193

AA14. Use table of soil retention in physical terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT	24 006						55		132 005	363 732		31 134	24 230			575 163
BE	5 611						32		2 530	9 950		68	0			18 192
BG	37 002						30		13 921	136 878		1 384	655			189 869
CY	2 839						3		330	8 319		3 009	86			14 587
CZ	21 421						61		8 652	53 786		52	2			83 974
DE	47 311						330		54 645	201 781		2 075	385			306 528
DK	3 041						19		60	1 066		31	0			4 217
EE	1 602						6		435	5 063		3	0			7 109
EL	54 550						21		36 436	191 054		86 708	4 699			373 468
ES	183 822						212		124 244	574 250		239 418	11 458			1 133 404
FI	2 471						10		82	37 061		1 905	49			41 578
FR	123 828						186		171 837	470 176		39 570	22 971			828 567
HR	21 768						32		16 397	146 786		4 906	1 021			190 910
HU	13 767						30		4 060	34 570		0	2			52 429
IE	3 846						8		18 429	9 520		3 781	1 953			37 537
IT	362 790						263		177 348	1 168 457		82 871	24 017			1 815 747
LT	5 608						40		778	7 260		1	0			13 687
LU	1 148						6		405	2 708		0	0			4 267
LV	3 366						15		1 674	10 220		0	1			15 276
MT	139						3		0	2		32	0			176
NL	1 008						24		747	598		47	0			2 423
PL	39 185						75		6 420	65 205		275	14			111 174
PT	25 979						30		2 552	61 902		11 293	1 592			103 349
RO	66 113						31		66 465	336 117		6 146	172			475 045
SE	6 487						89		6 429	158 887		36 226	4 201			212 319
SI	28 055						23		11 857	200 027		8 139	2 214			250 315
SK	14 090						12		6 516	77 004		1 191	195			99 007
UK	14 541						228		144 934	63 061		73 924	13 192			309 878
EU	1 115 392						1 873		1 010 190	4 395 439		634 189	113 109			7 270 193

AA15. Supply table of soil retention in monetary terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT								249								249
BE								59								59
BG								379								379
CY								28								28
CZ								223								223
DE								491								491
DK								32								32
EE								17								17
EL								564								564
ES								1 893								1 893
FI								26								26
FR								1 282								1 282
HR								218								218
HU								142								142
IE								41								41
IT								3 739								3 739
LT								57								57
LU								15								15
LV								34								34
MT								1								1
NL								10								10
PL								402								402
PT								267								267
RO								683								683
SE								67								67
SI								295								295
SK								147								147
UK								152								152
EU								11 512								11 512

AA16. Use table of soil retention in physical terms, year 2012

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	249						249									
BE	59						59									
BG	379						379									
CY	28						28									
CZ	223						223									
DE	491						491									
DK	32						32									
EE	17						17									
EL	564						564									
ES	1 893						1 893									
FI	26						26									
FR	1 282						1 282									
HR	218						218									
HU	142						142									
IE	41						41									
IT	3 739						3 739									
LT	57						57									
LU	15						15									
LV	34						34									
MT	1						1									
NL	10						10									
PL	402						402									
PT	267						267									
RO	683						683									
SE	67						67									
SI	295						295									
SK	147						147									
UK	152						152									
EU	11 512						11 512									

AA17. Supply table of water purification in physical terms, year 2006

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT							9	172	30	85	0.31	1.8	5.95	4.55		308
BE							26	245	27	36	0.21	0.6	0.04	1.19		336
BG							5	217	10	44	0.12	0.1	0.37	11.15		288
CY							1	17	0	1	0.00	1.0	0.24	0.06		21
CZ							12	358	22	92	0.14	0.01	0.00	4.85		489
DE							114	1 969	388	559	4.52	1.6	0.61	31.21		3 067
DK							10	406	4	28	1.63	0.9	0.10	1.70		452
EE							1	33	4	28	1.08	0.04	0.02	2.52		70
EL							6	329	22	45	0.51	23.3	3.30	2.14		432
ES							20	1 455	118	274	0.58	78.1	10.82	11.31		1 968
FI							4	111	0	168	3.17	0.3	0.21	13.00		300
FR							77	2 801	446	545	2.47	10.2	6.68	34.13		3 923
HR							3	141	9	50	0.34	0.8	0.51	3.61		209
HU							12	450	27	63	1.68	0	0.08	7.81		560
IE							9	150	409	50	23.10	2.1	1.83	7.06		651
IT							37	1 233	32	161	0.56	9.9	10.11	10.17		1 494
LT							3	178	9	45	0.64	0.02	0.02	4.03		240
LU							1	13	3	6	0.00	0	0.00	1.18		24
LV							1	61	9	41	0.97	0	0.00	2.66		116
MT							0	3	0	0	0.00	0.2	0.04	0.00		3
NL							38	346	183	40	3.65	2.3	0.88	4.94		619
PL							36	1 285	94	309	1.98	0.02	0.16	22.44		1 748
PT							3	158	3	48	0.02	3.8	1.02	2.37		219
RO							15	535	55	103	2.86	0.5	0.28	24.61		736
SE							7	209	7	191	3.88	2.0	1.93	19.35		441
SI							1	46	4	28	0.04	0.1	0.26	0.47		80
SK							5	136	5	37	0.07	0.1	0.07	2.15		185
UK							62	904	511	95	20.85	28.2	4.23	8.71		1 634
EU							517	13 962	2 431	3 171	75	168	50	239		20 614

AA18. Use table of water purification in physical terms, year 2006

	Economic unit							**Ecosystem type**									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
AT	224				84		308										0
BE	290				47		336										0
BG	218				70		288										0
CY	18				3		21										0
CZ	401				88		489										0
DE	2 572				496		3 067										0
DK	409				44		452										0
EE	49				20		70										0
EL	360				72		432										0
ES	1 714				254		1 968										0
FI	216				84		300										0
FR	3 400				524		3 923										0
HR	159				50		209										0
HU	473				87		560										0
IE	610				41		651										0
IT	1 190				304		1 494										0
LT	192				48		240										0
LU	21				4		24										0
LV	79				37		116										0
MT	3				0		3										0
NL	560				59		619										0
PL	1 440				308		1 748										0
PT	184				35		219										0
RO	565				171		736										0
SE	299				143		441										0
SI	55				25		80										0
SK	139				46		185										0
UK	1 464				170		1 634										0
EU	17 302	—			3 312	—	20 614	0	0	0	0	0	0	0	0	0	0

AA19. Supply table of water purification in monetary terms, year 2006

Economic unit							Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT							72	1 407	243	699	2.6	14.7	48.81	19		2 506
BE							22	202	23	30	0.2	0.5	0.03	8		285
BG							15	614	29	126	0.3	0.2	1.04	24		809
CY							1	21	0	2	0.0	1.2	0.29	0		26
CZ							15	464	28	119	0.2	0.0	0.01	36		663
DE							104	1 796	354	510	4.1	1.4	0.56	128		2 898
DK							6	266	3	18	1.1	0.6	0.07	19		314
EE							8	377	45	314	12.1	0.5	0.21	27		783
EL							13	738	50	101	1.1	52.3	7.40	8		970
ES							19	1 362	110	256	0.5	73.1	10.13	34		1 865
FI							115	3 375	5	5 091	95.9	10.1	6.47	790		9 489
FR							90	3 288	524	640	2.9	11.9	7.84	108		4 672
HR							10	440	29	157	1.1	2.4	1.59	7		648
HU							1	49	3	7	0.2	0.0	0.01	21		81
IE							14	234	637	78	36.0	3.3	2.86	34		1 039
IT							87	2 898	75	378	1.3	23.3	23.77	9		3 496
LT							7	487	25	123	1.7	0.0	0.05	42		686
LU							1	14	3	7	0.0	0.0	0.00	0		26
LV							7	444	68	299	7.1	0.0	0.02	30		856
MT							0	0	0	0	0.0	0.0	0.00	0		0
NL							12	113	60	13	1.2	0.8	0.29	25		226
PL							36	1 278	93	307	2.0	0.0	0.16	198		1 914
PT							5	277	5	84	0.0	6.7	1.79	9		390
RO							34	1 168	120	224	6.2	1.1	0.61	47		1 600
SE							195	5 969	193	5 465	110.9	56.3	55.07	1 351		13 395
SI							10	330	27	204	0.3	1.1	1.88	4		579
SK							16	470	17	126	0.2	0.2	0.25	10		640
UK							177	2 603	1 471	274	60.0	81.1	12.18	125		4 804
EU							1 094	30 686	4 242	15 650	349	343	183	3 114		55 662

AA20. Use table of water purification in monetary terms, year 2006

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	1 552				954		2 506									
BE	240				45		285									
BG	542				267		809									
CY	21				5		26									
CZ	524				139		663									
DE	2 356				541		2 898									
DK	282				32		314									
EE	454				329		783									
EL	777				193		970									
ES	1 592				274		1 865									
FI	5 876				3 613		9 489									
FR	3 961				711		4 672									
HR	440				208		648									
HU	70				12		81									
IE	970				69		1 039									
IT	2 599				897		3 496									
LT	523				163		686									
LU	21				4		26									
LV	458				398		856									
MT	0.22				0.01		0.23									
NL	204				22		226									
PL	1 540				374		1 914									
PT	315				74		390									
RO	1 107				493		1 600									
SE	7 264				6 131		13 395									
SI	318				261		579									
SK	430				211		640									
UK	4 257				548		4 804									
EU	38 695	0			16 967	0	55 662									

AA21. Supply table of water purification in physical terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT							9	170	29	85	0.31	1.59	5.69	4.2		304.68
BE							29	275	30	38	0.23	0.58	0.04	1.2		373.34
BG							6	273	12	48	0.14	0.06	0.37	10.5		350.58
CY							1	14	0	1	0.01	0.85	0.21	0.1		17.12
CZ							12	367	25	93	0.13	0.01	0.01	4.7		501.54
DE							106	1 931	348	507	4.24	1.45	0.52	29.3		2 926.75
DK							10	389	4	26	1.56	0.91	0.10	0.2		431.86
EE							1	47	6	37	1.36	0.05	0.02	2.8		94.68
EL							6	312	21	40	0.52	21.39	3.45	2.0		406.37
ES							20	1 377	110	253	0.54	71.43	8.87	9.7		1 850.98
FI							4	105	0	156	2.89	0.23	0.17	3.4		272.02
FR							74	2 671	412	511	2.33	9.07	5.44	32.1		3 717.94
HR							3	131	9	47	0.32	0.74	0.56	3.3		194.83
HU							11	412	24	58	1.52	0.00	0.07	7.2		514.18
IE							9	151	390	52	23.46	2.23	1.93	6.8		636.50
IT							35	1 133	30	151	0.51	9.66	9.88	9.7		1 378.16
LT							3	200	9	49	0.67	0.02	0.02	4.3		265.81
LU							1	15	3	7	0.00	0.00	0.00	1.1		27.04
LV							1	67	9	43	1.01	0.00	0.00	2.8		123.58
MT							0	2	0	0	0.00	0.16	0.04	0.0		2.71
NL							37	327	168	38	3.60	2.33	0.56	4.6		580.87
PL							37	1 351	91	311	2.02	0.02	0.14	22.6		1 815.16
PT							3	148	3	44	0.02	3.38	0.70	2.1		203.46
RO							20	687	71	121	3.28	0.52	0.30	24.0		927.01
SE							6	197	6	168	3.19	1.26	1.43	16.4		399.68
SI							1	29	3	20	0.03	0.15	0.26	0.4		53.78
SK							5	144	5	36	0.08	0.05	0.07	2.0		192.42
UK							60	897	497	91	19.00	26.20	3.87	8.5		1 602.45
EU							510	13 822	2 314	3 032	73	154	45	216	0	20 166

AA22. Use table of water purification in physical terms, year 2012

	Economic unit							Ecosystem type									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
AT	189				115		305										0
BE	313				60		373										0
BG	235				116		351										0
CY	14				3		17										0
CZ	392				110		502										0
DE	2 362				565		2 927										0
DK	386				46		432										0
EE	55				40		95										0
EL	325				81		406										0
ES	1 576				275		1 851										0
FI	160				112		272										0
FR	3 145				573		3 718										0
HR	133				62		195										0
HU	420				95		514										0
IE	593				43		636										0
IT	1 026				352		1 378										0
LT	200				66		266										0
LU	22				5		27										0
LV	65				58		124										0
MT	3				0		3										0
NL	520				61		581										0
PL	1 426				389		1 815										0
PT	164				39		203										0
RO	641				286		927										0
SE	204				195		400										0
SI	30				24		54										0
SK	129				64		192										0
UK	1 416				186		1 602										0
EU	16 144				4 021		20 166	0	0	0	0	0	0	0	0	0	0

AA23. Supply table of water purification in monetary terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT							76	1 434	241	714	2.6	13.4	47.85	18.6		2 547
BE							21	202	22	28	0.2	0.4	0.03	8.5		282
BG							15	624	26	110	0.3	0.1	0.85	24.1		801
CY							1	20	0	2	0.0	1.3	0.32	0.4		26
CZ							15	454	31	115	0.2	0.0	0.01	36.1		652
DE							101	1 838	331	482	4.0	1.4	0.49	128.2		2 886
DK							7	264	3	18	1.1	0.6	0.06	18.9		312
EE							7	362	43	290	10.6	0.4	0.16	26.5		741
EL							13	744	50	96	1.2	50.9	8.21	7.7		971
ES							19	1 312	104	241	0.5	68.0	8.44	33.8		1 787
FI							117	3 431	6	5 110	94.3	7.6	5.42	790.2		9 562
FR							93	3 323	512	636	2.9	11.3	6.77	107.6		4 692
HR							10	435	29	155	1.1	2.5	1.85	7.1		642
HU							4	137	8	19	0.5	0.0	0.02	21.3		190
IE							14	234	602	80	36.2	3.4	2.98	34.5		1 006
IT							89	2 899	77	386	1.3	24.7	25.28	9.2		3 511
LT							7	484	22	118	1.6	0.0	0.04	41.6		675
LU							1	14	3	6	0.0	0.0	0.00	0.4		25
LV							7	444	62	286	6.8	0.0	0.01	30.4		836
MT							0	0	0	0	0.0	0.0	0.00	0.0		0
NL							13	114	59	13	1.3	0.8	0.20	25.5		227
PL							35	1 285	87	296	1.9	0.0	0.14	198.0		1 904
PT							5	270	5	80	0.0	6.2	1.27	9.0		376
RO							33	1 111	115	195	5.3	0.8	0.49	46.9		1 507
SE							202	6 189	192	5 291	100	39.8	45.13	1 350.6		13 409
SI							10	323	28	223	0.3	1.6	2.87	3.7		592
SK							17	474	16	117	0.2	0.2	0.21	10.2		634
UK							175	2 620	1 452	267	55.5	76.5	11.30	125.5		4 783
EU							1 105	31 041	4 128	15 374	330	312	170	3 114	0	55 576

AA24. Use table of water purification in monetary terms, year 2012

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	1 577				969		2 547									
BE	238				45		282									
BG	537				264		801									
CY	21				5		26									
CZ	515				137		652									
DE	2 347				539		2 886									
DK	280				32		312									
EE	430				311		741									
EL	778				193		971									
ES	1 525				262		1 787									
FI	5 918				3 643		9 562									
FR	3 978				714		4 692									
HR	436				206		642									
HU	158				32		190									
IE	939				67		1 006									
IT	2 610				901		3 511									
LT	515				160		675									
LU	21				4		25									
LV	448				388		836									
MT	0				0		0									
NL	205				22		227									
PL	1 532				372		1 904									
PT	304				72		376									
RO	1 044				464		1 507									
SE	7 271				6 138		13 409									
SI	325				267		592									
SK	426				209		634									
UK	4 238				545		4 783									
EU	38 615				16 960		55 576									

AA25. Supply table of crop provision in physical terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT								1 076								1 076
BE								2 149								2 149
BG								1 010								1 010
CY								23								23
CZ								2 029								2 029
DE								16 014								16 014
DK								2 690								2 690
EE								148								148
EL								555								555
ES								4 975								4 975
FI								814								814
FR								22 594								22 594
HR								434								434
HU								2 973								2 973
IE								434								434
IT								7 525								7 525
LT								472								472
LU								228								228
LV								239								239
MT								7								7
NL								2 751								2 751
PL								6 646								6 646
PT								949								949
RO								4 011								4 011
SE								970								970
SI								148								148
SK								1 054								1 054
UK								4 628								4 628
EU							0	87 548	0	0	0	0	0	0	0	87 548

AA26. Use table of crop provision in physical terms, year 2000

	Economic unit							**Ecosystem type**									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
AT	1 076						1 076										0
BE	2 149						2 149										0
BG	1 010						1 010										0
CY	23						23										0
CZ	2 029						2 029										0
DE	16 014						16 014										0
DK	2 690						2 690										0
EE	148						148										0
EL	555						555										0
ES	4 975						4 975										0
FI	814						814										0
FR	22 594						22 594										0
HR	434						434										0
HU	2 973						2 973										0
IE	434						434										0
IT	7 525						7 525										0
LT	472						472										0
LU	228						228										0
LV	239						239										0
MT	7						7										0
NL	2 751						2 751										0
PL	6 646						6 646										0
PT	949						949										0
RO	4 011						4 011										0
SE	970						970										0
SI	148						148										0
SK	1 054						1 054										0
UK	4 628						4 628										0
EU	87 548	0	0	0	0	0	87 548	0	0	0	0	0	0	0	0	0	0

AA27. Supply table of crop provision in monetary terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT								106								106
BE								134								134
BG								105								105
CY								2								2
CZ								133								133
DE								1 236								1 236
DK								309								309
EE								14								14
EL								86								86
ES								699								699
FI								119								119
FR								2 224								2 224
HR								49								49
HU								221								221
IE								52								52
IT								694								694
LT								110								110
LU								12								12
LV								30								30
MT								1								1
NL								222								222
PL								412								412
PT								83								83
RO								486								486
SE								148								148
SI								14								14
SK								53								53
UK								610								610
EU							0	8 369	0	0	0	0	0	0	0	8 369

AA28. Use table of crop provision in monetary terms, year 2000

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	106						106									
BE	134						134									
BG	105						105									
CY	2						2									
CZ	133						133									
DE	1 236						1 236									
DK	309						309									
EE	14						14									
EL	86						86									
ES	699						699									
FI	119						119									
FR	2 224						2 224									
HR	49						49									
HU	221						221									
IE	52						52									
IT	694						694									
LT	110						110									
LU	12						12									
LV	30						30									
MT	1						1									
NL	222						222									
PL	412						412									
PT	83						83									
RO	486						486									
SE	148						148									
SI	14						14									
SK	53						53									
UK	610						610									
EU	8 369	0	0	0	0	0	8 369									

AA29. Supply table of crop provision in physical terms, year 2006

	Economic unit						Ecosystem type									
	Primary sector															
(1 000 tonnes)	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
AT								1 126								1 126
BE								2 107								2 107
BG								952								952
CY								28								28
CZ								1 934								1 934
DE								16 864								16 864
DK								2 130								2 130
EE								170								170
EL								439								439
ES								4 520								4 520
FI								831								831
FR								19 091								19 091
HR								596								596
HU								3 198								3 198
IE								403								403
IT								6 957								6 957
LT								533								533
LU								109								109
LV								335								335
MT								6								6
NL								2 629								2 629
PL								7 535								7 535
PT								889								889
RO								3 963								3 963
SE								862								862
SI								168								168
SK								1 131								1 131
UK								4 405								4 405
EU							0	83 910	0	0	0	0	0	0	0	83 910

AA30. Use table of crop provision in physical terms, year 2006

	Economic unit							Ecosystem type									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
AT	1 126						1 126										0
BE	2 107						2 107										0
BG	952						952										0
CY	28						28										0
CZ	1 934						1 934										0
DE	16 864						16 864										0
DK	2 130						2 130										0
EE	170						170										0
EL	439						439										0
ES	4 520						4 520										0
FI	831						831										0
FR	19 091						19 091										0
HR	596						596										0
HU	3 198						3 198										0
IE	403						403										0
IT	6 957						6 957										0
LT	533						533										0
LU	109						109										0
LV	335						335										0
MT	6						6										0
NL	2 629						2 629										0
PL	7 535						7 535										0
PT	889						889										0
RO	3 963						3 963										0
SE	862						862										0
SI	168						168										0
SK	1 131						1 131										0
UK	4 405						4 405										0
EU	83 910	0	0	0	0	0	83 910	0	0	0	0	0	0	0	0	0	0

AA31. Supply table of crop provision in monetary terms, year 2006

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT								80								80
BE								182								182
BG								126								126
CY								4								4
CZ								177								177
DE								1 069								1 069
DK								229								229
EE								28								28
EL								74								74
ES								610								610
FI								108								108
FR								1 968								1 968
HR								72								72
HU								391								391
IE								45								45
IT								597								597
LT								170								170
LU								9								9
LV								93								93
MT								1								1
NL								177								177
PL								565								565
PT								66								66
RO								573								573
SE								120								120
SI								13								13
SK								105								105
UK								473								473
EU							0	8 123	0	0	0	0	0	0	0	8 123

AA32. Use table of crop provision in monetary terms, year 2006

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	80						80									
BE	182						182									
BG	126						126									
CY	4						4									
CZ	177						177									
DE	1 069						1 069									
DK	229						229									
EE	28						28									
EL	74						74									
ES	610						610									
FI	108						108									
FR	1 968						1 968									
HR	72						72									
HU	391						391									
IE	45						45									
IT	597						597									
LT	170						170									
LU	9						9									
LV	93						93									
MT	1						1									
NL	177						177									
PL	565						565									
PT	66						66									
RO	573						573									
SE	120						120									
SI	13						13									
SK	105						105									
UK	473						473									
EU	8 123						8 123									

AA33. Supply table of crop provision in physical terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT								1 188								1 188
BE								2 170								2 170
BG								1 557								1 557
CY								36								36
CZ								2 238								2 238
DE								21 496								21 496
DK								2 036								2 036
EE								217								217
EL								418								418
ES								4 713								4 713
FI								758								758
FR								19 736								19 736
HR								592								592
HU								2 940								2 940
IE								437								437
IT								6 360								6 360
LT								816								816
LU								113								113
LV								483								483
MT								6								6
NL								2 801								2 801
PL								9 613								9 613
PT								856								856
RO								5 062								5 062
SE								927								927
SI								157								157
SK								1 098								1 098
UK								5 151								5 151
EU							0	93 978	0	0	0	0	0	0	0	93 978

AA34. Use table of crop provision in physical terms, year 2012

	Economic unit							Ecosystem type									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
AT	1 188						1 188										0
BE	2 170						2 170										0
BG	1 557						1 557										0
CY	36						36										0
CZ	2 238						2 238										0
DE	21 496						21 496										0
DK	2 036						2 036										0
EE	217						217										0
EL	418						418										0
ES	4 713						4 713										0
FI	758						758										0
FR	19 736						19 736										0
HR	592						592										0
HU	2 940						2 940										0
IE	437						437										0
IT	6 360						6 360										0
LT	816						816										0
LU	113						113										0
LV	483						483										0
MT	6						6										0
NL	2 801						2 801										0
PL	9 613						9 613										0
PT	856						856										0
RO	5 062						5 062										0
SE	927						927										0
SI	157						157										0
SK	1 098						1 098										0
UK	5 151						5 151										0
EU	93 978	0	0	0	0	0	93 978	0	0	0	0	0	0	0	0	0	0

AA35. Supply table of crop provision in monetary terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT								114								114
BE								239								239
BG								322								322
CY								4								4
CZ								303								303
DE								1 823								1 823
DK								277								277
EE								46								46
EL								87								87
ES								736								736
FI								113								113
FR								2 299								2 299
HR								89								89
HU								576								576
IE								58								58
IT								685								685
LT								181								181
LU								12								12
LV								91								91
MT								1								1
NL								212								212
PL								813								813
PT								71								71
RO								1 147								1 147
SE								179								179
SI								15								15
SK								152								152
UK								768								768
EU							0	11 412	0	0	0	0	0	0	0	11 412

AA36. Use table of crop provision in monetary terms, year 2012

	Economic unit							**Ecosystem type**								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	114						114									
BE	239						239									
BG	322						322									
CY	4						4									
CZ	303						303									
DE	1 823						1 823									
DK	277						277									
EE	46						46									
EL	87						87									
ES	736						736									
FI	113						113									
FR	2 299						2 299									
HR	89						89									
HU	576						576									
IE	58						58									
IT	685						685									
LT	181						181									
LU	12						12									
LV	91						91									
MT	1						1									
NL	212						212									
PL	813						813									
PT	71						71									
RO	1 147						1 147									
SE	179						179									
SI	15						15									
SK	152						152									
UK	768						768									
EU	11 412	0	0	0	0	0	11 412									

AA37. Supply table of timber provision in physical terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest available for wood supply	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million m^3)																
AT										35						35
BE										11						11
BG										16						16
CY										0						0
CZ										28						28
DE										112						112
DK										7						7
EE										18						18
EL										6						6
ES										36						36
FI										111						111
FR										156						156
HR										8						8
HU										9						9
IE										5						5
IT										39						39
LT										11						11
LU										1						1
LV										27						27
MT																—
NL										2						2
PL										73						73
PT										20						20
RO										53						53
SE										120						120
SI										4						4
SK										15						15
UK										29						29
EU							0	0	0	955	0	0	0	0	0	955

AA38. Use table of timber provision in physical terms, year 2000

	Economic unit							Ecosystem type									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest available for wood supply	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million m^3)																	
AT		35					35										0
BE		11					11										0
BG		16					16										0
CY		0					0										0
CZ		28					28										0
DE		112					112										0
DK		7					7										0
EE		18					18										0
EL		6					6										0
ES		36					36										0
FI		111					111										0
FR		156					156										0
HR		8					8										0
HU		9					9										0
IE		5					5										0
IT		39					39										0
LT		11					11										0
LU		1					1										0
LV		27					27										0
MT		—					—										0
NL		2					2										0
PL		73					73										0
PT		20					20										0
RO		53					53										0
SE		120					120										0
SI		4					4										0
SK		15					15										0
UK		29					29										0
EU	0	955	0	0	0	0	955	0	0	0	0	0	0	0	0	0	0

AA39. Supply table of timber provision in monetary terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest available for wood supply	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT										661						661
BE										302						302
BG										256						256
CY										3						3
CZ										611						611
DE										3 558						3 558
DK										189						189
EE										195						195
EL										152						152
ES										465						465
FI										3 164						3 164
FR										4 927						4 927
HR										124						124
HU										116						116
IE										371						371
IT										1 258						1 258
LT										133						133
LU										29						29
LV										262						262
MT																—
NL										32						32
PL										2 342						2 342
PT										352						352
RO										1 334						1 334
SE										1 761						1 761
SI										96						96
SK										178						178
UK										874						874
EU							0	0	0	23 745	0	0	0	0	0	23 745

AA40. Use table of timber provision in monetary terms, year 2000

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest available for wood supply	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT		661					661									
BE		302					302									
BG		256					256									
CY		3					3									
CZ		611					611									
DE		3 558					3 558									
DK		189					189									
EE		195					195									
EL		152					152									
ES		465					465									
FI		3 164					3 164									
FR		4 927					4 927									
HR		124					124									
HU		116					116									
IE		371					371									
IT		1 258					1 258									
LT		133					133									
LU		29					29									
LV		262					262									
MT		—					—									
NL		32					32									
PL		2 342					2 342									
PT		352					352									
RO		1 334					1 334									
SE		1 761					1 761									
SI		96					96									
SK		178					178									
UK		874					874									
EU	0	23 745	0	0	0	0	23 745									

AA41. Supply table of timber provision in physical terms, year 2006

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest available for wood supply	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million m^3)																
AT										36						36
BE										10						10
BG										15						15
CY										0						0
CZ										19						19
DE										103						103
DK										5						5
EE										8						8
EL										5						5
ES										48						48
FI										104						104
FR										131						131
HR										11						11
HU										10						10
IE										7						7
IT										40						40
LT										11						11
LU										1						1
LV										27						27
MT																—
NL										3						3
PL										79						79
PT										20						20
RO										29						29
SE										119						119
SI										10						10
SK										15						15
UK										31						31
EU							0	0	0	897	0	0	0	0	0	897

AA42. Use table of timber provision in physical terms, year 2006

	Economic unit							**Ecosystem type**									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest available for wood supply	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million m^3)																	
AT		36					36										0
BE		10					10										0
BG		15					15										0
CY		0					0										0
CZ		19					19										0
DE		103					103										0
DK		5					5										0
EE		8					8										0
EL		5					5										0
ES		48					48										0
FI		104					104										0
FR		131					131										0
HR		11					11										0
HU		10					10										0
IE		7					7										0
IT		40					40										0
LT		11					11										0
LU		1					1										0
LV		27					27										0
MT		—					—										0
NL		3					3										0
PL		79					79										0
PT		20					20										0
RO		29					29										0
SE		119					119										0
SI		10					10										0
SK		15					15										0
UK		31					31										0
EU	0	897	0	0	0	0	897	0	0	0	0	0	0	0	0	0	0

AA43. Supply table of timber provision in monetary terms, year 2006

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest available for wood supply	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT										644						644
BE										337						337
BG										385						385
CY										0						0
CZ										424						424
DE										2 673						2 673
DK										131						131
EE										105						105
EL										1						1
ES										752						752
FI										2 519						2 519
FR										3 281						3 281
HR										155						155
HU										140						140
IE										84						84
IT										2 873						2 873
LT										147						147
LU										30						30
LV										314						314
MT																—
NL										43						43
PL										2 941						2 941
PT										353						353
RO										533						533
SE										1 724						1 724
SI										272						272
SK										264						264
UK										497						497
EU							0	0	0	21 623	0	0	0	0	0	21 623

AA44. Use table of timber provision in monetary terms, year 2006

	Economic unit							Ecosystem type								
	Primary sector															
(million EUR)	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
AT		644					644									
BE		337					337									
BG		385					385									
CY		0					0									
CZ		424					424									
DE		2 673					2 673									
DK		131					131									
EE		105					105									
EL		1					1									
ES		752					752									
FI		2 519					2 519									
FR		3 281					3 281									
HR		155					155									
HU		140					140									
IE		84					84									
IT		2 873					2 873									
LT		147					147									
LU		30					30									
LV		314					314									
MT		—					—									
NL		43					43									
PL		2 941					2 941									
PT		353					353									
RO		533					533									
SE		1 724					1 724									
SI		272					272									
SK		264					264									
UK		497					497									
EU	0	21 623	0	0	0	0	21 623									

AA45. Supply table of timber provision in physical terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest available for wood supply	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million m³)																
AT										38						38
BE										8						8
BG										15						15
CY										0						0
CZ										25						25
DE										109						109
DK										7						7
EE										19						19
EL										4						4
ES										40						40
FI										119						119
FR										93						93
HR										12						12
HU										12						12
IE										8						8
IT										36						36
LT										11						11
LU										1						1
LV										23						23
MT																—
NL										2						2
PL										79						79
PT										20						20
RO										33						33
SE										113						113
SI										7						7
SK										16						16
UK										34						34
EU							0	0	0	885	0	0	0	0	0	885

AA46. Use table of timber provision in physical terms, year 2012

	Economic unit							Ecosystem type									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million m^3)																	
AT		38					38										0
BE		8					8										0
BG		15					15										0
CY		0					0										0
CZ		25					25										0
DE		109					109										0
DK		7					7										0
EE		19					19										0
EL		4					4										0
ES		40					40										0
FI		119					119										0
FR		93					93										0
HR		12					12										0
HU		12					12										0
IE		8					8										0
IT		36					36										0
LT		11					11										0
LU		1					1										0
LV		23					23										0
MT		—					—										0
NL		2					2										0
PL		79					79										0
PT		20					20										0
RO		33					33										0
SE		113					113										0
SI		7					7										0
SK		16					16										0
UK		34					34										0
EU	0	885	0	0	0	0	885	0	0	0	0	0	0	0	0	0	0

AA47. Supply table of timber provision in monetary terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest available for wood supply	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT										865						865
BE										254						254
BG										430						430
CY										1						1
CZ										786						786
DE										3 626						3 626
DK										176						176
EE										299						299
EL										49						49
ES										840						840
FI										3 190						3 190
FR										2 018						2 018
HR										40						40
HU										208						208
IE										307						307
IT										893						893
LT										209						209
LU										41						41
LV										189						189
MT																—
NL										46						46
PL										2 777						2 777
PT										530						530
RO										626						626
SE										3 520						3 520
SI										226						226
SK										240						240
UK										331						331
EU							0	0	0	22 714	0	0	0	0	0	22 714

AA48. Use table of timber provision in monetary terms, year 2012

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT		865					865									
BE		254					254									
BG		430					430									
CY		1					1									
CZ		786					786									
DE		3 626					3 626									
DK		176					176									
EE		299					299									
EL		49					49									
ES		840					840									
FI		3 190					3 190									
FR		2 018					2 018									
HR		40					40									
HU		208					208									
IE		307					307									
IT		893					893									
LT		209					209									
LU		41					41									
LV		189					189									
MT		—					—									
NL		46					46									
PL		2 777					2 777									
PT		530					530									
RO		626					626									
SE		3 520					3 520									
SI		226					226									
SK		240					240									
UK		331					331									
EU		22 714					22 714									

AA49. Supply table of carbon sequestration in physical terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT										10 652			—			10 652
BE										1 718			—			1 718
BG										7 443			—			7 443
CY										0			—			—
CZ										5 007			—			5 007
DE										51 105			—			51 105
DK										403			—			403
EE										2 519			—			2 519
EL										749			—			749
ES										26 284			—			26 284
FI										18 996			—			18 996
FR										23 845			—			23 845
HR										5 273			—			5 273
HU										309			—			309
IE										1 271			—			1 271
IT										16 934			—			16 934
LT										6 192			—			6 192
LU										559			—			559
LV										9 410			—			9 410
MT										0			—			—
NL										1 363			—			1 363
PL										24 589			—			24 589
PT										6 175			1 195			7 371
RO										18 536			—			18 536
SE										27 985			—			27 985
SI										3 046			—			3 046
SK										5 344			—			5 344
UK										14 652			—			14 652
EU							0	0	0	290 358	0	0	1 195	0	0	291 554

AA50. Use table of carbon sequestration in physical terms, year 2000

	Economic unit							Ecosystem type									
	Primary sector																
(1 000 tonnes)	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
AT						10 652	10 652										0
BE						1 718	1 718										0
BG						7 443	7 443										0
CY						—	—										0
CZ						5 007	5 007										0
DE						51 105	51 105										0
DK						403	403										0
EE						2 519	2 519										0
EL						749	749										0
ES						26 284	26 284										0
FI						18 996	18 996										0
FR						23 845	23 845										0
HR						5 273	5 273										0
HU						309	309										0
IE						1 271	1 271										0
IT						16 934	16 934										0
LT						6 192	6 192										0
LU						559	559										0
LV						9 410	9 410										0
MT						—	—										0
NL						1 363	1 363										0
PL						24 589	24 589										0
PT						7 371	7 371										0
RO						18 536	18 536										0
SE						27 985	27 985										0
SI						3 046	3 046										0
SK						5 344	5 344										0
UK						14 652	14 652										0
EU	0	0	0	0	0	291 554	291 554	0	0	0	0	0	0	0	0	0	0

AA51. Supply table of carbon sequestration in monetary terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT										320			—			320
BE										52			—			52
BG										223			—			223
CY										—			—			—
CZ										150			—			150
DE										1 533			—			1 533
DK										12			—			12
EE										76			—			76
EL										22			—			22
ES										789			—			789
FI										570			—			570
FR										715			—			715
HR										158			—			158
HU										9			—			9
IE										38			—			38
IT										508			—			508
LT										186			—			186
LU										17			—			17
LV										282			—			282
MT										—			—			—
NL										41			—			41
PL										738			—			738
PT										185			36			221
RO										556			—			556
SE										840			—			840
SI										91			—			91
SK										160			—			160
UK										440			—			440
EU							0	0	0	8 711	0	0	36	0	0	8 747

AA52. Use table of carbon sequestration in monetary terms, year 2000

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT						320	320									
BE						52	52									
BG						223	223									
CY						—	—									
CZ						150	150									
DE						1 533	1 533									
DK						12	12									
EE						76	76									
EL						22	22									
ES						789	789									
FI						570	570									
FR						715	715									
HR						158	158									
HU						9	9									
IE						38	38									
IT						508	508									
LT						186	186									
LU						17	17									
LV						282	282									
MT						—	—									
NL						41	41									
PL						738	738									
PT						221	221									
RO						556	556									
SE						840	840									
SI						91	91									
SK						160	160									
UK						440	440									
EU	0	0	0	0	0	8 747	8 747									

AA53. Supply table of carbon sequestration in physical terms, year 2006

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT										1 991						1 991
BE										2 238						2 238
BG										7 098						7 098
CY										131						131
CZ										1 979						1 979
DE										27 257						27 257
DK										—						—
EE										2 945						2 945
EL										1 500						1 500
ES										26 628						26 628
FI										29 127						29 127
FR										46 972						46 972
HR										5 428						5 428
HU										1 881						1 881
IE										1 989						1 989
IT										22 347						22 347
LT										2 970						2 970
LU										463						463
LV										6 984						6 984
MT										—						—
NL										1 346						1 346
PL										28 964						28 964
PT										7 275						7 275
RO										17 651						17 651
SE										23 825						23 825
SI										3 983						3 983
SK										3 799						3 799
UK										15 443						15 443
EU							0	0	0	292 213	0	0	0	0	0	292 213

AA54. Use table of carbon sequestration in physical terms, year 2006

	Economic unit							**Ecosystem type**									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
AT						1 991	1 991										0
BE						2 238	2 238										0
BG						7 098	7 098										0
CY						131	131										0
CZ						1 979	1 979										0
DE						27 257	27 257										0
DK						—	—										0
EE						2 945	2 945										0
EL						1 500	1 500										0
ES						26 628	26 628										0
FI						29 127	29 127										0
FR						46 972	46 972										0
HR						5 428	5 428										0
HU						1 881	1 881										0
IE						1 989	1 989										0
IT						22 347	22 347										0
LT						2 970	2 970										0
LU						463	463										0
LV						6 984	6 984										0
MT						—	—										0
NL						1 346	1 346										0
PL						28 964	28 964										0
PT						7 275	7 275										0
RO						17 651	17 651										0
SE						23 825	23 825										0
SI						3 983	3 983										0
SK						3 799	3 799										0
UK						15 443	15 443										0
EU	0	0	0	0	0	292 213	292 213	0	0	0	0	0	0	0	0	0	0

AA55. Supply table of carbon sequestration in monetary terms, year 2006

	Economic unit						**Ecosystem type**									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT										60						60
BE										67						67
BG										213						213
CY										4						4
CZ										59						59
DE										818						818
DK										—						—
EE										88						88
EL										45						45
ES										799						799
FI										874						874
FR										1 409						1 409
HR										163						163
HU										56						56
IE										60						60
IT										670						670
LT										89						89
LU										14						14
LV										210						210
MT										—						—
NL										40						40
PL										869						869
PT										218						218
RO										530						530
SE										715						715
SI										119						119
SK										114						114
UK										463						463
EU							0	0	0	8 766	0	0	0	0	0	8 766

AA56. Use table of carbon sequestration in monetary terms, year 2006

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT						60	60									
BE						67	67									
BG						213	213									
CY						4	4									
CZ						59	59									
DE						818	818									
DK						—	—									
EE						88	88									
EL						45	45									
ES						799	799									
FI						874	874									
FR						1 409	1 409									
HR						163	163									
HU						56	56									
IE						60	60									
IT						670	670									
LT						89	89									
LU						14	14									
LV						210	210									
MT						—	—									
NL						40	40									
PL						869	869									
PT						218	218									
RO						530	530									
SE						715	715									
SI						119	119									
SK						114	114									
UK						463	463									
EU	0	0	0	0	0	8 766	8 766									

AA57. Supply table of carbon sequestration in physical terms, year 2012

	Economic unit						**Ecosystem type**									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT										3 032						3 032
BE										2 138						2 138
BG										4 066						4 066
CY										198						198
CZ										4 356						4 356
DE										40 021						40 021
DK										2 828						2 828
EE										1 928						1 928
EL										1 452						1 452
ES										27 197						27 197
FI										30 556						30 556
FR										41 044						41 044
HR										4 391						4 391
HU										2 916						2 916
IE										2 352						2 352
IT										19 116						19 116
LT										6 806						6 806
LU										304						304
LV										4 552						4 552
MT										—						—
NL										1 540						1 540
PL										27 540						27 540
PT										7 544						7 544
RO										17 536						17 536
SE										29 965						29 965
SI										3 737						3 737
SK										4 104						4 104
UK										15 089						15 089
EU							0	0	0	306 308	0	0	0	0	0	306 308

AA58. Use table of carbon sequestration in physical terms, year 2012

	Economic unit							Ecosystem type									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
AT						3 032	3 032										0
BE						2 138	2 138										0
BG						4 066	4 066										0
CY						198	198										0
CZ						4 356	4 356										0
DE						40 021	40 021										0
DK						2 828	2 828										0
EE						1 928	1 928										0
EL						1 452	1 452										0
ES						27 197	27 197										0
FI						30 556	30 556										0
FR						41 044	41 044										0
HR						4 391	4 391										0
HU						2 916	2 916										0
IE						2 352	2 352										0
IT						19 116	19 116										0
LT						6 806	6 806										0
LU						304	304										0
LV						4 552	4 552										0
MT						—	—										0
NL						1 540	1 540										0
PL						27 540	27 540										0
PT						7 544	7 544										0
RO						17 536	17 536										0
SE						29 965	29 965										0
SI						3 737	3 737										0
SK						4 104	4 104										0
UK						15 089	15 089										0
EU	0	0	0	0	0	306 308	306 308	0	0	0	0	0	0	0	0	0	0

AA59. Supply table of carbon sequestration in monetary terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT										91						91
BE										64						64
BG										122						122
CY										6						6
CZ										131						131
DE										1 201						1 201
DK										85						85
EE										58						58
EL										44						44
ES										816						816
FI										917						917
FR										1 231						1 231
HR										132						132
HU										87						87
IE										71						71
IT										573						573
LT										204						204
LU										9						9
LV										137						137
MT										—						—
NL										46						46
PL										826						826
PT										226						226
RO										526						526
SE										899						899
SI										112						112
SK										123						123
UK										453						453
EU							0	0	0	9 189	0	0	0	0	0	9 189

AA60. Use table of carbon sequestration in monetary terms, year 2012

	Economic unit							**Ecosystem type**								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT						91	91									
BE						64	64									
BG						122	122									
CY						6	6									
CZ						131	131									
DE						1 201	1 201									
DK						85	85									
EE						58	58									
EL						44	44									
ES						816	816									
FI						917	917									
FR						1 231	1 231									
HR						132	132									
HU						87	87									
IE						71	71									
IT						573	573									
LT						204	204									
LU						9	9									
LV						137	137									
MT						—	—									
NL						46	46									
PL						826	826									
PT						226	226									
RO						526	526									
SE						899	899									
SI						112	112									
SK						123	123									
UK						453	453									
EU	0	0	0	0	0	9 189	9 189									

AA61. Supply table of crop pollination in physical terms, year 2000

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT								433								433
BE								404								404
BG								56								56
CY								14								14
CZ								427								427
DE								1 503								1 503
DK								67								67
EE								17								17
EL								342								342
ES								679								679
FI								13								13
FR								966								966
HR								56								56
HU								503								503
IE								5								5
IT								785								785
LT								20								20
LU								6								6
LV								28								28
MT								1								1
NL								358								358
PL								1 573								1 573
PT								232								232
RO								324								324
SE								38								38
SI								42								42
SK								71								71
UK								359								359
EU							0	9 322	0	0	0	0	0	0	0	9 322

AA62. Use table of crop pollination in physical terms, year 2000

	Economic unit							Ecosystem type									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
AT	433						433										0
BE	404						404										0
BG	56						56										0
CY	14						14										0
CZ	427						427										0
DE	1 503						1 503										0
DK	67						67										0
EE	17						17										0
EL	342						342										0
ES	679						679										0
FI	13						13										0
FR	966						966										0
HR	56						56										0
HU	503						503										0
IE	5						5										0
IT	785						785										0
LT	20						20										0
LU	6						6										0
LV	28						28										0
MT	1						1										0
NL	358						358										0
PL	1 573						1 573										0
PT	232						232										0
RO	324						324										0
SE	38						38										0
SI	42						42										0
SK	71						71										0
UK	359						359										0
EU	9 322	0	0	0	0	0	9 322										0

AA63. Supply table of crop pollination in monetary terms, year 2000

	Economic unit						**Ecosystem type**									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT								231								231
BE								204								204
BG								18								18
CY								6								6
CZ								135								135
DE								611								611
DK								26								26
EE								5								5
EL								155								155
ES								266								266
FI								6								6
FR								516								516
HR								27								27
HU								156								156
IE								2								2
IT								277								277
LT								14								14
LU								3								3
LV								8								8
MT								1								1
NL								176								176
PL								698								698
PT								134								134
RO								192								192
SE								17								17
SI								26								26
SK								20								20
UK								166								166
EU							0	4 092	0	0	0	0	0	0	0	4 092

AA64. Use table of crop pollination in monetary terms, year 2000

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	231						231									
BE	204						204									
BG	18						18									
CY	6						6									
CZ	135						135									
DE	611						611									
DK	26						26									
EE	5						5									
EL	155						155									
ES	266						266									
FI	6						6									
FR	516						516									
HR	27						27									
HU	156						156									
IE	2						2									
IT	277						277									
LT	14						14									
LU	3						3									
LV	8						8									
MT	1						1									
NL	176						176									
PL	698						698									
PT	134						134									
RO	192						192									
SE	17						17									
SI	26						26									
SK	20						20									
UK	166						166									
EU	4 092	0	0	0	0	0	4 092									

AA65. Supply table of crop pollination in physical terms, year 2006

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT								471								471
BE								470								470
BG								72								72
CY								18								18
CZ								321								321
DE								1 802								1 802
DK								118								118
EE								26								26
EL								434								434
ES								715								715
FI								22								22
FR								1 309								1 309
HR								64								64
HU								565								565
IE								7								7
IT								725								725
LT								104								104
LU								5								5
LV								63								63
MT								2								2
NL								405								405
PL								1 623								1 623
PT								255								255
RO								390								390
SE								81								81
SI								56								56
SK								88								88
UK								583								583
EU							0	10 795	0	0	0	0	0	0	0	10 795

AA66. Use table of crop pollination in physical terms, year 2006

	Economic unit							Ecosystem type									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
AT	471						471										0
BE	470						470										0
BG	72						72										0
CY	18						18										0
CZ	321						321										0
DE	1 802						1 802										0
DK	118						118										0
EE	26						26										0
EL	434						434										0
ES	715						715										0
FI	22						22										0
FR	1 309						1 309										0
HR	64						64										0
HU	565						565										0
IE	7						7										0
IT	725						725										0
LT	104						104										0
LU	5						5										0
LV	63						63										0
MT	2						2										0
NL	405						405										0
PL	1 623						1 623										0
PT	255						255										0
RO	390						390										0
SE	81						81										0
SI	56						56										0
SK	88						88										0
UK	583						583										0
EU	10 795	0	0	0	0	0	10 795										0

AA67. Supply table of crop pollination in monetary terms, year 2006

Economic unit							Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT								262								262
BE								217								217
BG								21								21
CY								8								8
CZ								158								158
DE								1 068								1 068
DK								71								71
EE								16								16
EL								182								182
ES								226								226
FI								15								15
FR								624								624
HR								37								37
HU								185								185
IE								3								3
IT								215								215
LT								105								105
LU								3								3
LV								26								26
MT								1								1
NL								189								189
PL								791								791
PT								140								140
RO								222								222
SE								44								44
SI								33								33
SK								39								39
UK								345								345
EU							0	5 244	0	0	0	0	0	0	0	5 244

AA68. Use table of crop pollination in monetary terms, year 2006

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	262						262									
BE	217						217									
BG	21						21									
CY	8						8									
CZ	158						158									
DE	1 068						1 068									
DK	71						71									
EE	16						16									
EL	182						182									
ES	226						226									
FI	15						15									
FR	624						624									
HR	37						37									
HU	185						185									
IE	3						3									
IT	215						215									
LT	105						105									
LU	3						3									
LV	26						26									
MT	1						1									
NL	189						189									
PL	791						791									
PT	140						140									
RO	222						222									
SE	44						44									
SI	33						33									
SK	39						39									
UK	345						345									
EU	5 244	0	0	0	0	0	5 244									

AA69. Supply table of crop pollination in physical terms, year 2012

	Economic unit						Ecosystem type									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																
AT								304								304
BE								355								355
BG								160								160
CY								13								13
CZ								377								377
DE								1 608								1 608
DK								124								124
EE								40								40
EL								375								375
ES								451								451
FI								15								15
FR								884								884
HR								100								100
HU								624								624
IE								6								6
IT								544								544
LT								174								174
LU								4								4
LV								76								76
MT								1								1
NL								408								408
PL								2 303								2 303
PT								239								239
RO								414								414
SE								83								83
SI								45								45
SK								112								112
UK								652								652
EU							0	10 491	0	0	0	0	0	0	0	10 491

AA70. Use table of crop pollination in physical terms, year 2012

	Economic unit							Ecosystem type									
	Primary sector																
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(1 000 tonnes)																	
AT	304						304										0
BE	355						355										0
BG	160						160										0
CY	13						13										0
CZ	377						377										0
DE	1 608						1 608										0
DK	124						124										0
EE	40						40										0
EL	375						375										0
ES	451						451										0
FI	15						15										0
FR	884						884										0
HR	100						100										0
HU	624						624										0
IE	6						6										0
IT	544						544										0
LT	174						174										0
LU	4						4										0
LV	76						76										0
MT	1						1										0
NL	408						408										0
PL	2 303						2 303										0
PT	239						239										0
RO	414						414										0
SE	83						83										0
SI	45						45										0
SK	112						112										0
UK	652						652										0
EU	10 491	0	0	0	0	0	10 491										0

AA71. Supply table of crop pollination in monetary terms, year 2012

	Economic unit						**Ecosystem type**									
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area	**Total**
(million EUR)																
AT								152								152
BE								180								180
BG								43								43
CY								7								7
CZ								112								112
DE								629								629
DK								45								45
EE								13								13
EL								173								173
ES								176								176
FI								7								7
FR								459								459
HR								46								46
HU								189								189
IE								2								2
IT								192								192
LT								118								118
LU								1								1
LV								19								19
MT								1								1
NL								204								204
PL								1 010								1 010
PT								138								138
RO								220								220
SE								34								34
SI								27								27
SK								32								32
UK								296								296
EU							0	4 525	0	0	0	0	0	0	0	4 525

AA72. Use table of crop pollination in monetary terms, year 2012

	Economic unit							Ecosystem type								
	Primary sector															
	Agriculture	Forestry	Secondary sector	Tertiary sector	Households	Global society	**Total**	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrubland	Sparsely vegetated land	Rivers and lakes	Coastal/intertidal area
(million EUR)																
AT	152						152									
BE	180						180									
BG	43						43									
CY	7						7									
CZ	112						112									
DE	629						629									
DK	45						45									
EE	13						13									
EL	173						173									
ES	176						176									
FI	7						7									
FR	459						459									
HR	46						46									
HU	189						189									
IE	2						2									
IT	192						192									
LT	118						118									
LU	1						1									
LV	19						19									
MT	0						0									
NL	204						204									
PL	1 010						1 010									
PT	138						138									
RO	220						220									
SE	34						34									
SI	27						27									
SK	32						32									
UK	296						296									
EU	4 524	0	0	0	0	0	4 524									

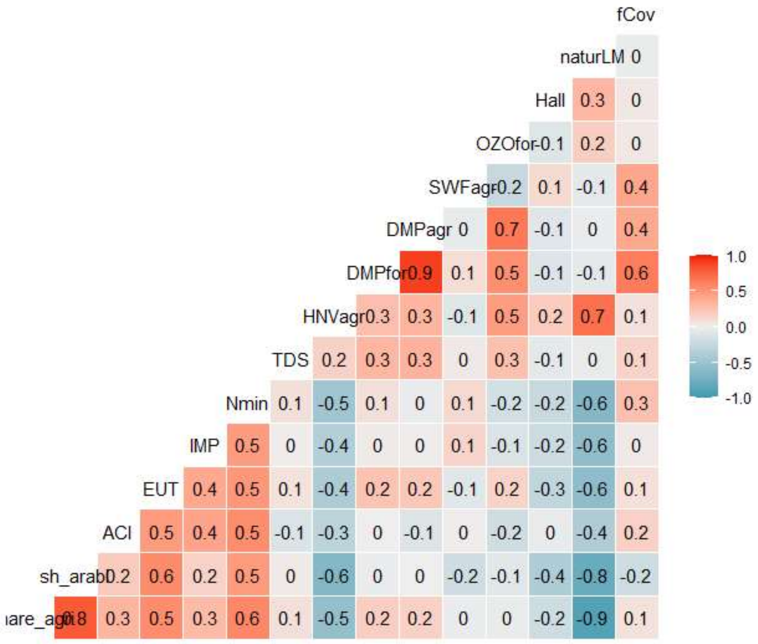
14. Methodological annexes

MA1. Predictor variables initially considered for the modelling of the ecological condition of ecosystems

Number	Variable	Acronym	Input data/source	Comment
	Condition indicators: EU-wide ecosystem assessment			
1	Tropospheric ozone in forest ([a])	OZO	EMEP	Larger values in ecosystems with favourable ecological condition
2	Exceedances of critical loads for acidification	ACI	EMEP	Non-significant in the logistic model
3	Exceedances of critical loads for eutrophication	EUT	EMEP	Non-significant in the logistic model
4	Dry matter productivity in forest	DMPfor	Copernicus	Non-significant in the logistic model
5	Dry matter productivity in agriculture area ([b])	DMPagr	Copernicus	Highly correlated with dry matter productivity in forests
6	Imperviousness	IMP	Copernicus	Predictor in the logistic model
7	High natural value farmland in agro-ecosystems	HNV	SEEA EEA ([c])	Predictor in the logistic model
8	Mineral fertiliser nitrogen input into the soil	Nmin	CAPRI model	Predictor in the logistic model
9	Total drought severity	TDS	E-OBS (version 19.0e)	Pressure on ecosystems with favourable ecological condition
10	Land mosaic -natural	Lmnat	EU-wide ecosystem assessment	Highly correlated with the share of arable land
	Ancillary indicators			
11	Small woody features in agro-ecosystems	SWF	Copernicus ([d])	Larger values in ecosystems with unfavourable ecological condition
12	Fraction of green vegetation cover	Fcov		Larger values in ecosystems with unfavourable ecological condition
13	Shannon’s land cover diversity index (not urban)	Hall	Own elaboration ([e])	Non-significant in the logistic model
14	Ecosystem type (categorical)	codeeco	Spatial data under Article 17 of the habitats directive	Categorical predictor in the logistic model
15	Share of arable land	sh_arab	Own elaboration ([e])	Non-significant in the logistic model
16	Share of agricultural land	sh_agri	Own elaboration ([e])	Highly correlated with the share of arable land

([a]) Accumulated ozone exposure over a threshold of 40 parts per billion.
([b]) Equivalent to net primary productivity.
([c]) Masked only for agro-ecosystems (cropland and grassland).
([d]) To further explore the potential use of Copernicus data for ecosystem accounting.
([e]) Based on the CLC accounting layers.

MA2. Correlation analysis of continuous independent variables

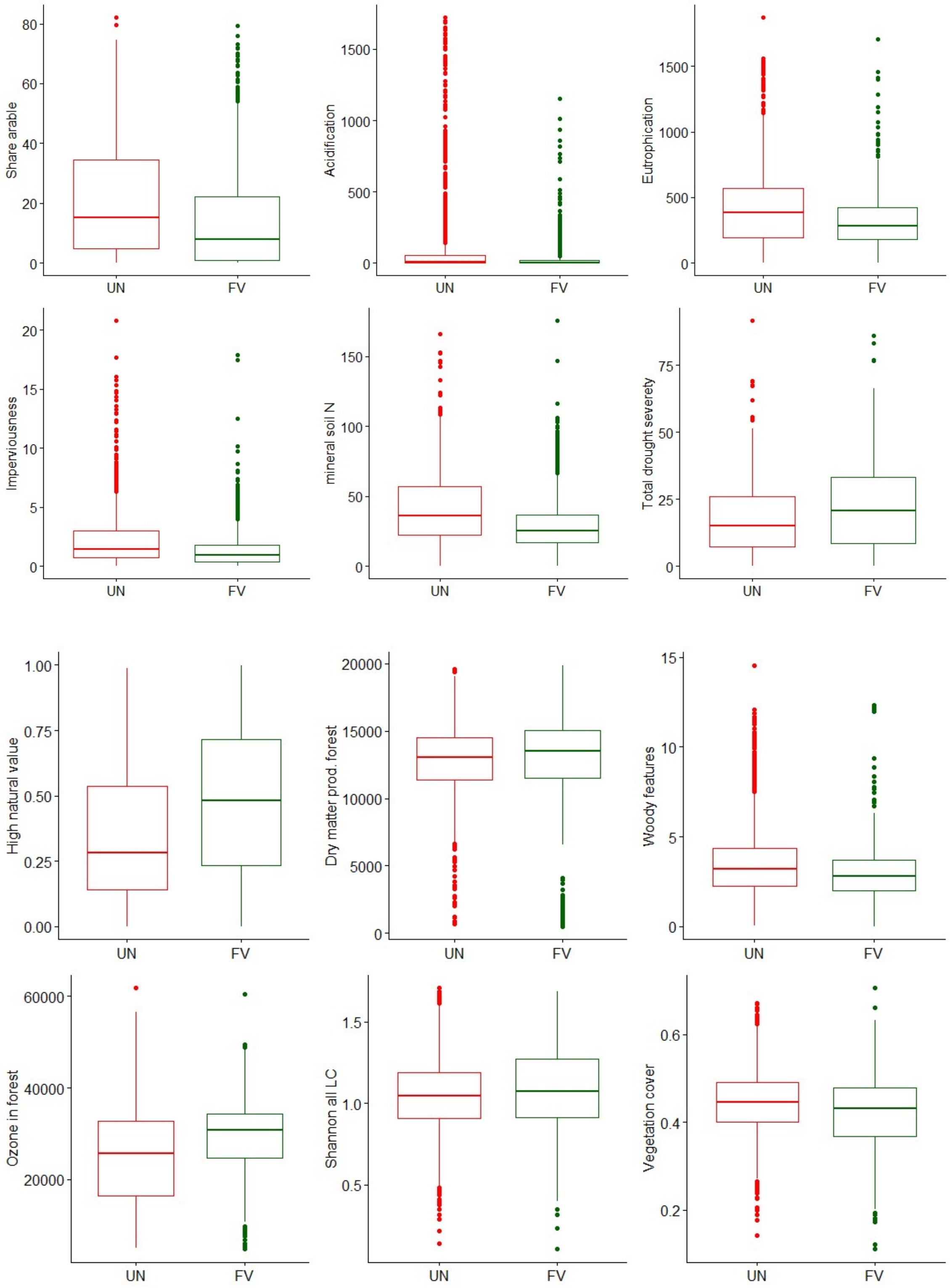


MA3. Confusion matrix for the correct and incorrect predictions of favourable and unfavourable ecosystem conditions

		Observed		Percentage correct prediction
		Favourable	Unfavourable	
Predicted	Favourable	253	146	63%
	Unfavourable	570	1 531	73%
		Overall correct prediction: 71%		

Correct classification	Incorrect classification

MA4. Box plots for the indicators selected for favourable (FV) and unfavourable (UN) ecological condition

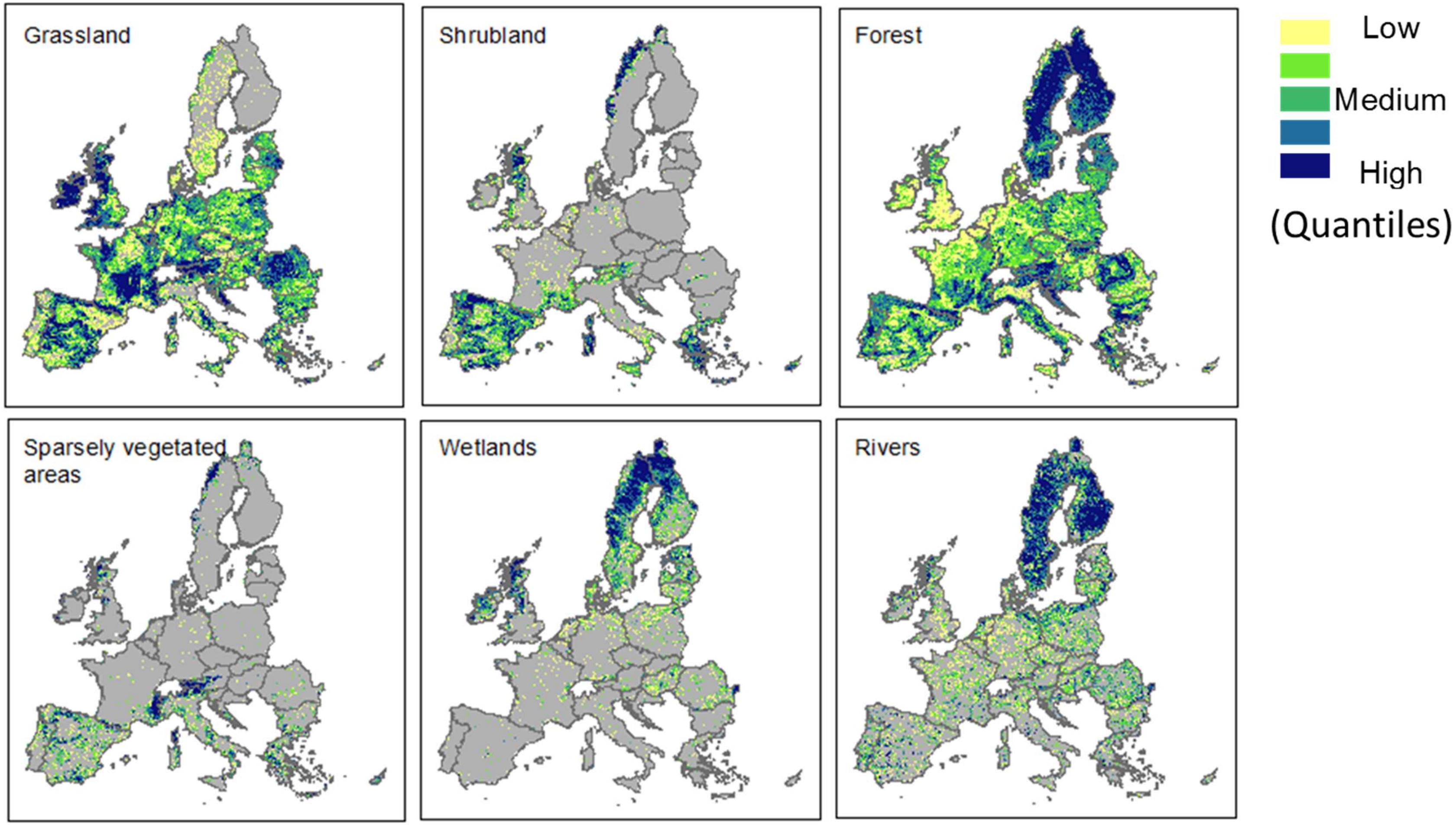


MA5. Summary statistics for species richness by country and biogeographical region

Country	Biogeographical region	Number of 10 km cells	Minimum richness	Maximum richness	Average richness	Standard deviation richness
Austria	Continental	314	84	134	119.97	6.99
Austria	Alpine	526	67	128	98.29	12.29
Belgium	Continental	121	102	121	112.43	4.16
Belgium	Atlantic	184	95	128	111.14	6.84
Bulgaria	Mediterranean	2	119	126	122.50	3.50
Bulgaria	Alpine	174	93	135	116.22	8.42
Bulgaria	Black Sea	73	103	126	115.96	6.30
Bulgaria	Continental	854	101	137	120.46	5.71
Bulgaria	Steppic	1	120	120	120.00	0.00
Croatia	Continental	310	99	126	114.89	3.93
Croatia	Alpine	87	98	127	113.23	6.54
Croatia	Mediterranean	163	78	123	106.14	9.16
Croatia	Pannonian	1	118	118	118.00	0.00
Cyprus	Mediterranean	94	42	60	51.40	3.77
Czechia	Pannonian	33	119	131	124.70	3.07
Czechia	Continental	756	102	131	122.73	4.45
Denmark	Atlantic	134	93	121	107.62	5.92
Denmark	Continental	288	93	122	110.13	4.84
Estonia	Boreal	441	97	130	120.00	5.07
Finland	Alpine	161	34	73	56.01	7.43
Finland	Boreal	3 197	58	123	93.89	14.26
France	Alpine	311	80	135	105.55	10.49
France	Continental	1 844	95	136	115.76	5.82
France	Mediterranean	652	54	136	109.07	19.54
France	Atlantic	2 684	75	127	108.15	8.70
Germany	Continental	2 822	92	134	120.14	6.54
Germany	Alpine	41	91	115	104.85	5.47
Germany	Atlantic	700	87	130	116.84	7.76
Greece	Continental	1	120	120	120.00	0.00
Greece	Alpine	1	106	106	106.00	0.00
Greece	Mediterranean	1 303	33	130	89.48	20.00
Hungary	Pannonian	929	98	131	117.27	5.72
Hungary	Continental	1	113	113	113.00	0.00
Ireland	Atlantic	692	50	77	67.88	4.87
Italy	Mediterranean	1 612	35	115	87.76	14.66
Italy	Continental	880	88	121	104.63	6.53

Country	Biogeographical region	Number of 10 km cells	Minimum richness	Maximum richness	Average richness	Standard deviation richness
Italy	Alpine	509	70	123	99.59	11.21
Latvia	Boreal	653	102	135	124.39	5.08
Lithuania	Boreal	651	121	138	131.09	2.33
Lithuania	Continental	4	122	135	126.25	5.17
Luxembourg	Continental	25	112	122	117.56	2.61
Netherlands	Atlantic	352	84	125	107.78	9.58
Poland	Continental	3 023	110	139	130.10	3.77
Poland	Alpine	100	100	132	124.43	6.25
Portugal	Mediterranean	840	80	121	103.88	7.83
Portugal	Atlantic	46	76	104	90.17	7.72
Portugal	Macaronesia	26	1	19	14.85	3.76
Romania	Steppic	368	88	125	113.08	5.21
Romania	Black Sea	36	79	114	100.00	11.27
Romania	Pannonian	148	102	126	112.32	3.98
Romania	Alpine	487	86	133	114.45	9.33
Romania	Continental	1 326	100	129	116.10	5.27
Slovakia	Pannonian	141	111	134	122.99	4.87
Slovakia	Alpine	347	99	134	122.21	7.37
Slovenia	Pannonian	1	123	123	123.00	0.00
Slovenia	Continental	127	103	126	116.54	5.19
Slovenia	Alpine	76	90	128	106.00	8.83
Spain	Alpine	93	89	126	106.30	7.95
Spain	Mediterranean	4 330	36	136	114.72	10.30
Spain	Atlantic	559	64	133	100.47	13.51
Spain	Macaronesia	71	19	32	25.20	3.73
Sweden	Continental	159	100	127	115.68	4.85
Sweden	Boreal	3 447	56	128	95.90	15.61
Sweden	Alpine	863	36	93	61.77	11.18
United Kingdom	Atlantic	2 428	32	102	81.81	12.06

MA6. Maps of habitat suitability to support species by ecosystem type



MA7. Input data for soil retention accounts

Name			Source	Comments	Spatial resolution	Temporal resolution
Biophysical modelling						
Ecosystem service potential	*C*-factor (arable)	Crop extent	https://ec.europa.eu/eurostat/web/products-datasets/-/apro_cpshr	A 2- to 3-year period was used to calculate the mean for each year modelled. In this way, crop extent to model 2000 is the mean of 2000 and 2001, to model 2006 is the mean of 2005–2007, and to model 2012 is the mean of 2011–2013. The areas are expressed in 1 000 ha [apro_cpshr]	NUTS 0, NUTS 1, NUTS 2	2000–2013
		Farm structure survey data	https://ec.europa.eu/eurostat/web/microdata/farm-structure-survey	Survey on the structure of agricultural holdings carried by Eurostat. Among other information, it reports the extent (in 1 000 ha) under different soil conservation measures at regional level (NUTS 2). When NUTS 2 data are missing, the values for NUTS 0 are used	NUTS 2	2010 (applied to model 2006 and 2012); data for 2016 can be applied to model 2018
	C-factor (non-arable)	Land cover data	https://www.eea.europa.eu/data-and-maps/data/corine-land-cover-accounting-layers	CLC status layers harmonised to create a statistically solid basis for CLC-based time series analysis	100 × 100 m^2	2000, 2006, 2012
		F_{cover}	https://land.copernicus.eu/global/products/fcover	Satellite-derived product from the Copernicus programme providing information on the fraction of ground covered by green vegetation	1 km^2	2000, 2006, 2012
Factors RUSLE (for the demand and actual flow)	*R*-factor		https://esdac.jrc.ec.europa.eu/content/rainfall-erosivity-european-union-and-switzerland	Rainfall erosivity for the EU-28 derived from rainfall erosivity database on the European scale. The Gaussian process regression model was used to interpolate the rainfall erosivity values of single stations and to generate the *R*-factor map	500 × 500 m^2	Static: reference years 1970–2010 (predominance 2000–2010)

	Name	Source	Comments	Spatial resolution	Temporal resolution
	K-factor	https://esdac.jrc.ec.europa.eu/content/soil-erodibility-k-factor-high-resolution-dataset-europe	Soil erodibility in the EU-28, derived from the land use / land cover area frame survey (LUCAS) 2009 point survey exercise and the European soil database	500 × 500 m^2	Static: reference year 2009
	LS-factor	https://esdac.jrc.ec.europa.eu/content/ls-factor-slope-length-and-steepness-factor-eu	Calculation of the topographic factor (*LS*) based on Desmet and Govers (1996)	25 × 25 m^2	Static
	P-factor	https://esdac.jrc.ec.europa.eu/content/support-practices-factor-p-factor-eu	European support practices to reduce soil loss taking into account contour farming, maintenance of stone walls and grass margins	1 × 1 km^2	Static: reference year 2010
Monetary valuation					
Actual flow in monetary terms	Nitrogen	https://esdac.jrc.ec.europa.eu/content/chemical-properties-european-scale-based-lucas-topsoil-data	Maps of soil chemical properties at European scale based on LUCAS 2009/2012 topsoil data	500 × 500 m^2	2009
	Phosphorus	https://esdac.jrc.ec.europa.eu/content/chemical-properties-european-scale-based-lucas-topsoil-data	Maps of soil chemical properties at European scale based on LUCAS 2009/2012 topsoil data	500 × 500 m^2	2009
	Fertiliser costs	https://ec.europa.eu/agriculture/markets-and-prices/price-monitoring_en https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/markets/prices/commodity-price-dashboard_en https://ec.europa.eu/info/files/market-brief-fertilisers-eu_en http://www.amis-outlook.org/amis-monitoring#.XekaVJP7SUk			

Name	Source	Comments	Spatial resolution	Temporal resolution
Reference layers				
NUTS 0, NUTS 2	https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units	Reference layers for the extraction of NUTS regions, version 2010. For the update, it was recommended to use the latest version available in the geographical information system for the Commission, closest to the last year modelled		

MA8. Aggregation levels for non-arable land cover types from Corine based on the literature: *C*-factors reviewed

Urban and marine classes, together with beaches, bare rocks and glaciers, were removed from the analysis.

CLC code	CLC inventory	MAES ecosystem type	*C*-land use ranges for non-arable land
141	Green urban areas ([a])	Urban	0.003–0.05
221	Vineyards	Cropland	0.15–0.45
222	Fruit trees and berry plantations		0.1–0.3
223	Olive groves		0.1–0.3
231	Pastures	Grassland	0.05–0.15
241	Annual crops associated with permanent crops	Cropland	0.07–0.35
242	Complex cultivation patterns		0.07–0.2
243	Land principally occupied by agriculture, with significant areas of natural vegetation		0.05–0.2
244	Agro-forestry areas		0.03–0.13
311	Broad-leaved forest	Forest	0.0001–0.003
312	Coniferous forest		0.0001–0.003
313	Mixed forest		0.0001–0.003
321	Natural grasslands	Grassland	0.01–0.08
322	Moors and heathland	Heathland and shrub	0.01–0.1
323	Sclerophyllous vegetation		0.01–0.1
324	Transitional woodland-shrub	Forest	0.003–0.05
333	Sparsely vegetated areas	Sparsely vegetated	0.1–0.45
334	Burnt areas		0.1–0.55

([a]) Green urban areas (CLC code = 141) were assigned the same *C*-factor as transitional woodland-shrub (CLC code = 324).

MA9. Aggregation levels for non-arable land cover types from Corine based on the literature

Crop type	**Proportion (%) of the total arable land (2000)**	**Proportion (%) of the total arable land (2006)**	**Proportion (%) of the total arable land (2012)**	**Crop-specific *C*-factor**
Aromatic	0.15	0.20	0.22	0.8
Barley	17.25	17.67	15.81	0.21
Cotton seed	0.11	0.09	0.03	0.5
Dry pulses	2.36	2.06	1.85	0.38
Durum wheat	4.56	4.06	3.23	0.2
Energy crops	0	0	0.06	0.32
Fibre crops	0.74	0.66	0.52	0.28
Grain maize	11.78	11.31	12.42	0.38
Hops	0.04	0.04	0.03	0.8
Linseed (oil flax)	0.20	0.11	0.09	0.25
Oats	5.68	5.87	5.01	0.2
Other cereals	0.23	0.32	0.33	0.2
Other oilseed	0.30	0.32	0.17	0.28
Rape and turnip rape seeds	4.95	7.12	8.45	0.3
Rice	0.494	0.53	0.59	0.15
Root crops	7.269	5.719	4.45	0.34
Rye and winter cereal mixtures (maslin)	4.49	3.23	3.27	0.2
Soya	0.622	0.62	0.58	0.28
Sorghum	0.145	0.13	0.16	0.15
Sunflower seed	3.81	3.852	5.72	0.32
Tobacco	0.194	0.114	0.13	0.49
Triticale	2.37	3.222	3.40	0.2
Wheat and spelt	32.25	32.68	33.48	0.2

MA10. Extent of the ecosystem types (km^2) considered for 2000, 2006 and 2012

The values correspond to the aggregation of the CLC classes considered in this study.

Ecosystem type	**2000**	**2006**	**2012**
Study area (land cover with soil)			
All	3 860 611	3 855 452	3 850 587
Urban green areas	3 044	3 038	3 073
Cropland: arable	1 592 862	1 096 251	1 092 252
Cropland: non-arable	492 421	492 853	492 599
Forests	1 563 544	1 564 626	1 565 529
Grassland	496 600	495 299	494 393
Heathland and shrubland	173 141	172 328	171 897
Sparsely vegetated land	31 420	31 058	30 844

MA11. Export coefficients (kg/ha/year) as identified in the literature

Cropland

Non-irrigated arable land (CLC code 211)

	Yang et al. (2014)
Single value (mean, where range was provided)	16.09
Low value = mean value minus …	13.99
High value = mean value plus …	63.51
Type of 'single value'	
Single value	X
Mean calculated based on range provided	
Category in source study	Cropland

Grassland

Pastures (CLC code 231)

	Yang et al. (2014)
Single value (mean, where range was provided)	8.65
Low value = mean value minus …	7.17
High value = mean value plus …	22.2
Type of 'single value'	
Single value	X
Mean calculated based on range provided	
Category in source study	Pasture

Urban

Discontinuous urban fabric (CLC code 112)

	Yang et al. (2014)
Single value (mean, where range was provided)	9.97
Low value = mean value minus …	8.49
High value = mean value plus …	28.5
Type of 'single value'	
Single value	X
Mean calculated based on range provided	
Category in source study	Urban

Wetland

Peat bogs (CLC code 412)

	Yang et al. (2014)
Single value (mean, where range was provided)	0
Low value = mean value minus …	0

High value = mean value plus …	0
Type of ‘single value’	
Single value	X
Mean calculated based on range provided	
Category in source study	Water/wetland

Woodland and forest

Coniferous forest (CLC code 312)

	Yang et al. (2014)
Single value (mean, where range was provided)	2.86
Low value = mean value minus …	1.48
High value = mean value plus …	3.4
Type of ‘single value’	
Single value	X
Mean calculated based on range provided	
Category in source study	Forest (in the United States)

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