The SEEA EEA biophysical ecosystem service supply-use account for the Netherlands

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March, 2018

Executive summary

Aim and context of biophysical supply – use accounts

Ecosystem accounting is an approach to systematically measure and monitor ecosystem services and ecosystem condition over time for decision making and planning. It follows the framework of the United Nations the System of Environmental Economic Accounting – Experimental Ecosystem Accounting (SEEA EEA). The framework prescribes the development of core accounts (extent and condition of ecosystems, the supply and use of ecosystem services (biophysical and monetary) and the monetary ecosystem asset account), and the development of four thematic accounts, centred around the themes carbon, biodiversity, water and land. Within the current project, all core accounts will be developed as well as the thematic accounts for carbon (Lof et al., 2017) and biodiversity (under development, see box 1.2 in section 1.1). In this report the biophysical ecosystem service supply and use accounts for the Netherlands for 2013 are presented, as well as the extent accounts for 2006 and 2013. These were developed within the project 'Ecosystem Accounting for the Netherlands' by Statistics Netherlands and Wageningen University. All maps will be made available on the CBS website.

This project builds on a vast amount of data and analyses, either developed within this project or kindly provided by others. The aim of this report was to provide a state-of-the art overview of biophysical ecosystem modelling and accounting. Clearly, considering the vast interest in ecosystem services and modelling, in time data and model improvements will become available. Where possible, such improvements will be incorporated in the future.

The biophysical supply and use accounts presented in this report record the flows of ecosystem services from ecosystems to society and identify the economic beneficiaries of these services. Quantitatively, supply equals use following SEEA EEA definitions. Thus, here we assume that all supplied services are also used in the economy. The physical supply account is one of the core ecosystem accounts and provides the basis for the monetary ecosystem service supply and use account. Theoretically, the supply of ecosystem services depends on the extent of given ecosystem types and their condition. Therefore the extent account is also discussed briefly in box 1.1 and Appendix 1. The condition account is currently under development and will be published separately.

To provide spatial information on physical supply, high-resolution models were developed for a broad range of ecosystem services. Thirteen ecosystem services were modelled (see table i): five provisioning services, six regulating services and two cultural services. These services are in good agreement with the definition of ecosystem services in the Common International Classification of Ecosystem Services (CICES) and were selected based on data availability and quality, as well as relevance for the Netherlands.

Ecosystem services were analysed and maps were produced using existing data and models where possible (see figure i for an example), and implementing new data and insights where needed. Based on these results, biophysical supply tables were populated. The ecosystem services supply tables were developed for the Netherlands, for each ecosystem type (total and mean values, tables 4.1.1 and 4.1.2) as well as for each of the Dutch provinces (tables 4.2.1 and 4.2.2). Use tables were set up for the different economic sectors that benefit from these ecosystem services (table 4.3.1).

Table i Ecosystem services included in the biophysical supply and use account for the Netherlands and their relation to the international CICES classification

CICES for ecosystem accounting				***Ecosystem Services, this study***
Section	**Division**	**Group**	**Class**	
Provisioning	Nutrition	Biomass	Cultivated crops	**Crop production**
			Reared animals and their outputs	
			Wild plants, algae and their outputs	
			Wild animals and their outputs	
			Plants and algae from in-situ aquaculture	
			Animals from in-situ aquaculture	
		Water	Surface water for drinking	**Drinking water production**
			Ground water for drinking	
	Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	**Wood production**
			Materials from plants, algae and animals for agricultural use	**Fodder production**
			Genetic materials from all biota	
		Water	Surface water for non-drinking purposes	
			Ground water for non-drinking purposes	
	Energy	Biomass-based energy sources	Plant-based resources	**Biomass from non-agricultural sources**
			Animal-based resources	
		Mechanical energy	Animal-based energy	
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals	
			Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	
		Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems	
			Dilution by atmosphere, freshwater and marine ecosystems	
			Mediation of smell/noise/visual impacts	
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	**Erosion prevention**
			Buffering and attenuation of mass flows	
		Liquid flows	Hydrological cycle and water flow maintenance	**Protection against heavy rainfall**
			Flood protection	

		Gaseous / air flows	Storm protection	
			Ventilation and transpiration	
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	**Pollination**
			Maintaining nursery populations and habitats	
		Pest and disease control	Pest control	**Pest control**
			Disease control	
		Soil formation and composition	Weathering processes	
			Decomposition and fixing processes	
		Water conditions	Chemical condition of freshwaters	
			Chemical condition of salt waters	
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	**Carbon sequestration in biomass**
			Micro and regional climate regulation	**Air filtration**
Cultural	Physical and intellectual interactions with biota etc.,	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings	**Tourism; Nature recreation**
			Physical use of land-/seascapes in different environmental settings	
		Intellectual and representative interactions	Scientific	
			Educational	
			Heritage, cultural	
			Entertainment	
			Aesthetic	
	Spiritual, symbolic and other	Spiritual and/or emblematic	Symbolic	
			Sacred and/or religious	
		Other cultural outputs	Existence	
			Bequest	

Results

The biophysical supply tables show that forests and agricultural land supply the highest total quantities of ecosystem services, mainly because these ecosystem types cover the largest extents. More natural ecosystem types (e.g. dunes, heath and deciduous forest) supply higher average quantities of ecosystem services (per ha) compared to less natural ecosystem types. The supply of ecosystem services from Dutch provinces is highly heterogeneous, with each province providing a different set of services, in part due to differences in dominant ecosystem types. Limburg has a relatively high supply of ecosystem services per ha, supplying all ecosystem services at or above national average levels.

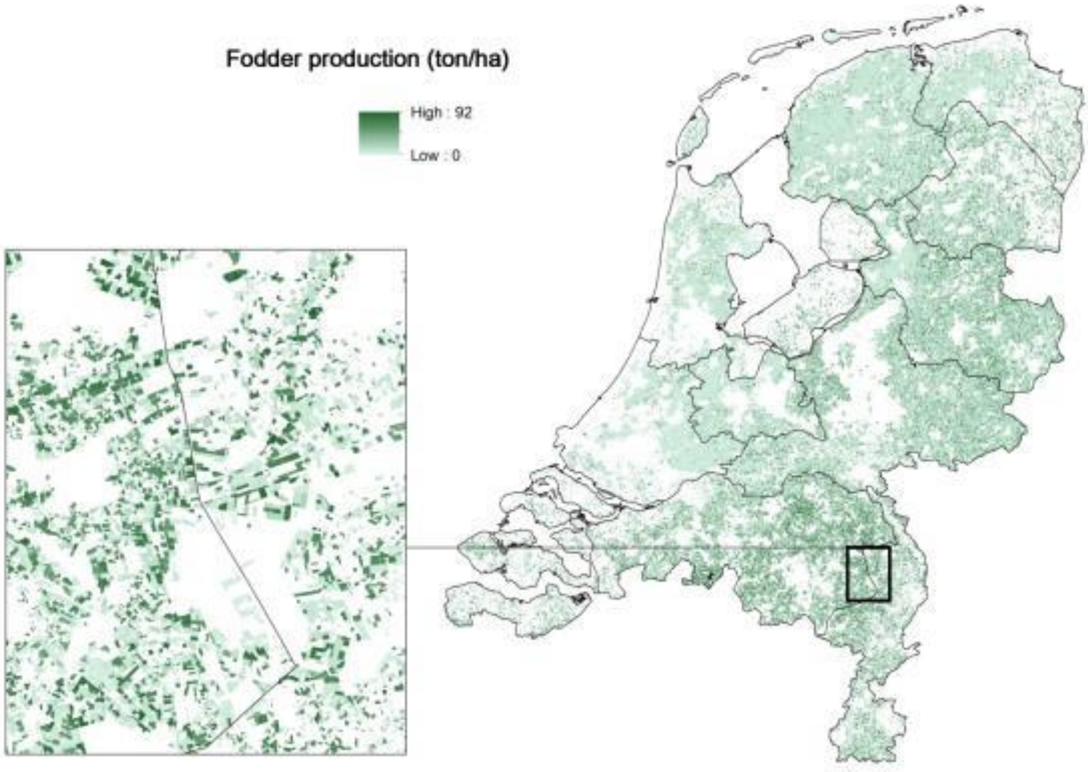

Figure i Example of ecosystem supply model result map. Fodder production in the Netherlands (tons/ha/yr), comprising maize and grass production for livestock.

The biophysical use table reflects which economic sectors (following ISIC, the International Standard Industrial Classification of all economic activities) are the most important users of the various ecosystem services. The use of ecosystem services erosion control and protection against flooding from heavy rainfall has been allocated to sectors based on land ownership. The ISIC sector Agriculture, forestry and fisheries uses the most ecosystem services (seven), followed by households (four).

Applications and future developments

Data availability and models on or related to ecosystem services are rapidly improving, increasing the possibilities to account for ecosystem service supply and use. Given current national efforts to model ecosystem services, future supply and use accounts can include a larger number of ecosystem services.

The results from the biophysical supply and use account can be used for multiple policy applications, providing information for spatial planning, developing a circular economy, and assessing particular sectors, and providing a basis for monitoring existing policies. For example, new residential or infrastructure investments can be designed in such a way that the negative effects on natural capital providing ecosystem services can be minimized. In addition, land owners can use the accounts to assess where other, comparable, areas provide more ecosystem services in order to adjust their land use. As an example, the accounts demonstrate that small forest patches and hedgerows in agricultural landscapes are very important for crop production since they contribute to pollination of crops and to natural pest control. The importance of these services for crop production, and thereby the importance of the small landscape elements may often be overlooked in spatial planning.

The accounts also provide detailed information on material flows from ecosystems to the economy, and allow closing such flows for example for wood and other biomass. The accounts specify that there are several sources of such materials where use can possibly be increased without affecting the sustainability of this specific use (e.g. currently only around one third of the regrowth in Dutch forest is harvested). Simultaneously, the accounts can also provide insight into changes in the supply of other ecosystem services if the use of a specific service is increased.

The high level of detail and expected regular repetition of the accounts provides the possibility to assess supply and use from national to local level and monitor changes over time. The accounts include maps of ecosystem services supply and use that are at such a fine resolution (10 meters for many services) that they also are relevant for ecosystem management in Dutch municipalities and provinces. However, at the same time, even though the models are all state-of-the art and represent the most accurate representation that can be given at national scale given current availability of data, the accuracy of most models is not yet verified. Therefore it is not yet well understood if the maps are sufficiently accurate to also provide meaningful information at the level of the municipality. In the third year of the Ecosystem Accounting project for the Netherlands (i.e. 2018-2019) this accuracy will be tested and discussions with a broad group of potential users will be held in order to verify the relevance of the product for local scale natural capital management.

In addition, the authors concur with the UN SEEA that the SEEA EEA approach greatly increases its potential to support policy making if the accounts are produced on a regular basis (e.g. two or three year cycles). This is in line with the national accounts that record the use of human and produced capital (and of some natural capital, i.e. subsoil assets such as oil and gas), which are produced on an annual basis. Many if not all models developed in this project can reproduced if and when the accounts are to be updated in the future.

Finally, this report presents the world's first national scale ecosystem services supply and use accounts developed in line with the UN SEEA Ecosystem Accounting methodology. The lessons of this project are directly relevant for the forthcoming process in which the currently available framework and technical recommendations (to be published in fall 2017) will be enhanced into a statistical standard. The report and the methodologies applied are already being shared with the SEEA community in several ways including presentations at meetings of the London Group on SEEA. Hence, in addition to its capacity to support monitoring and using ecosystem capital in the Netherlands, this work presents a major contribution to the international field of the SEEA.

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1. Introduction

1.1 Overview

For several decades there has been worldwide recognition that ecosystems and their biodiversity are under increasing pressure (e.g. MA, 2005; UN, 1992; WCED, 1987). These pressures, that result from increasing human population and accompanying economic activities, threaten both the integrity of the ecosystems as well as the economic benefits that humans can obtain from them. These economic benefits result from so-called ecosystem services. Ecosystems services can be defined as the contributions of ecosystems to benefits used in economic and other human activity (UN et al., 2014b par 2.23; UN et al., 2017). Examples of ecosystem services include the provision of food and natural resources, capturing of greenhouse gases and pollutants by vegetation to improve air quality and mitigate climate change and the provision of attractive areas for recreation and learning.

Ecosystem accounting is an approach to systematically measure and monitor ecosystem services and ecosystem condition over time for decision making and planning. Under the auspices of the United Nations, the System of Environmental Economic Accounting – Experimental Ecosystem Accounting (SEEA EEA) has been developed to guide the implementation of ecosystem accounting (UN et al., 2014b). One of the main objectives of the SEEA EEA is to measure ecosystem services in a way that is aligned with the System of National Accounting (SNA) (UN et al., 2009). Worldwide, the SNA forms the basis for economic statistics and is used to calculate indicators such as GDP in a consistent manner. For ecosystem accounting, the SEEA EEA prescribes the development of a series of connected core accounts (see figure 1.1.1), representing the extent and condition of ecosystems, the supply and use of ecosystem services (biophysical and monetary) and the monetary ecosystem asset. Within the group of biophysical core accounts, the extent account and condition account record information on the size and state of ecosystems, which, in theory, determines the flow of physical ecosystem services (supply account). Because supply equals use (following the SNA), the use account records the biophysical flow of services to beneficiaries. Hence, physical supply cannot, by definition, exceed demand. In this study we thus assume that all supplied services are used in the economy (see individual model set up and descriptions for more details, section 3 and Appendix 2). In the Netherlands, with its high population density, this is considered a likely assumption.

In a following step, biophysical supply models will be combined with additional data to develop monetary supply models. These are used to calculate monetary ecosystem service supply and use account (which records monetary ecosystem service flows; both geographically explicit) and the monetary ecosystem asset account, which records the value of ecosystem assets (stocks) based on their long term ability to provide a basket of ecosystem services. In addition to the core accounts for ecosystem accounting, the SEEA EEA promotes the development of four thematic accounts for carbon, biodiversity, water and land. To account for ecosystems, the ecosystems are classified into ecosystem types (formerly referred to as Ecosystem Units, or Land Cover and Ecosystem Units) (UN et al. 2017). Ecosystem types are classes in which similar ecosystems can be grouped (e.g. broad-leafed forest, heath or perennial crops), to create an aggregated set of ecosystem types to account for.

In 2016 Statistics Netherlands and Wageningen University started a three year project 'Ecosystem Accounting for the Netherlands', on behalf of the Dutch Ministries of Economic Affairs and Infrastructure and the Environment. Its aim was to test and implement SEEA EEA ecosystem accounting for the Netherlands. The choice was made to develop the core accounts and include carbon and biodiversity as thematic accounts (table 1.1.1). Further information on the role of biodiversity in the ecosystem accounts is provided in box 1.2. The focus of this research project is primarily on terrestrial ecosystems.

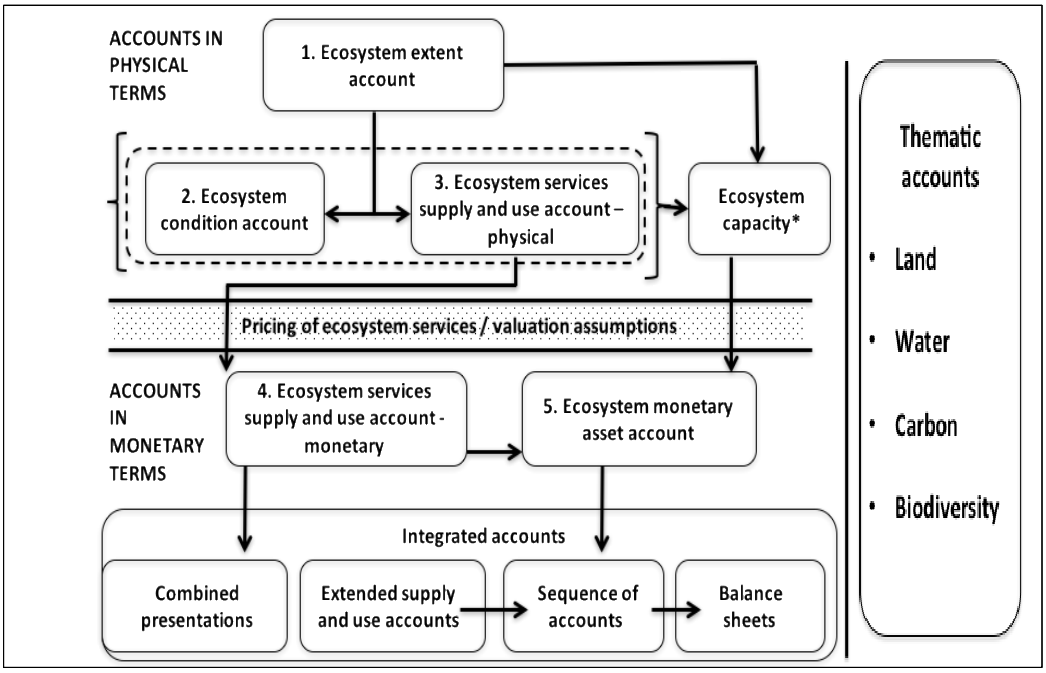

Figure 1.1.1 Connections between ecosystem and related accounts and concepts, as presented in SEEA EEA. Source: UN et al., 2017

Table 1.1.1 Accounts in the System of Environmental-Economic Accounting to be developed for the Netherlands. Bold indicates the account presented in this report.

Core ecosystem accounts	
Ecosystem extent account	Records the size of ecosystems (see Box 1.1).
Ecosystem condition account	Records indicators that describe the quality and state of ecosystems.
Biophysical ecosystem service supply and use account	**Records the biophysical flows of ecosystem services to society and identifies its users.**
Monetary ecosystem service supply and use account	Records the monetary flows of ecosystem services to society and identifies its users.
Ecosystem capacity account	Records what ecosystems can sustainably produce in terms of ecosystem services, given the current state and management (exploratory).
Ecosystem asset account	Records the value of the stocks of ecosystems, given the basket of ecosystem services that they produce (exploratory).
Thematic accounts	

Carbon account	Records the stocks and flows of carbon in the country, related to the geosphere, biosphere and economy.
Biodiversity account	Records the current status and trends in biodiversity. in the country, based on multiple indicators (see Box 1.2).

In this report we focus on the biophysical ecosystem service supply and use account for the Netherlands. Supply is defined as the ecosystem services that are produced by ecosystems within the Netherlands, and that are subsequently used in the economy. Use is considered as use by industries, households, government or the rest of the world. In addition, results for the extent accounts for the years 2006 and 2013 can be found in Appendix 1. The carbon account was published recently (Lof et al., 2017). The remaining core accounts (condition, monetary supply and use, asset) and the biodiversity account are currently in development.

The biophysical ecosystem service supply and use account for the Netherlands builds on a pilot study for Limburg province by Statistics Netherlands and Wageningen University (de Jong et al., 2015). Results and lessons learned from the pilot project were used to further develop ecosystem accounts for the Netherlands, applying similar, and if possible, improved modelling methods, new data sources, and a larger array of ecosystem services.

Box 1.1: Extent Account

Ecosystem extent provides the information on the total (summed) extent of each ecosystem unit as mapped for a given year. Within this project, extent accounts were developed for the years 2006 and 2013. These show that the total of agricultural land represents nearly half of the total surface area of the Netherlands despite a small decrease, whereas built up and paved areas cover just over 13% and have slightly increased. Because the extent accounts are based on spatial data, it is to track the causes for changes. In other words, one can analyse the increase in e.g. built-up areas, and at the expense of which other ecosystem units this occurred. Interestingly, the analyses show that for example forests (more or less stable total extent) were in part changed into agricultural land and 'other unpaved terrain', whereas new forest was also developed on these same ecosystem units, but (inherently) on different locations. In total, between 2006 and 2013, roughly 11% of the Netherlands total surface area had changed into a different ecosystem unit. Full details are provided in Appendix 1.

Box 1.2: Biodiversity in ecosystem accounts

Biodiversity is a fundamental characteristic of ecosystems and consists of the following three components: ecosystem, species and genetic diversity. Determining the role and position of biodiversity in the SEEA EEA is a challenge (see discussion in section 5.1). In many cases biodiversity underpins processes leading to an ecosystem service. For example, insect diversity is necessary for the pollination and pest control services, and iconic species may contribute significantly to nature tourism. Biodiversity can also be seen as a direct ecosystem service, providing for example cultural and education services. However, these services generally do not involve consumption or any kind of flow. Therefore, biodiversity is not included in the services supply and use account. A separate thematic account about biodiversity is developed (work in progress), in line with the SEEA EEA. Spatial information and suitable indicators are collected for this thematic account, focussing on ecosystem and species diversity. Also in the condition account several indicators related to biodiversity will be included (work in progress).

1.2 The SEEA EEA supply and use account

The supply of ecosystem services by ecosystem assets and the use of these services by economic types, including households, are the central features of ecosystem accounting (UN et al., 2014a; UN et al., 2014b; UN et al., 2017). These are the flows between ecosystem assets and economic and human activity.

The ecosystem services supply and use account records the flows of ecosystem services supplied by ecosystem types and used by economic units during an accounting period (in this study the year 2013). Data in the ecosystem supply and use tables relate to a given ecosystem territory. This may be the national territory or any region on a sub-regional scale.

Table 1.2.1 Ecosystem supply and use tables

ECOSYSTEM SUPPLY TABLE										
		Ecosystem Type								
	Measurement units	Artifical surfaces	Herbaceous crops	Woody crops	Multiple or layered crops	Grassland	Tree covered	Etc.	**TOTAL SUPPLY**
Ecosystem services									
Provisioning services									
Regulating services									
Cultural services									

ECOSYSTEM USE TABLE									
		Economic Unit							
	Measurement units	Agriculture, forestry and fisheries	Electricity and gas supplky	Water collection, treatment and syupply	Other industries	Households	Accumulation	Rest of the world - exports	**TOTAL USE**
Ecosystem services									
Provisioning services									
Regulating services									
Cultural services									

The structure of the supply and use account for ecosystem accounting is shown in table 1.2.1. This basic structure is the physical supply and use tables (PSUT), as used for environmental accounting in the SEEA Central Framework (UN et al., 2014a). There are two principle differences between the PSUT for ecosystem accounting (cf. SEEA EEA) and environmental accounting (cf. SEEA CF). First, for ecosystem accounting the columns of the supply table and use tables describe different set of units than for environmental accounting, namely ecosystem types in the supply table and economic units in the use table. Rather than showing just one column representing the environment in the supply table, there are multiple columns showing the different ecosystem types. Second, in the SEEA CF there are three types of flows, i.e. natural inputs, products and residuals. In the ecosystem supply and use tables there is just one (i.e. ecosystem services)[1].

[1] In the SEEA technical recommendations also products are added as a row category (UN et al., 2017). Here, we have chosen not to add this category in order to not further complicate the tables.

The supply table records which ecosystem types provide biophysical quantities of ecosystem services. This gives insight into the wide range of services that are offered by natural and semi-natural vegetation, as well as human dominated ecosystems. As the supply account is based on ecosystem service maps, locations of supply can be traced in detail. The use table records which economic sectors (including households) benefit from the ecosystem services, following the classifications used in the national accounts.

The ecosystem service accounts can be compiled both in biophysical and monetary terms. When compiled in biophysical terms each ecosystem service will have a different measurement unit as well as a different interpretation; for example tons of crop production (which represents the full set of inputs into agricultural production, including labour, investments etc. as well as a natural component), or the number of tourists for nature tourism (which represents the number of tourists stating attractive nature as the main reason for a touristic visit, based on questionnaire data). As a consequence, there can be no aggregation of the different ecosystem service types, nor can there be a direct interpretation of the economic significance of an ecosystem service in comparison to another. These challenges will receive full attention in the monetary accounts that will be developed in the next project phase. For the current physical flow accounts, aggregation within a single row is possible to estimate the total flows from all types of ecosystem types. In addition, spatial patterns can be studied by comparing the same ecosystem services for different regions.

1.3 Study scope and aim

The main aim of this study is to provide a first biophysical ecosystem service supply and use account for the Netherlands, following the SEEA EEA guidelines. Spatial models are developed for a set of ecosystem services, in order to assess the supply of ecosystem services for various areas in detail and represent the spatial heterogeneity of ecosystem service provision throughout the Netherlands. Based on these spatial models, biophysical supply tables are developed and analysed. Use tables are set up for the different economic sectors that benefit from the ecosystem services.

In Chapter 2 a short overview of the applied methods in this report is provided. Chapter 3 gives a detailed overview of each studied ecosystem service in the Netherlands, with an overview of the data and methodology that were applied, the main results including maps, as well as additional analyses of the services. In Chapter 4 the biophysical supply and use account for the Netherlands is presented. An overview of the ecosystem service supply per province and at national scale is given, as well as the supply of ecosystem services per ecosystem type. In addition, the use tables show the flow of services to sectors of the Dutch economy. In Chapter 5 the results are discussed, as well as policy applications and future directions. Chapter 6 provides the main conclusions of the report. Appendix 1 provides more details on the Ecosystem Type maps of 2006 and 2013 and makes a comparison between them. Appendix 2 shows the methodological details of each ecosystem service model used in this report. Last, Appendix 3 connects Natural Capital Accounting with the circular economy.

2. Methodology

2.1 Data sources and ecosystem service models

The goal of this biophysical supply and use account was to model a broad range of ecosystem services. The focus is on final ecosystem services (i.e. the last point at which ecosystems contribute to human benefits, cf. Boyd and Banzhaf, 2007). However, to representatively capture how ecosystems contribute to economic activity, the inclusion of some intermediate services was also necessary (i.e. ecosystem services that contribute to the production of final services). The intermediate services that were included in this account are pollination and natural pest control.

Based on current data availability, experience from the previous pilot study for Limburg province and discussions with the Dutch Ministry of Economic Affairs, the Ministry of Infrastructure and Environment and other stakeholders, we selected 13 ecosystem services (table 2.1.1): 5 provisioning services, 6 regulating services and 2 cultural services. These ecosystem services have been selected to represent all three main ecosystem service categories from CICES (CICES, 2017). Additionally, the ecosystem services could be quantified and modelled with available data at national level. The focus is on terrestrial ecosystems. Marine ecosystem services were outside the scope of this study. Additional ecosystem services were considered during early stages of the project, but not all services could be quantified and modelled for a variety of reasons. These ecosystem services will be discussed in Chapter 3.

Table 2.1.1 Ecosystem services included in the biophysical supply and use account for the Netherlands, and whether this service is classified as a final or intermediate service.

Ecosystem service	Final or intermediate service
Provisioning services	
Crop production	Final service
Fodder production	Final service
Wood production	Final service
Biomass from non-agricultural sources	Final service
Drinking water	Final service
Regulating services	
Carbon sequestration in biomass and soil	Final service
Pollination	Intermediate service
Natural pest control	Intermediate service
Erosion control	Final service
Air filtration	Final service
Protection against flooding due to heavy rainfall	Final service
Cultural services	
Nature recreation (hiking)	Final service
Nature tourism	Final service

In order to account for a large range of ecosystem services for a complete ecosystem territory the use of spatial models is necessary. These spatial models were largely developed by the research team, based on existing methods (e.g. Remme et al., 2014), or by developing new methods. The model for erosion control was provided by the National Institute for Public Health and the Environment (RIVM), developed for the Atlas of Natural Capital (www.atlasnatuurlijkkapitaal.nl). This model was applied in unaltered form. All models were developed based on existing datasets and applied functions from scientific literature or expert knowledge. The data for the models originated from multiple Dutch institutes, including Wageningen University and Research, RIVM and Statistics Netherlands. Each model is briefly explained as part of the analysis in Chapter 3, and the technical details are provided in Appendix 2. The spatial models were developed with high spatial resolution (generally 10 x 10 m), to accurately account for spatial variation in the landscape. As the Dutch landscape is highly heterogeneous, the high spatial resolution is necessary to account for local variation.

The Ecosystem Type map was specifically developed by Statistics Netherlands for the purpose of ecosystem accounting. The map shows the major ecosystem types in the Netherlands, and was developed for two years (2006 and 2013). For this report the 2013 map was used for analyses (figure 2.1.1). The Ecosystem Type map was developed based on multiple land cover and land use datasets, to obtain all relevant data (Statistics Netherlands, 2017a; van Leeuwen et al., 2017). The Ecosystem Type map was used as input for multiple ecosystem service models and to analyse biophysical ecosystem service supply per ecosystem type. The Ecosystem Type map was also used to create an extent account, presented in Appendix 1. The extent account provides information on the size of different ecosystems and the changes that occurred in the extent of these ecosystems between 2006 and 2013.

Two basic approaches were used to produce the physical supply account. First, for some services such as crop production and drinking water extraction a 'top-down' approach was used. This involves a spatial disaggregation of information that is already in the SNA. Second, for other services such as carbon sequestration and erosion control, a 'bottom-up' approach was used. This approach was used for services that are not in the SNA, and for which national aggregates were obtained by aggregating local information based on various models. Further detail on the exact modelling approach is provided in Chapter 3 and Appendix 2. Note that a top-down and a bottom-up approach involve different types of uncertainty. In a top-down approach the aggregate value is fully aligned with the SNA. In this case there is mainly a spatial uncertainty: the models indicate service supply at different locations but the supply at any given location may be over- or underestimated. By definition, the total amount of local over- and underestimation cancel out at the national scale. In the bottom-up approach, there is both spatial uncertainty and uncertainty on the aggregate supply of ecosystem services.

2.2 Biophysical ecosystem service supply table

A biophysical ecosystem service supply table was developed for all modelled ecosystem services. Tables were set up to account supply per ecosystem type and per Dutch province. In addition, accounts were set up for the total quantity of an ecosystem service provided by an ecosystem or a province, as well as the mean quantity provided per hectare. The supply tables were developed using the ecosystem service supply models that are explained in Chapter 3 and Appendix 2.

Total quantities were not calculated for the ecosystem service 'natural pest control' because a relative indicator was used that cannot be summed. To calculate mean values the entire extent of an ecosystem or a province was taken into account, including areas that did not supply a specific ecosystem service.

Figure 2.1.1 Ecosystem Type map for the Netherlands for 2013. For an analysis of ecosystem extent see Appendix 1.

2.3 Biophysical ecosystem service use table

A biophysical use table was developed representing all modelled ecosystem services. To populate the use tables, beneficiaries were identified as the users of the ecosystem service, not the final produced good (i.e. the farmer uses crop related ecosystem services, not the consumer that buys the processed produce).

For the use account the classification of the International Standard Industrial Classification of All Economic Activities (ISIC) was followed, supplemented by additional sectors that are essential in an ecosystem services use account (i.e. households, government) and adding a Global Goods category. This last category applies when an ecosystem service is not used by specific (national) users but by the (global) community. Carbon sequestration is an example of such a global service.

The main user groups were identified per ecosystem service and the supply totals were attributed to the relevant users. Most ecosystem services were attributed entirely to the single most important user group, unless no dominant user group could be identified. For example, for ecosystem services related to agriculture the agricultural sector is the user of the service, which contributes to the final product (i.e. the produce sold on the market). In the case that use was bound by location, spatial data on land ownership from the Dutch Business Register (by ISIC) were used. Prerequisite for this approach was that the analysed ecosystem service was used in the same location as it was supplied, otherwise users cannot be identified. Totals of the supply and use accounts match, as all supplied services must be used (cf. SNA).

3. Results per ecosystem service

This chapter provides more detailed information for each individual ecosystem service in the supply and use accounts. For each ecosystem service, maps covering the Netherlands are presented, with a short explanation of the results and further analysis. The data used and the overall methods are explained briefly. Appendix 2 provides further details on methods used.

3.1 Crop production

Among others, agricultural land delivers ecosystem services in the form of harvest of crops for human consumption. Crop production is considered as a final ecosystem service, which involves contributions from other ecosystem services such as pollination, water retention and maintenance of soil fertility, but also human contributions in the form of management (e.g. ploughing, drainage, fertilisation). In this study the total crop production was defined as an ecosystem service. In reality, however, crop production cannot only be attributed to the ecosystem but requires other factors such as (human) capital. Disentangling the contribution of the ecosystem alone is complex; a method for this remains to be developed. Conform CICES (CICES, 2017) the production of crops is therefore currently entirely attributed to the ecosystem.

For the analyses of crop production on agricultural land data from the harvest projections (Statistics Netherlands, 2017c) and the registry on agricultural parcels (Basisregistratie Gewaspercelen) (RVO.nl, 2017) were combined. In this analyse, only crops grown in open fields were taken into account. Crops grown in greenhouses are much more difficult to relate to the ecosystems surrounding the greenhouses and were therefore disregarded. All relevant crops for human consumption , including potatoes, wheat, sugar beets, and open field vegetables were used in the model. The results presented here focus on an aggregate indicator where all crops are accumulated. However, results can also be presented for crops individually or in types of crops (as shown in figure 3.1.2).

From the registry on agricultural parcels both the geographical location and the type of crop grown as registered on May 15, 2013 are known. A selection of the relevant parcels leads to a total of 137 thousand parcels used in the analysis. The list of crops on which this selection was based can be found in Appendix 2, table A2.1.1. In addition, each year Statistics Netherlands produces harvest projections for a large collection of crops (Statistics Netherlands, 2017b). Data are published on average production (in kg) per ha per province. In this study both data sources were combined. It differs per crop type whether the weight of production represents dry matter or total weight (including water). Here, the methodology was aligned with the harvest projections where different amounts of moisture content are allowed (depending on the use and characters of the specific crops).

The results (figure 3.1.1) show that there are very specific areas in the Netherlands which produce larger amounts (in weight) of crops than others. Areas which are important in crop production are the provinces Zeeland, Flevoland, along the coast in Friesland and Groningen and the eastern parts of Groningen and Drenthe. Also areas in the north of Noord-Holland and Noord-Brabant and Limburg are producing large amounts of crops.

Figure 3.1.2 shows the results for two crops individually: potatoes and cereals. The aggregate category of crops consists of the sum of potatoes, cereals and other crops (mainly sugar beets, onions, but also vegetables and fruits). This figure indicates that the analysis can be done for individual or groups of specific crops.

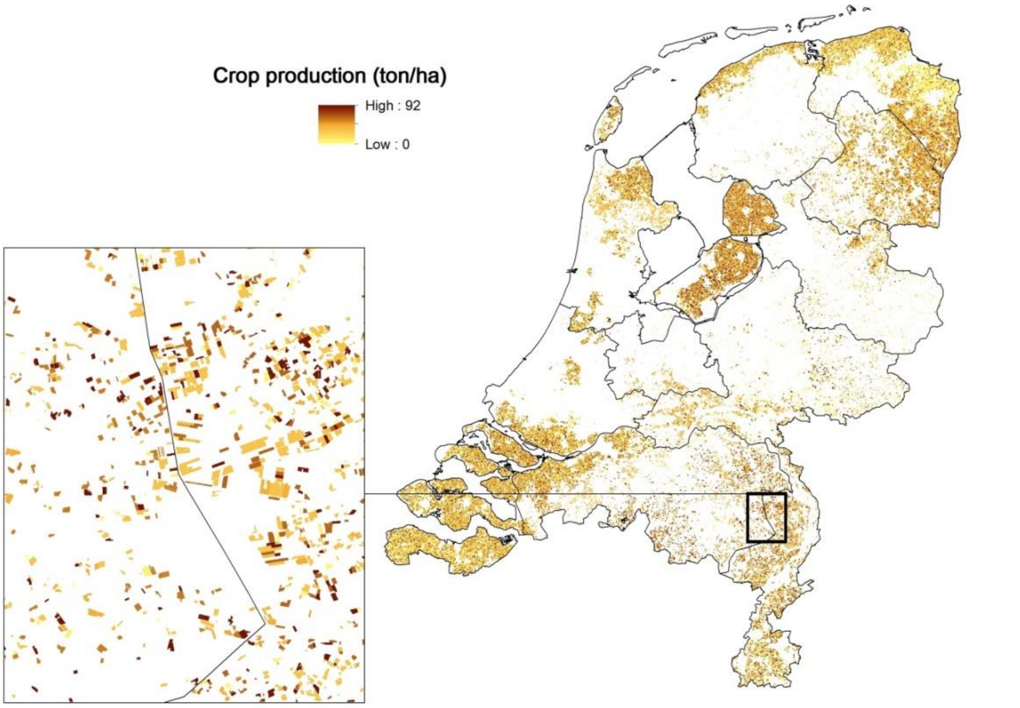

Figure 3.1.1 Crop production in the Netherlands in 2013 (ton/ha)

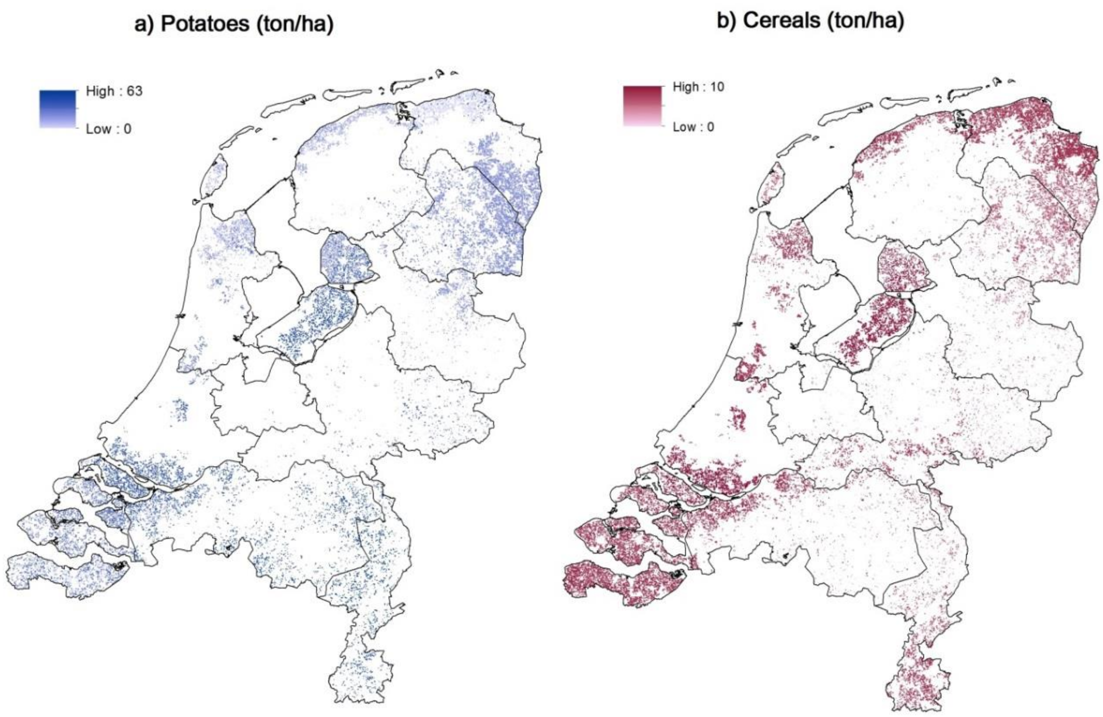

Figure 3.1.2 Potato and cereal production in the Netherlands in 2013 (ton/ha)

Table 3.1.1 shows the results both for the aggregate of crops, as for the three subcategories potatoes, cereals and other crops. There are large differences in the total area used for production of crops between different provinces. Additionally, mean production (ton/ha)[2] of crops differs because of different crops being produced in each province and because of large differences in weight of the individual crops. Also this table indicates that the provinces Zeeland and Flevoland produce most crops and Utrecht the least. Potatoes are grown mostly in Drenthe and Groningen, cereals mostly in Groningen and Zeeland and other crops mostly in Flevoland and Zeeland.

It should be noted that the results as presented in this chapter and in the overall supply account (Chapter 4) are different from the results of the harvest projections presented annually on the website of the Statistics Netherlands (Statistics Netherlands, 2017c). The main reason for this is differences in the set-up and source data between the harvest projections and the analysis in this report, e.g. the total extent that is taken into account in the analysis and the selection of crops differ. Nevertheless, the total crop production in this analysis is about 95% of the amount of the harvest projections. Provincial differences are larger, which is especially the case in the less-producing provinces. A reason for this is the location of the parcels: in this analysis the geographical position defines the location, while in the harvest projections the registered address of the business farm defines the location.

Table 3.1.1 Crop production per province in 2013, for major crop groups.

	Total area (1000ha)				**Mean production (ton/ha)**				**Total production (kton)**			
	Total	Potatoes	Cereals	Other	Total	Potatoes	Cereals	Other	Total	Potatoes	Cereals	Other
Groningen	81	25	41	15	27	37	8	61	2,178	923	336	919
Friesland	20	7	9	4	29	37	8	58	590	268	71	251
Drenthe	54	26	16	12	36	39	7	67	1,950	1,019	113	818
Overijssel	10	5	4	2	31	38	6	58	310	172	23	115
Flevoland	63	18	17	28	41	46	10	57	2,605	818	161	1,626
Gelderland	21	3	10	8	29	43	8	47	611	144	75	393
Utrecht	2	0	0	2	33	42	6	41	71	2	3	66
Noord-Holland	33	9	11	13	32	38	8	48	1,067	339	95	633
Zuid-Holland	38	10	16	12	33	48	9	50	1,241	475	146	620
Zeeland	82	18	35	29	30	42	9	48	2,429	742	302	1,385
Noord-Brabant	55	15	14	26	37	49	8	45	2,010	718	119	1,173
Limburg	33	6	10	17	37	54	8	47	1,199	311	81	806
Netherlands	492	141	182	169	33	42	8	52	16,259	5,932	1,523	8,804

3.2 Fodder production

Besides products for human consumption, agricultural land also delivers services to the economy through the production of fodder for livestock. In this analysis, fodder was defined as a combination of grass harvest (including grass directly consumed by the livestock) and harvest from maize crops specifically used as fodder. Other fodder crops were not taken into account because of a lack of data.

[2] This is different compared to table 4.1.2 and 4.2.2 in Chapter 4 where mean production is based on the entire land area and not only on the areas that produce crops.

In terms of methodology, the analysis is similar to that of crop production. Harvest projections (Statistics Netherlands, 2017c; Statistics Netherlands, 2017d) were linked with a selection of relevant parcels from the registry on agricultural parcels (Basisregistratie Gewaspercelen) (RVO.nl, 2017). See Appendix 2 for an overview of the selected crops. Because harvest projections of grass are available on a more aggregated spatial level compared to the harvest projections of crops, another data source was added. Net primary productivity (NPP) based on remote sensing (Lorenzo Cruz, 2017; see also section 3.4) shows the annual carbon uptake in high spatial detail. To increase the spatial resolution in the final results, the mean harvest projections were re-allocated following the distribution patterns in the NPP data.

Figure 3.2.1 shows the results for total fodder production. Areas such as Friesland (with exception of the coastline), Overijssel, east of Gelderland and the border between Utrecht and Zuid-Holland are intensely used for fodder production. Areas in Noord-Brabant, and to a lesser degree Limburg, are important in terms of weight because of their large contributions to fodder maize production (table 3.2.1). The mean production (ton/ha) indicator used in this table is based only on the land used for fodder production[3]. From figure 3.2.2 it can be seen that maize production is much more evenly dispersed across the country, with the exception of the coastal provinces, compared to grass production. Important areas for grass production are Friesland, the border between Utrecht and Zuid-Holland, Overijssel and the eastern part of Gelderland.

It should be noted that the results as presented in this chapter and in the overall supply table (Chapter 4) are different from the results of the harvest projections presented elsewhere on the website of the Statistics Netherlands (Statistics Netherlands, 2017c; Statistics Netherlands, 2017d). The main reason for this is differences in the set-up and source data between the harvest projections and the analysis in this report, e.g. the total extent that is taken into account in the analysis differs. Nevertheless, the total fodder production in this analysis is about 95% of the amount of the harvest projections. Provincial differences are larger, which is especially the case in the less-producing provinces. A reason for this is the location of the parcels: in this analysis the geographical position defines the location, while in the harvest projections the registered address of the business farm defines the location.

[3] This is different compared to table 4.1.2 and 4.2.2 in Chapter 4 where mean production is based on the entire land area and not only on the area that produce fodder.

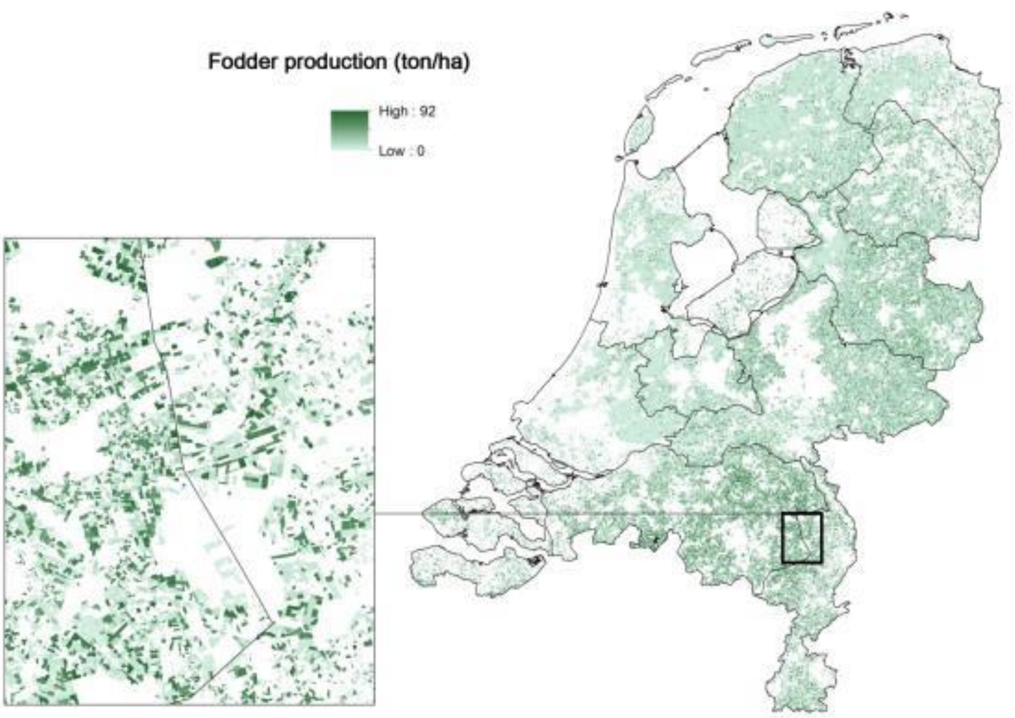

Figure 3.2.1 Fodder production in the Netherlands (tons/ha/yr) comprising of maize and grass production for livestock.

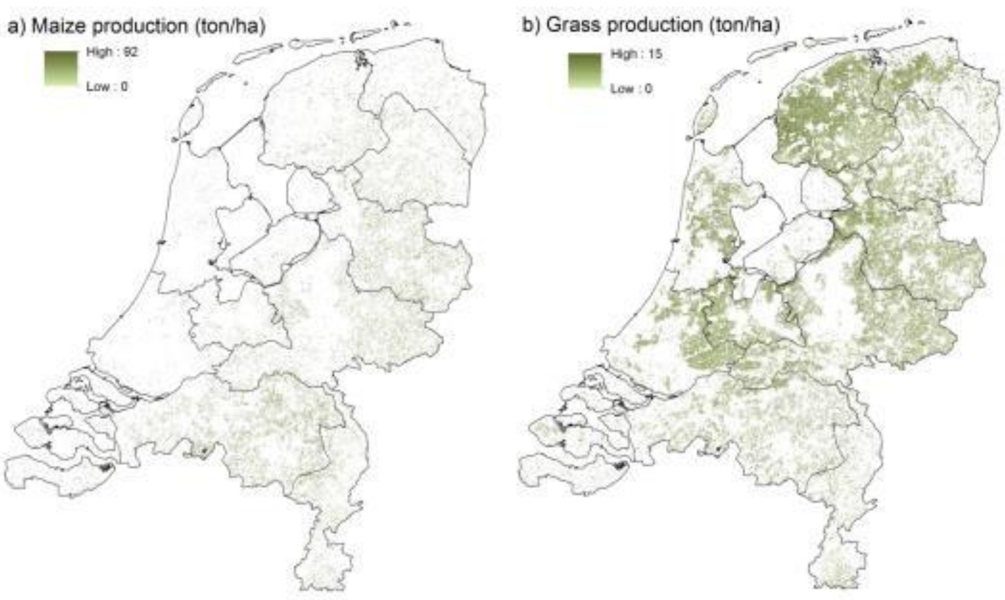

Figure 3.2.2 (a) Maize production and **(b)** grass production in the Netherlands in 2013 (tons/ha/yr).

Table 3.2.1 Grass, maize and total fodder production per province in 2013.

	Total area (1000ha)			Mean production (ton/ha)			Total production (kton)		
	Total	Maize	Grass	Total	Maize	Grass	Total	Maize	Grass
Groningen	70	9	61	11	41	7	786	388	398
Friesland	187	16	171	10	43	7	1,839	712	1,127
Drenthe	86	22	64	15	39	6	1,258	851	407
Overijssel	174	41	133	15	44	6	2,657	1,810	846
Flevoland	13	3	10	16	46	6	216	150	66
Gelderland	193	45	148	15	43	6	2,879	1,941	938
Utrecht	57	6	51	10	39	6	557	241	316
Noord-Holland	66	4	62	9	41	7	591	179	412
Zuid-Holland	70	4	66	8	41	6	562	174	388
Zeeland	20	6	14	16	41	5	330	257	73
Noord-Brabant	151	64	87	22	44	6	3,353	2,796	557
Limburg	51	22	28	20	38	6	1,012	840	172
Netherlands	1,139	245	895	14	42	6	16,039	10,340	5,699

3.3 Wood production

Forests and other wooded areas provide timber that can be used for economic activities. The ecosystem service 'wood production' is defined as all timber extracted to be used as input for economic activities, i.e. both as building material or for the use of energetic purposes.

For the ecosystem service wood production we used data collected in 2012 and 2013 for the sixth Dutch Forest Monitor (Zesde Nederlandse Bosinventarisatie, NBI6) (Schelhaas et al., 2014; Probos, 2017). In this inventory, data were collected at 3190 sample points, of which 1235 were also sampled in the 2001-2005 Forest Monitor (Meetnet Functievervulling, MFV). For each sample point, the characteristics of the forest were determined. Observations on dominant tree species, age of important tree species ("kiemjaar"), cover of tree layer and shrub layer and tree diameter at breast height were collected. Sample points had a variable radius. A sample point reflected the density of trees per hectare of the forest and included at least 20 trees in a circle with a maximum radius of 20 meter. The total area of forest in the Netherlands according to the Ecosystem Type map (2013) is 325,579 ha (categories 'deciduous forest', 'coniferous forest', 'mixed forest' and 'dunes with permanent vegetation'). The 3190 samples in the inventory represent a random subset of forests in the Netherlands, which Schelhaas et al. (2014) assume to be representative for the Dutch forest. Hence, on average one sample point represents 325,579/3190 = 102.06 ha forest. The mean harvest per hectare was estimated at 3.3 m^3/ha/yr. The total harvest in the Netherlands in 325,579 ha forest was 1.1 million m^3 timber per year (table 3.3.2). Most timber was harvested in Gelderland, followed by Noord-Brabant and Drenthe. The estimated total harvest is highest for coniferous forests. On average, the timber stock increased with 7.3 m^3/ha/yr and 3.3 m^3/ha/yr of the timber is harvested (table 3.3.1). Comparison in mean harvest per province shows that the mean harvest per hectare is significantly higher in Flevoland ($p < 0.001$) and the northern provinces (Groningen, Friesland and Drenthe) ($p < 0.001$) (figure 3.3.1b and Appendix A2.3). Forests in Flevoland are relatively young and grow fast related in part to soil conditions, which has a positive effect on the harvest.

Table 3.3.1 Mean harvestable stock, calculated per province, disaggregated by coniferous and deciduous forests. The mean values for the Netherlands are weighted for the number of sample points per province. Estimated total harvest per province (NBI6 data, including felling 'kapvlaktes')

	Total area (1000ha)	Mean harvest (m^3/ha/yr)			Harvest ($1000m^3$/yr)
		Mean	Coniferous	Deciduous	
Groningen	6	2.7	5.9	2.4	16
Friesland	14	3.4	5.9	2.4	47.5
Drenthe	31	4.0	5.9	2.4	122
Overijssel	34	3.1	4.2	2.3	106
Flevoland	14	5.3	6.9	5.1	75
Gelderland	88	3.3	4.2	2.3	293
Utrecht	17	3.2	4.2	2.3	54
Noord-Holland	17	2.7	3.6	2.2	46
Zuid-Holland	8	2.4	3.6	2.2	18
Zeeland	4	2.4	3.6	2.2	9
Noord-Brabant	65	3.2	3.8	2.5	209
Limburg	29	3.0	3.8	2.5	88
Netherlands	326	3.3	4.7	2.4	1,085

Table 3.3.2 Estimated total harvest per forest type (NBI6 data, excluding felling "kapvlaktes")

	Total area (1000ha)	Harvest (1000m3/yr)
Coniferous forest	82	348
Deciduous forest	109	289
Mixed forest	119	398
Dunes with permanent vegetation	16	50
Netherlands	326	1,085

Mean values for coniferous forest, deciduous forest and mixed forest are calculated for five clusters of provinces; the northern provinces (Groningen, Friesland and Drenthe), the western provinces (Noord-Holland, Zuid-Holland, Zeeland), the southern provinces (Noord-Brabant and Limburg), the provinces in the center of the Netherlands (Utrecht, Gelderland and Overijssel) and Flevoland was taken separately. The division in three forest types for each cluster of provinces improved the estimation of harvest as compared to one mean value for the Netherlands. However, as the mean values are calculated per cluster of provinces, and variation is high between individual forests (figure 3.3.1), it is less suitable to predict the actual harvest at the local scale. Dominant tree type is the best predictor for timber harvest. Interestingly, age did not have a significant effect on harvest (Appendix A2.3). A possible explanation could be that the relationship with age is non-linear. Dominant tree type is only available for the sample points of NBI6. Mapping dominant tree types for forests in the Netherlands could strongly improve predictions at the local scale. The dependence of harvest on dominant tree species can be explained by the fact that harvest is estimated based on tree species and size in the NBI6.

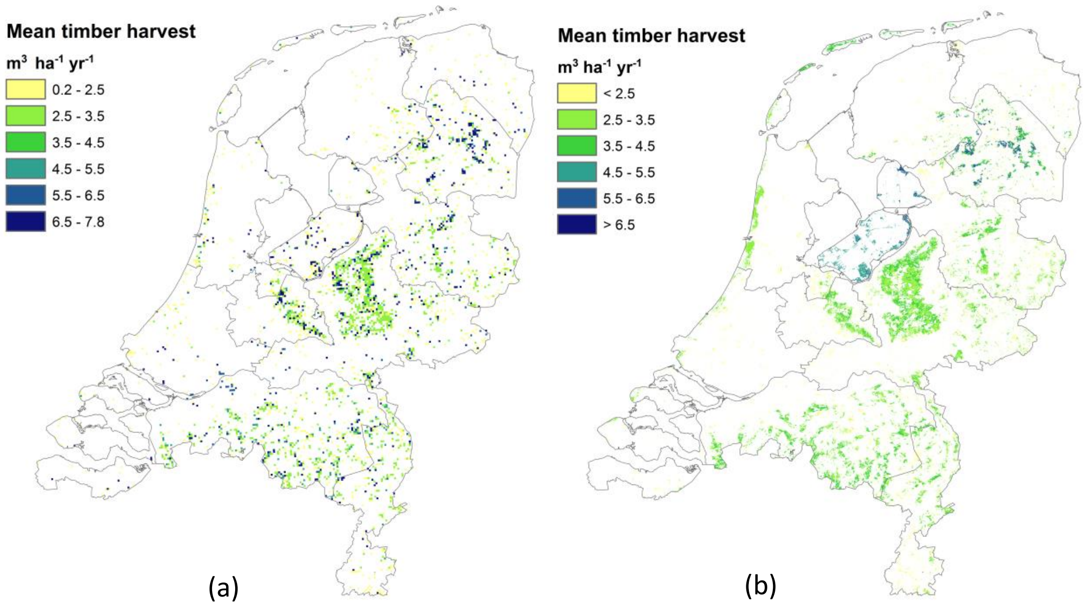

Figure 3.3.1 a) Timber harvest depicted for the sample points of the sixth Dutch Forest Monitor (NBI6). **b)** Mean timber harvest depicted for deciduous, coniferous and mixed forests in the Netherlands based on data of the sixth Dutch Forest Monitor (NBI6) and the Ecosystem Type map.

3.4 Biomass production from non-agricultural and non-forest sources

Biomass from vegetation can be used for multiple purposes, such as food production or wood production, but also for energetic purposes or as an input for a biobased economy. Here we focus on biomass production from non-agricultural and non-forest areas that can be used for the production of biobased products or energy production.

In the applied methodology the focus is primarily on biomass production from grassland, shrubs and tree litter. Agricultural areas and forestland are excluded from the analysis, as biomass produced in those ecosystems is used for other purposes (food and timber), and are modelled as separate ecosystem services. For the biomass production model the ecosystem types '(semi) natural grassland' and 'other unpaved terrain' (e.g. roadsides and dry ditches) from the Ecosystem Type map are used. Biomass may be produced in other ecosystem types as well (e.g. 'hedgerows' and 'public green space'), however many of these areas also constitute artificial surfaces, and biomass in many of these areas is not harvested. Using the remote sensing based net primary productivity (NPP) map developed by RIVM for the Atlas of Natural Capital (Lorenzo Cruz, 2017), the annual carbon uptake in these ecosystem types was determined. As a large part of the NPP occurs below ground in grasslands and shrubs, a root-to-shoot ratio of 2:1 was applied in accordance with the LULUCF Good Practice Guidance (IPCC, 2003). Hence, 33% of NPP was assumed to be applicable as biomass for further economic use. To revert the carbon content of biomass (NPP) to weight of the vegetation an average conversion rate of 20% carbon content was applied, based on the Phyllis2 database (ECN, 2012).

As biomass production is linked to only two ecosystem types, the ecosystem service covers only a small extent of the Netherlands (figure 3.4.1). In total approximately 79 thousand hectares was available for biomass production in 2013. In '(semi) natural grassland' the average biomass production was 7.7 tons/ha/yr, while in 'other unpaved terrain' the average production was 4.5 tons/ha/yr. The most biomass is produced in the provinces Noord-Holland, Zuid-Holland and Noord-Brabant. This information can be used to plan or increase the use of other biomass in a circular economy.

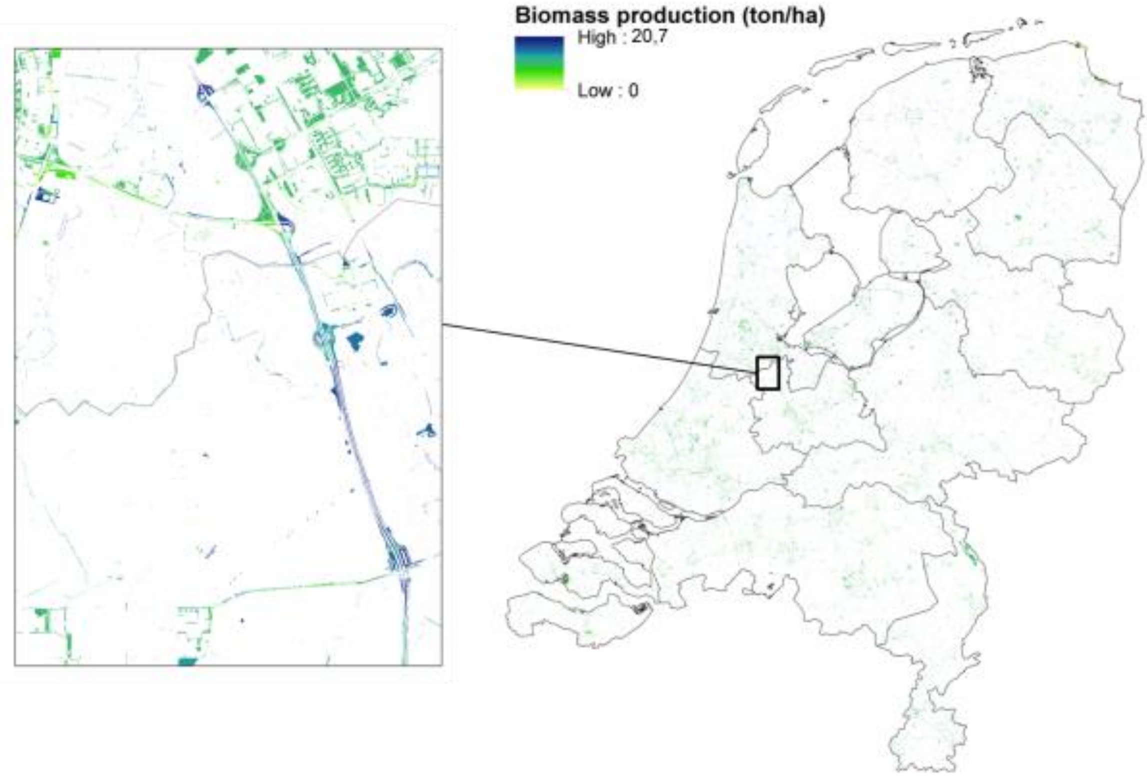

Figure 3.4.1 Biomass production in natural grasslands and other unpaved terrain (tons/ha).

3.5 Drinking water production

Ecosystems contribute to the supply of drinking water in the form of natural filtration of (ground)water. There are different types of drinking water extraction in the Netherlands. Here three types were taken into account, which together represent 30% of the total water extraction in the Netherlands. First, surface water that was transported from elsewhere is pumped into filtration basins in the dunes. The dunes thus deliver the service of water filtration. Second, 'river bank filtration water' has its origin in surface water from lakes, rivers and other water bodies. This water is allowed to infiltrate in the ground (riverbanks or other easily permeable layers) before it is pumped up again. Third, groundwater is extracted from the sub-soil. Considering the latter source of drinking water, only phreatic aquifers are taken into account. This means that there is no impermeable layer (seal) on top of the tapped groundwater aquifer. This implies there is a clear connection between the (ecosystem) service being delivered and the ecosystem on top of it.

The analysis was performed by combining geographical data on areas of water extraction and water protection (Interprovinciaal Overleg, 2013) and data on the amount of water extracted per well (LGR, 2016). Extraction of water was evenly distributed over the total areas of extraction (*waterwingebied*) and water protection (grond*waterbeschermingsgebied*).

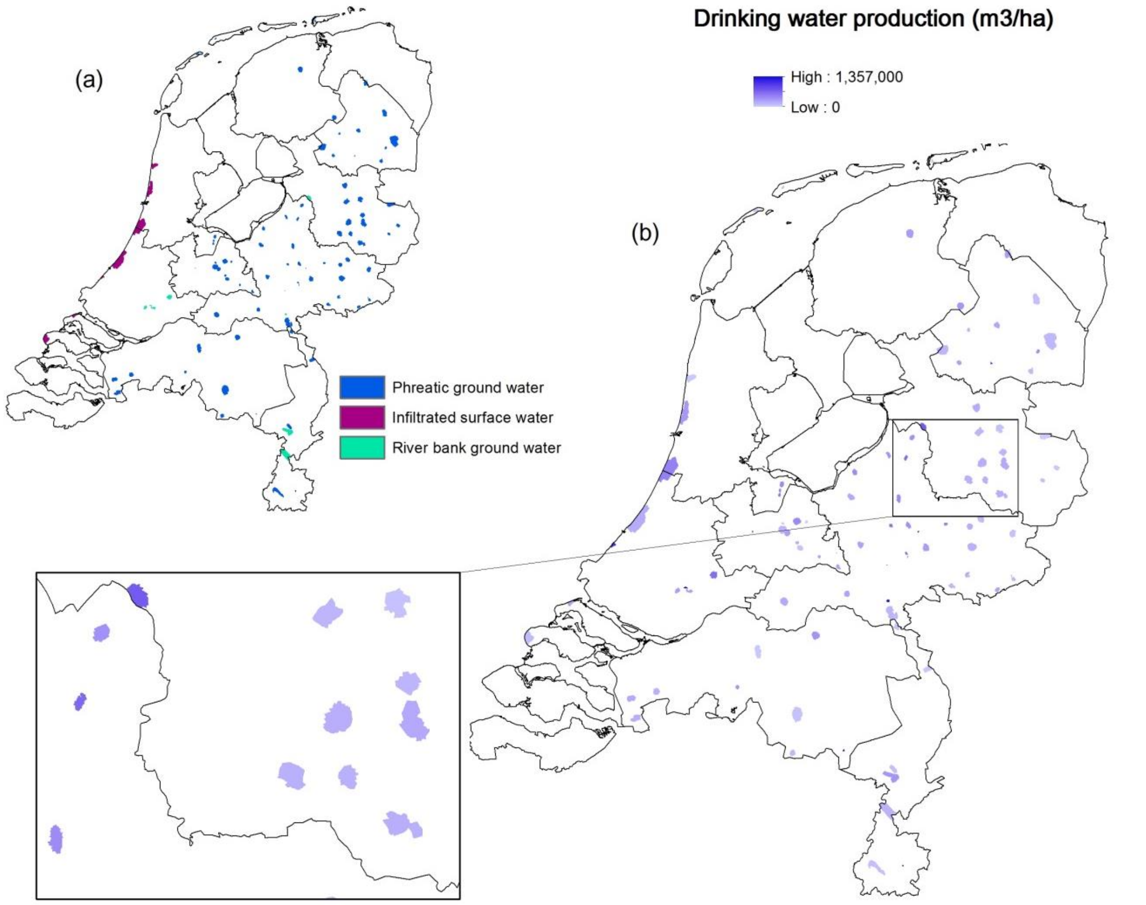

Figure 3.5.1 (a) Drinking water production from different types of water extraction and **(b)** the amount of extraction (m3/ha).

Figure 3.5.1 shows the results both by relative production of drinking water (m3/ha) and by the type of water extraction. Phreatic groundwater is extracted in the inland provinces and is the most common type of extraction. Surface water filtration by definition takes place in dunes, whereas water filtration along river banks takes place alongside rivers.

Drinking water production is mainly produced from phreatic wells (table 3.5.1). However, in terms of effectiveness in supplying services, wells from the other two types of extraction produce relatively higher amounts of drinking water per ha. Most of the production takes place in the provinces Noord-Holland, Zuid-Holland and Gelderland. Table 3.5.2 shows that dunes deliver the largest service, but also agriculture and forest areas contribute substantially to the phreatic extraction.

Table 3.5.1 Drinking water production from different types of extraction per province

	Total area (1000ha)				Mean production (1000 m³/ha)				Total production (million m³)			
	Total	Phreatic ground-water	River bank filtration water	Infiltrated surface water	Total	Phreatic ground-water	River bank filtration water	Infiltrated surface water	Total	Phreatic ground-water	River bank filtration water	Infiltrated surface water
Groningen	0	0	0	0	10	10	0	0	1	1	0	0
Friesland	2	2	0	0	8	8	0	0	14	14	0	0
Drenthe	6	6	0	0	5	5	0	0	32	32	0	0
Overijssel	9	8	0	0	5	4	24	0	49	38	11	0
Flevoland	0	0	0	0	0	0	0	0	0	0	0	0
Gelderland	10	9	0	0	8	8	42	0	77	74	3	0
Utrecht	3	3	0	0	11	11	0	0	31	31	0	0
Noord-Holland	6	0	0	5	12	15	0	11	67	7	0	60
Zuid-Holland	7	0	1	6	11	0	16	10	75	0	17	57
Zeeland	1	0	0	1	3	0	0	3	3	0	0	3
Noord-Brabant	6	6	0	0	5	5	0	0	32	32	0	0
Limburg	6	3	4	0	5	2	7	0	31	6	25	0
Netherlands	56	38	5	12	7	6	11	10	413	235	57	121

Table 3.5.2 Drinking water production from different types of extraction per ecosystem type

	Total area (1000ha)				Mean production (1000 m³/ha)				Total production (million m³)			
	Total	Phreatic ground-water	River bank filtration water	Infiltrated surface water	Total	Phreatic ground-water	River bank filtration water	Infiltrated surface water	Total	Phreatic ground-water	River bank filtration water	Infiltrated surface water
Agriculture	16	14	2	0	5	5	11	10	86	65	19	1
Dunes and beaches	11	0	0	11	10	2	0	10	109	1	0	108
Forests	12	11	0	0	7	7	8	7	81	77	3	1
Other (semi) natural environments	8	7	1	1	8	7	12	8	65	50	10	5
Temporarily inundated lands	1	0	1	0	19	95	11	0	12	6	6	0
Build-up and paved areas	7	5	1	1	8	7	12	7	52	35	12	6
Water	1	0	0	0	11	9	12	7	9	3	6	0

3.6 Carbon sequestration in biomass and soil

Terrestrial carbon sequestration is the storage of carbon in biomass and in soils. Carbon sequestration can be related to net ecosystem productivity (NEP), i.e. the difference between net primary productivity (NPP) and soil respiration. The biocarbon cycle is known as a short carbon cycle because storage of the carbon is, in principle, relatively short lived; if trees or wood are burned, carbon is released again into the atmosphere. Similarly, the release of soil carbon can be triggered by e.g. ploughing or erosion, and carbon stored in peatlands may be released when water levels change, be it by natural or man-made causes. Therefore, the duration of carbon storage in the form of biocarbon is relatively instable in the long geological perspective. Nevertheless, biocarbon stocks can be substantial and are highly relevant because of their sensitivity to land use and hence to policy measures.

The results presented here have also been used to develop the Carbon Account (Lof et al., 2017). In general, the methodology was based upon a qualitative look-up table (LUT) approach; each spatial unit (i.e. ecosystem type) in the Ecosystem Type map was attributed a specific value for carbon sequestration. These values were based on values used for greenhouse gas reporting of the LULUCF sector in the Netherlands (Arets et al, 2015) and scientific literature. The look-up table for carbon stock in above ground biomass is provided in Appendix 2, table A2.6.1.

Figure 3.6.1 represents the modelled C sequestration in biomass. Table 3.6.1 summarizes the total C sequestration rates in biomass for the Netherlands in 2013, calculated per province. Carbon sequestration was mostly concentrated in the forest areas in the Netherlands; Gelderland, Utrecht, Limburg, Noord-Brabant, Drenthe and Overijssel have the highest mean carbon sequestration rates in the biomass, closely followed by Friesland and Flevoland. In total 975 kton C per year was sequestered in vegetation, mostly in forests and meadows. Even though the total area is small, tidal salt marshes have a very high sequestration rate (table A2.6.1 and figure 3.6.1); almost half of the total amount of carbon fixed in Zeeland is captured by salt marshes. All forest types and meadows have the highest contribution to the total sequestration rate (table 3.6.2).

To attune our study with relevant reporting on carbon, the carbon sequestration rate for forests used in the look-up table approach in this study were equal to values used in greenhouse reporting by the LULUCF sector. At present, there is a difference between the total area of forest in the Ecosystem Type map for the Netherlands and the total area of forest that is reported for the LULUCF sector. As a result, the total area of forest in the Ecosystem Type map is lower than in the LULUCF-GHG inventory. Further harmonisation of classification of forest at the development phase of the Ecosystem Type map for the Netherlands could reduce the difference between the results from the current study with the CO_2 reporting of the LULUCF sector. The Carbon Account presents further details on the applicability of this information for policy making (Lof et al., 2017).

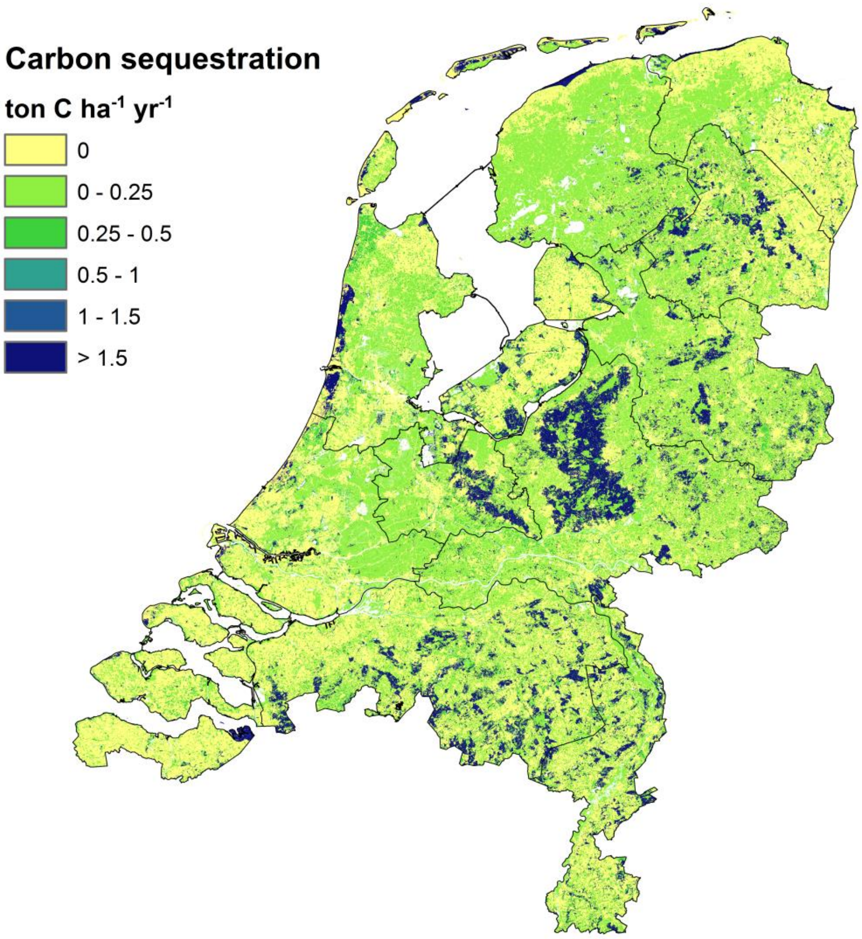

Figure 3.6.1 Carbon sequestration in above and below ground biomass. Based on Ecosystem Type map and Appendix 2, table A2.6.1.

Table 3.6.1 Carbon sequestration and carbon stock in biomass in the Netherlands; totals per Province. Data based on previous figures.

Province	Total carbon sequestration (kton C/yr)	Mean carbon sequestration (ton C/ha/yr)
Groningen	38	0.16
Friesland	90	0.26
Drenthe	81	0.30
Overijssel	100	0.29
Flevoland	36	0.25
Gelderland	216	0.42
Utrecht	47	0.33
Noord-Holland	60	0.21
Zuid-Holland	41	0.13
Zeeland	30	0.16
Noord-Brabant	163	0.33
Limburg	73	0.33
Netherlands	975	0.28

Table 3.6.2 Carbon sequestration in the Netherlands; totals per ecosystem type.

Ecosystem type	Extent (1000ha)	Total carbon sequestration (10^3 ton C/yr)
Non-perennial plants	781	0
Perennial plants	79	30
Greenhouses	12	0
Meadow	927	167
Bushes and hedges bordering	36	6
Farmyards and barns	35	0
Dunes with permanent vegetation	16	30
Active coastal dunes	34	0
Deciduous forest	109	206
Coniferous forest	82	155
Mixed forest	119	224
Heath land	41	8
Inland dunes	2	0
Fresh water wetlands	34	8
(semi) Natural grassland	54	10
Public green space	68	18
Other unpaved terrain	295	53
River flood basin	73	15
Salt marshes	11	45
Build-up and paved areas	540	0

3.7 Pollination

Plants can be self-pollinating, i.e. the plant can fertilize itself, or can be cross-pollinating, i.e. the plant needs a vector to get pollen from another flower of the same species. Vectors include wind, water, or pollinators, i.e. animals that transfer pollen from plant to plant. Crop pollinators include a range of insects (e.g. beetles, flies and butterflies), as well as birds and bats. However, the majority of crops are most effectively pollinated by bees (Klein et al., 2007; Ricketts et al., 2006). Pollinator visits not only move outcross pollen among individuals but also increase the total amount of pollen deposited on flower stigmas, both of which are known to increase quantity and quality of crops. About 75% of the leading global food crops species depend on animal pollination (Klein et al., 2007), together these crop species produce 35% of the global production volume. Without animal pollination the production of these crops will be up to 90% lower. Animal pollination reduces the production loss, i.e. it increases the production. We define the pollination service as the contribution of ecosystems to the avoided reduction in production loss (i.e. increase in production in presence of pollinators).

The vulnerability of a cross-pollinating crop depends on its dependency on pollinators. Crops differ in pollination requirements. Klein et al. (2007) divided crops, depending on degree of production dependence, in five classes (Appendix 2, table A2.7.1). These are used to assign pollination demand to crops in the Netherlands based on the spatial location of crops in 2013 ("Basisregistratie Gewaspercelen 2013", RVO.nl, 2017) (Appendix 2, table A2.7.2).

Most studies on natural pollination have focussed on wild bees and bumble bees. Historically, pollination demand was fulfilled by wild pollinators that live in the agricultural landscape. Nowadays, beekeepers often place hives with cultivated honey bees, *Apis mellifera*, close to pollination demanding crops. Many crops, however, are also effectively pollinated by wild bees. A field study carried out by Alterra (de Groot et al., 2015) showed that for Elstar, a common apple species in the Netherlands, up to 60% of the flowers were pollinated by wild bees despite a lower occurrence of wild bees in comparison to honey bees. Based on their study, de Groot et al. (2015) estimated that 23-24% of the total Elstar apple yield (in kg per hectare) depends on wild bees and bumble bees. For blueberries this contribution amounts to 12%. In the pollination service provided by ecosystems in our model, pollination by wild organisms such as wild bees, bumble bees, butterflies and hoverflies was considered. Managed honey bees were excluded. Wild pollinators require sufficient resources in the agricultural landscape. These resources include suitable nesting habitats (e.g. tree cavities, or suitable soil substrate) as well as sufficient floral resources (i.e. pollen and nectar). Bees are central place-foragers, meaning that they return to their nest site after foraging. The availability of nesting habitats close to agricultural fields is critical for bee-pollinated crops (Ricketts et al., 2006). Ecosystems differ in their suitability for pollinators, because there are differences in the presence of tree cavities or suitable substrates for nesting, and differences in the availability and suitability of floral resources (Kennedy et al., 2013). We used indicators for total nesting and floral resource availability for the suitability of the ecosystem types (Appendix 2, table A2.7.3). These indicators were based on a meta-analysis of 39 studies that was conducted by Kennedy et al. (2013). Note that for private gardens (residential areas) as well as farmyards and barns, this value was set to zero in absence of suitable data on potential nesting sites (Appendix A2.7). Clearly, this leads to an underestimation of suitable nesting locations. As a consequence both these ecosystem types deliver zero pollination service.

The maps for the pollination account were generated based on the spatial location of crops that require pollination (Basisregistratie Gewaspercelen 2013; RVO.nl, 2017) and the spatial location of ecosystems that are suitable for pollinators on the Ecosystem Type map 2013. We generate three maps; 1) a map that plots the potential pollination service of the ecosystems, based on the *demand of the crop* and the distance between the demanding crop to the pollination providing ecosystem (i.e. the use of the pollination service, in percentage avoided production loss); 2) a map that plots the potential pollination service of the ecosystems, based on the *suitability of the ecosystems for pollination* and the distance between the suitable ecosystem and the crop (i.e. the supply of the pollination service) (figure 3.7.1). We combine the first map, with the use of the pollination service in percentage avoided production loss, with the crop production map to generate a third map that shows the avoided production loss in ton crop per hectare (figure 3.7.2). Different species of pollinators move at different length scales. Large pollinators like bumble bees forage over long distance (up to 1750 meter) (Walther-Hellwig and Frankl, 2000), while small pollinators, like solitary bees, forage over shorter distances (up to several hundred meter). We generate the suitability and demand maps for all natural pollinators. Ricketts et al. (2006) found in their meta-analysis on 13 studies in temperate biomes that visitation rates of pollinators declined to half its maximum at 1308 meter distance between the nesting sites and the crop. Pollinators leave their nesting sites to forage in the surrounding landscape. We assume that pollinators from all suitable habitats in the local landscape contribute to pollination.

Table 3.7.1 Pollination service by wild pollinators (thus excluding managed honey bees) (percentage avoided production loss per ha) by all pollinators. Mean potential loss (i.e. mean loss when there would be no pollination) and mean avoided loss (i.e. mean loss that is avoided due to pollination by wild pollinators) are calculated based on the area of crops that require pollination (left columns) and are calculated for the total area of the province (middle columns). For the total area of the province also the mean contribution of the ecosystems to the avoided production loss is calculated (supply, figure 3.7.1).

	Area crops	Mean potential loss *demand crop*	Mean avoided loss *use crop*	Total area	Mean potential loss *demand crop*	Mean avoided loss *use crop*	Mean avoided loss *supply ecosystems*	Percentage of potential loss prevented
Province	**1000 ha**	**% avoided production loss per hectare crop**		**1000 ha**	**% avoided production loss per total area**			**Use crop/ demand crop**
Groningen	3.8	20.7	12.8	239	0.33	0.21	0.21	61.9
Friesland	1.7	18.8	14.8	353	0.09	0.07	0.08	78.9
Drenthe	2.3	14.2	12.8	268	0.12	0.11	0.11	90.1
Overijssel	1.4	13.7	13.5	341	0.06	0.05	0.10	98.1
Flevoland	14.9	21.3	12.1	147	2.16	1.23	1.09	57.0
Gelderland	7.0	52.2	51.5	512	0.71	0.70	0.67	98.8
Utrecht	1.7	62.0	61.9	144	0.74	0.74	0.83	99.8
Noord-Holland	20.1	14.1	11.2	286	0.99	0.79	0.79	79.4
Zuid-Holland	7.6	19.7	12.6	306	0.49	0.31	0.30	64.2
Zeeland	11.9	32.7	14.0	183	2.13	0.91	0.91	42.9
Noord-Brabant	15.4	26.0	22.3	505	0.80	0.68	0.71	85.8
Limburg	11.8	30.5	28.8	221	1.63	1.53	1.49	94.3

Table 3.7.2 Pollination service by wild pollinators; mean avoided production loss in ton crop per ha due to pollination.

	Area crops* (ha)	Mean avoided loss *use crop* (ton/ha)
Groningen	2,642	2.1
Friesland	915	4.4
Drenthe	673	7.6
Overijssel	332	7.5
Flevoland	8,784	5.3
Gelderland	5,234	22
Utrecht	1,477	25.6
Noord-Holland	6,693	7.1
Zuid-Holland	3,597	6.6
Zeeland	8,083	5.8
Noord-Brabant	12,129	7.6
Limburg	8,226	10.4

* We combined the crop production map with the percentage avoided production loss. However a few crops, especially flowers, were not included in the crop production map (i.e. flower nursery plants, flower bulbs, sunflower), therefore, the area for this calculation is lower than in table 3.7.1.

There are large differences between provinces in the pollination service by surrounding ecosystems (table 3.7.1). In Utrecht the demand for pollination is high, with on average a potential production loss per hectare (with pollination dependent crops) of 62.0%. At the same time, the pollination service by the landscape is also very high. As a result 99.8% of the potential production loss is avoided by natural pollination, equal to on average 25.6 ton crop per hectare (table 3.7.2). In Flevoland the demand for pollination is much lower, with on average 21.3% potential production loss per hectare. However, also the service by solitary bees in the landscape is much lower as less suitable ecosystems for pollinators are available close to the demanding crops. As a result solitary bees can only avoid 57.0 % of the potential production loss, equal to on average 5.3 ton crop per hectare (table 3.7.2). Natural pollination service (in percentage of production loss prevented) is very high in Utrecht, Gelderland, Overijssel and Limburg (table 3.7.1). In these provinces, crops that demand pollination and ecosystems that provide pollination are well mixed. Natural pollination is lowest in Zeeland, Flevoland, Groningen and Zuid-Holland. These results show that in some areas in the Netherlands, pollination by honey bees is necessary. The mean avoided loss in ton crop per hectare is highest in Utrecht and Gelderland, where fruit production highly depends on pollination (table 3.7.2).

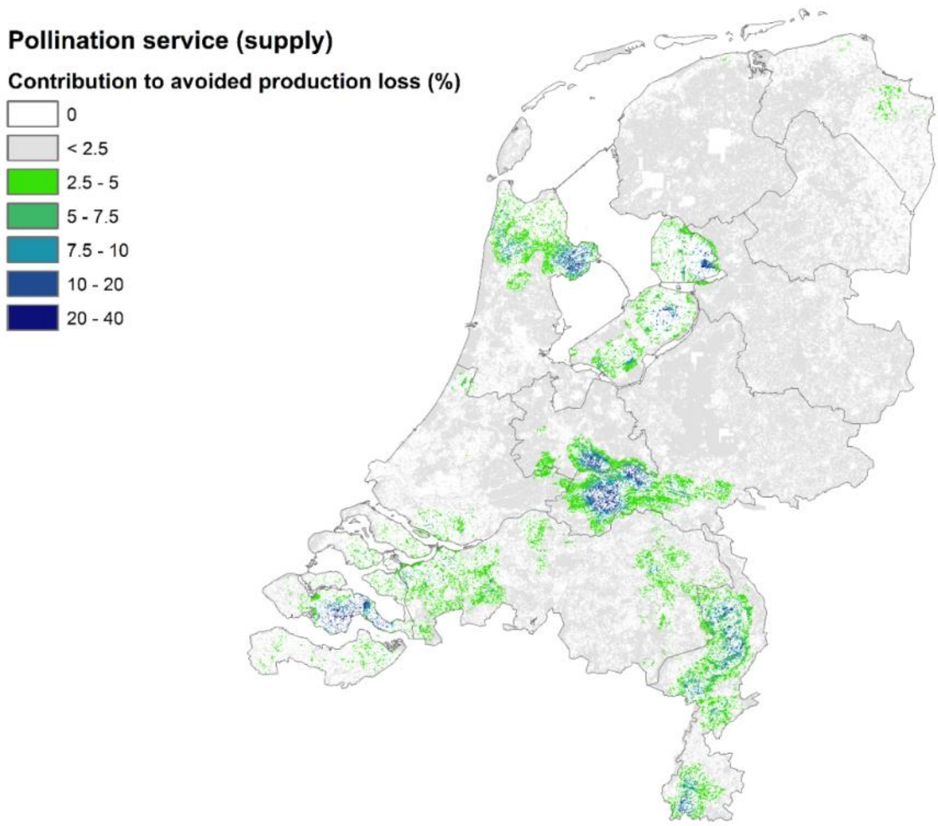

Figure 3.7.1 Ecosystem contribution to avoided production loss (%) due to the presence of pollinators.

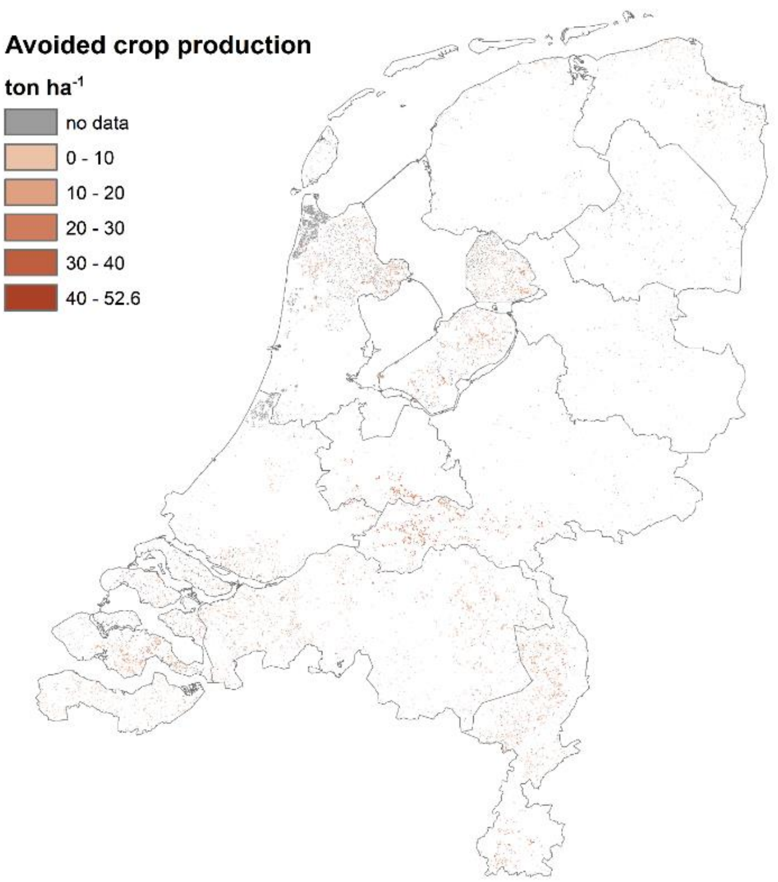

Figure 3.7.2 Avoided production loss in ton per hectare due to the presence of pollinators.

Pollinators in deciduous forests, river flood basins, hedgerows, natural grasslands, and other unpaved surfaces have relatively the largest contribution to avoided production loss (table 3.7.3, figure 3.7.1). Differences in contribution of ecosystems to pollination can partly be explained by habitat suitability; deciduous forests, hedgerows and natural grasslands are very suitable for pollinators, and partly by distance from agricultural fields that require pollination. Other unpaved surfaces and river flood basins are often close to agricultural fields and orchards. Heath land and dunes with permanent vegetation are very suitable for pollinators, but have a relatively small contribution to avoided production loss, as they are often situated further from agricultural fields.

Pollination is an intermediate service. It contributes to the crop production. In the current account we define the service as the avoided production loss. This is the potential service from the natural and semi-natural ecosystems to crop production. It is not corrected for use of honey bees by the farmers (on the basis of commercial beehives being brought to farms). This use will be different for different crops. For the valuation of the pollination service we will consider the contribution of honey bees and natural pollinators. Furthermore, we made a first step in combining the calculated percentage avoided production loss with the crop production map. However, not all crops that need pollination are included in the crop production map. For instance, flower nurseries are not a crop that is used for consumption, but do depend on pollination. For the valuation of the pollination service the missing crops will be included.

The account provides important new information on pollination. Pollination is a typical example of an ecosystem service that is provided for free by ecosystems, and where society generally assumes that it is not in short supply, and which therefore is not generally considered in decision making (e.g. in land use planning in rural areas (‘ruilverkaveling’)). However the account shows that several parts of the country have a shortage of (wild) pollinators compared to the pollination that crops require (e.g. parts of Zeeland and Groningen). The pollination service depends upon small landscape elements such as hedgerows or forest patches. If these are further converted to intensive croplands in these areas there is a risk that crop production would decline (or farmers would have to bring in additional beehives). In this context it is relevant to note that honeybees require a certain temperature to fly, in colder times of the year only bumble bees pollinate crops. Hence it is not a given that if pollination due to natural pollinators is lost that this can be fully compensated by commercial pollinators. The results from this account may have important ramifications for landscape management in areas in the Netherlands where there is a shortage of pollination services: in these areas more care needs to be taken that small landscape elements are preserved.

Table 3.7.3 Pollination service (contribution to % avoided production loss per ha) by all pollinators per ecosystem type.

Ecosystem type	Mean contribution to avoided production loss (%)
Non-perennial plants	0
Perennial plants	0
Greenhouses	0
Meadows (grazing)	0.92
Bushes and hedges bordering	1.6
Farmyards and barns	0
Dunes with permanent vegetation	0.47
Active coastal dunes	0.15
Deciduous forest	2.01
Coniferous forest	0.57
Mixed forest	0.76
Heath land	0.55
Inland dunes	0.13
Fresh water wetlands	0.63
(semi) Natural grassland	1.45
Public green space	0.82
Other unpaved terrain	1.24
River flood basin	1.81
Salt marsh	0.63
Build-up and paved areas	0
Water	0

3.8 Natural pest control

Natural pest control is a complex ecosystem service. Natural pest control is only needed when a pest is present. Furthermore, there are many pests of agricultural crops, and many natural enemies (among others, birds, rodents, insect predators that eat their host, or parasitoids that lay their egg in or on their host). To our knowledge there is not one model available at the moment that can combine all these aspects. Therefore, we decided to model one example as an indicator for pest control, an abundant natural enemy that eats a host that is present on a wide variety of crops: the seven-spot ladybug (*Coccinella septempunctata*) that eats several aphid species that are pests on many crops. *C. septempunctata* is very common in the Netherlands and is found in all provinces and on the Wadden Islands (Cuppen et al., 2017). *C. septempunctata* hibernates in forests in litter, on pine trees or between leaves of broad-leaved trees. In spring adults awake from hibernation and start feeding on aphids. Based on scientific literature, we assume that ladybirds only hibernate in forests and start dispersing to the surroundings of these forests in spring.

Ladybugs that start searching for food after hibernating in forests in the Netherlands can reach almost every agricultural field and orchard in the Netherlands (figure 3.8.1a). Only in Groningen and Zeeland a very small fraction less than 0.1% (respectively 475.5 ha and 0.2 ha) is not reached by ladybugs, in all other provinces all agricultural fields can be visited by ladybugs. As both adult ladybugs and their offspring eat aphids, the species is very successful in providing pest control even at low visitation rates of the adults (Woltz et al., 2012). In the current model we do not convert visitation by the natural enemy in the fields to a level of predation of pests in the crop. For the valuation of the service, this will be incorporated.

In our model, all forest types have an equal potential for their suitability of hosting ladybugs during hibernation (this is set at 100 for each forest). When we look at the mean contribution (i.e. the percentage of the potential that contributes to pest control in agricultural fields) per forest area, Zeeland and Groningen have the highest contribution to visitation by natural enemies in agricultural fields. The height of the mean contribution depends on two important things: 1) whether forests are close to agricultural fields (if there is no demand, the supply will also be low), 2) the area of forest close to agricultural fields. If there is a large area of forests close to the agricultural fields, the supply of each hectare forest is relatively low (the demand is divided over a large area), in contrast if there is a small area of forest close to the agricultural fields the supply of each hectare forest is relatively high. The latter is the case for Zeeland and Groningen.

Deciduous forests have the highest contribution to pest control in Zeeland (38.7%), Groningen (30.7%) and Drenthe (25.2%) (table 3.8.1). This indicates that in these provinces forests and agricultural fields or orchards are often situated close to each other. Overall in the Netherlands, deciduous forests have the highest contribution to visitation of crop fields by ladybugs (17.7%), since they are most often situated close to agricultural fields. Dunes with permanent vegetation have the lowest contribution (2.1%) indicating that they are situated further from agricultural fields.

The model for pest control is a first attempt to model the service. It should be viewed as an indicator for the service and not the complete service. The service pest control is inherently complex. The presence of pests in crops is dynamic, they are not always present, and if they are present they do not always cause economic damage. This complicates the estimation of the need for pest control. To our knowledge, there is no model available that can capture the demand for pest control for several crops and model the pest control provided by natural enemies. Also in Belgium, this service is not modelled for the report on ecosystem services in Belgium (de Bruyn, 2014). The Atlas of Natural Capital (ANK) is currently working on a pest control model. Possibly this can be used to update or extend the pest control service when it is finalised.

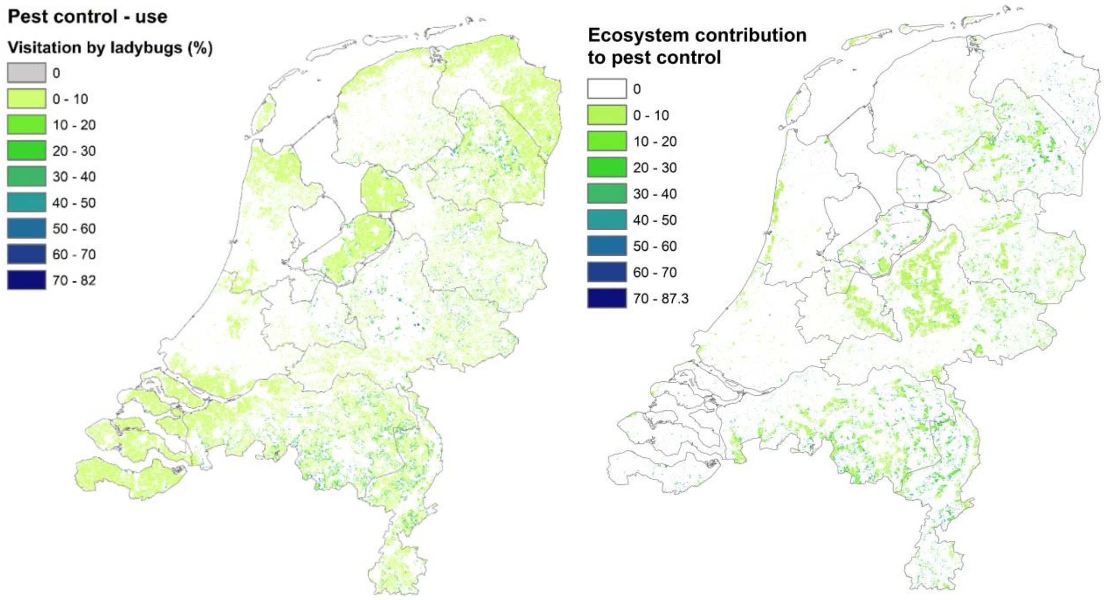

Figure 3.8.1 a) Use of pest control in the fields - visitation of agricultural fields and orchards by ladybugs (%) **b)** Supply of pest control by the ecosystems - contribution of forests to visitation of agricultural fields and orchards by ladybugs (%).

Table 3.8.1 Mean use and supply of pest control service per province. Percentage of potential pest control by deciduous forest, coniferous forest, mixed forest, and dunes with permanent vegetation contributed to visitation of agricultural fields. Mean use is in percentage per hectare crop in the province. Mean supply per forest type is in percentage per their respective areas within the province.

	Mean use	Mean supply				
	Total area	**Total area**	**Deciduous forest**	**Coniferous forest**	**Mixed forest**	**Dunes with permanent vegetation**
Groningen	1.9	0.8	30.7	36.3	31.8	-
Friesland	2.8	0.3	11.5	8.4	9.3	0.1
Drenthe	6.8	2.2	25.2	14	17.8	-
Overijssel	7.2	1.2	14.2	9.4	12.3	-
Flevoland	3.1	1.7	17.6	14.8	15.8	-
Gelderland	7.2	1	12.8	3.3	5.2	-
Utrecht	7.4	0.5	6.4	2.6	3.8	-
Noord-Holland	1	0.3	8.2	2.6	4.4	2.3
Zuid-Holland	1	0.2	9.8	0.8	2.2	2.6
Zeeland	1	0.6	38.7	20.8	26.8	5.5
Noord-Brabant	7.7	2.1	21.2	14.2	16	-
Limburg	9.5	2.7	23.5	17.9	19.5	-

Table 3.8.2 Mean contribution of ecosystem types to visitation of agricultural fields by ladybugs (supply of pest control)

Ecosystem type	Mean contribution to visitation of agricultural fields
Non-perennial plants	0
Perennial plants	0
Greenhouses	0
Meadows (grazing)	0
Hedgerows	0
Farmyards and barns	0
Dunes with permanent vegetation	2.1
Active coastal dunes	0
Deciduous forest	17.7
Coniferous forest	9.6
Mixed forest	11.2
Heath land	0
Inland dunes	0
Fresh water wetlands	0
(semi) Natural grassland	0
Public green space	0
Other unpaved terrain	0
River flood basin	0
Salt marsh	0
Build-up and paved areas	0
Water	0

3.9 Erosion control

Vegetation prevents the loss of soil as a result of surface run-off (water erosion). The ecosystem service erosion control is especially relevant in hilly landscapes. The prevention of soil loss results in more soil and more nutrient availability for local ecosystems. An important note is that due to the flat topography of the Netherlands, this form of erosion control is relevant for only limited number of areas, mainly southern Limburg and some hilly areas in Gelderland and Overijssel. Wind erosion has not been taken into account, as this requires a different modelling approach and different input data.

To model erosion control the methodology developed by RIVM and VITO for the Atlas of Natural Capital was applied (RIVM, 2017b). The model uses the Revised Universal Soil Loss Equation (RUSLE), based on land cover, slope and slope length. Cropland is used as a benchmark for comparison with other land cover types. Land cover types with higher or more permanent vegetation cover (such as grassland or forest) prevents more soil loss than cropland, while bare soil (such as sand areas) prevents less soil loss. As negative values are not possible for the purpose of ecosystem accounting (cf. SNA) the model was adapted for this report. If the model output for a certain location was 0 ton/ha/yr or lower, the ecosystem service erosion control was considered to be unavailable in that location.

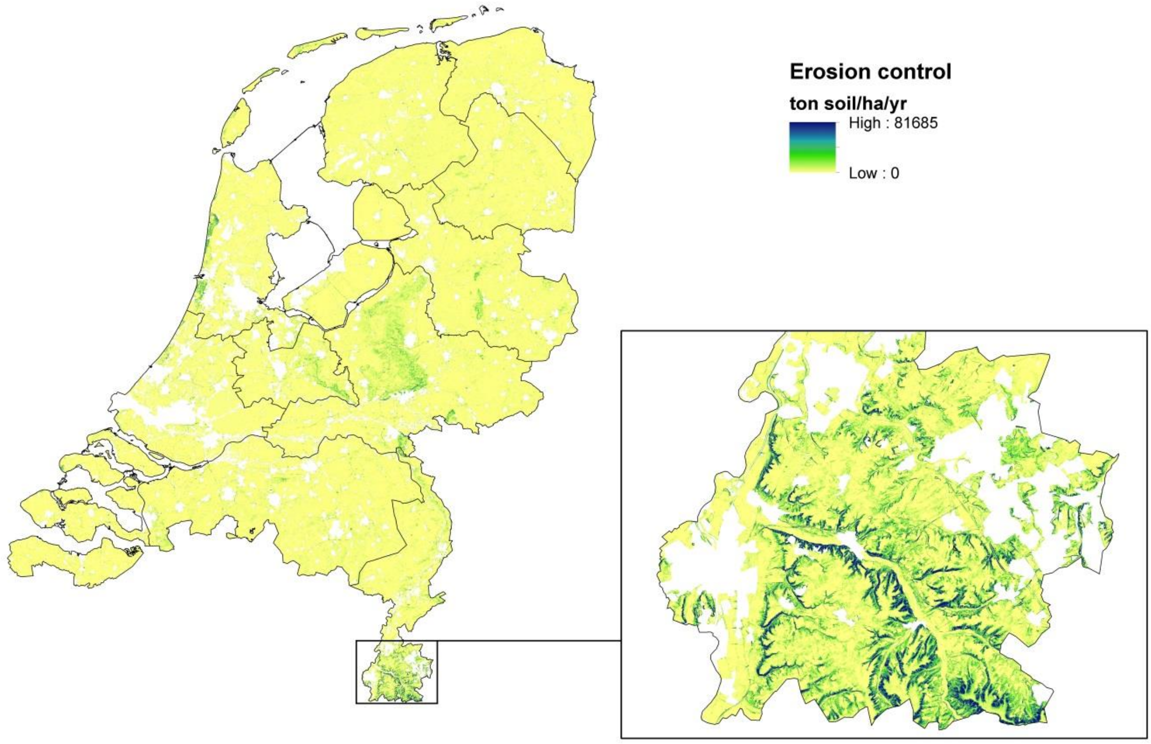

Figure 3.9.1 Erosion control by all ecosystem types (excluding urban areas) (avoided loss of tons topsoil/ha/yr).

The Netherlands is an exceptionally flat country, resulting in relatively little soil erosion by surface run-off. Figure 3.9.1 shows that vegetation in the hilly areas in South Limburg, Gelderland (Veluwe and Nijmegen areas) and parts of Utrecht and Overijssel regulates erosion, while in most of the country values are nearly zero. Areas with natural vegetation such as forests, heath and vegetated dunes also control erosion fairly strongly. The outcome of this model indicates a few areas that contribute to erosion control. The rest of the country is generally flat and has little demand for erosion control.

3.10 Air filtration

Particulate pollution covers a broad spectrum of pollutant types that permeate the atmosphere. Particulate matter is commonly referred to by size groupings: coarse and fine. PM_{10} includes particles up to < 10 µm in aerodynamic diameter, whereas $PM_{2.5}$ only represents the smallest particles (<2.5 µm). The health effects of $PM_{2.5}$ particles are larger compared to the fraction between 2.5 and 10 µm because these smaller particles penetrate deeper into the lungs. Both PM_{10} and $PM_{2.5}$ are included in the Dutch PM_{10} data. Trees and other vegetation play an important role in the reduction of air pollution (Jeanjean et al., 2016; Powe and Willis, 2004). Particulate matter is captured through deposition on leaf and bark surfaces. The process of deposition depends on tree type and meteorological conditions (Powe and Willis, 2004). Deposition varies depending on density of the foliage and leaf form (which, in part, is expressed through the so-called leaf area index, LAI, that expresses the surface area of all leaves per ha).

For the calculation of PM_{10} capture by vegetated ecosystems (e.g. forests, natural grasslands, cropland, heath land) we combined the Ecosystem Types map with a 10 meter spatial resolution with a map of yearly average PM_{10} concentration in µg m^3 (based on 24 hour daily averages) for 2013 on a 1000 meter spatial grid (RIVM, 2013). This PM_{10} map (RIVM) represents the yearly average of daily average PM_{10} concentrations. In this account, PM_{10} capture was estimated using the equation for PM_{10} capture in Powe and Willis (2004) (see Appendix 2, table A2.10). In this model PM_{10} capture is calculated based on the capture rates of different types of vegetation combined with the actual PM_{10} concentration. This results in relatively low service in areas with low ambient PM_{10} concentration and high service in areas with high ambient PM_{10} concentration.

Table 3.10.1 Total PM_{10} capture, in ton PM_{10}, and mean PM_{10} capture, in kg PM_{10} per ha per province.

Province	Total capture (ton PM_{10})	Capture density (kg PM_{10}/ha)
Groningen	777	3.9
Friesland	1,258	4.5
Drenthe	1,861	8.1
Overijssel	2,417	8.6
Flevoland	877	6.9
Gelderland	5,650	13.9
Utrecht	1,209	11.5
Noord Holland	1,165	6.1
Zuid Holland	982	5.2
Zeeland	629	4.2
Noord Brabant	4,902	12.6
Limburg	2,107	12.5
Netherlands	23,832	8.8

The total annual reduction in air pollution by PM_{10} through deposition on vegetation in the Netherlands is 23,800 tonne PM_{10}. Gelderland and Noord-Brabant have the largest total reduction in PM_{10} (table 3.10.1). Gelderland, Noord-Brabant, Limburg and Utrecht have on average large total capture per vegetated hectare, while Groningen, Zeeland and Friesland have a low mean PM_{10} capture per hectare vegetated habitat. This difference can mainly be attributed to differences in the total area of forest and differences in ambient PM_{10} concentration. Ambient PM_{10} concentration is lower in the northern provinces. Coniferous forests, mixed forests and deciduous forests account for the largest capture of PM_{10} in the Netherlands (table 3.10.2). These ecosystems provide a strong contribution to the reduction of air pollution in the Netherlands. Figure 3.10.1 shows that all forest types and vegetated dunes have a large per hectare contribution to capture of PM_{10}. Due to higher ambient PM_{10} concentrations in the south-east of Noord-Brabant the PM_{10} capture in forests in Noord-Brabant per hectare is larger than in Utrecht and Gelderland.

Table 3.10.2 Total PM_{10} capture, in tonne PM_{10}, and mean PM_{10} capture, in kg PM_{10} per ha per ecosystem type.

Ecosystem type	Total capture (tonne PM_{10})	Mean capture (kg PM_{10}/ha)
Annual crops	2,725	3.5
Perennial crops	287	3.6
Meadow	3,266	3.5
Hedgerows	127	3.5
Dunes with permanent vegetation	463	29.1
Deciduous forest	4,063	37.2
Coniferous forest	5,014	61.2
Mixed forest	5,835	49.2
Heath land	145	3.6
Fresh water wetlands	114	3.3
(semi) Natural grassland	192	3.5
Public green space	252	3.7
Other unpaved terrain	1,071	3.6
River flood basin	290	3.8

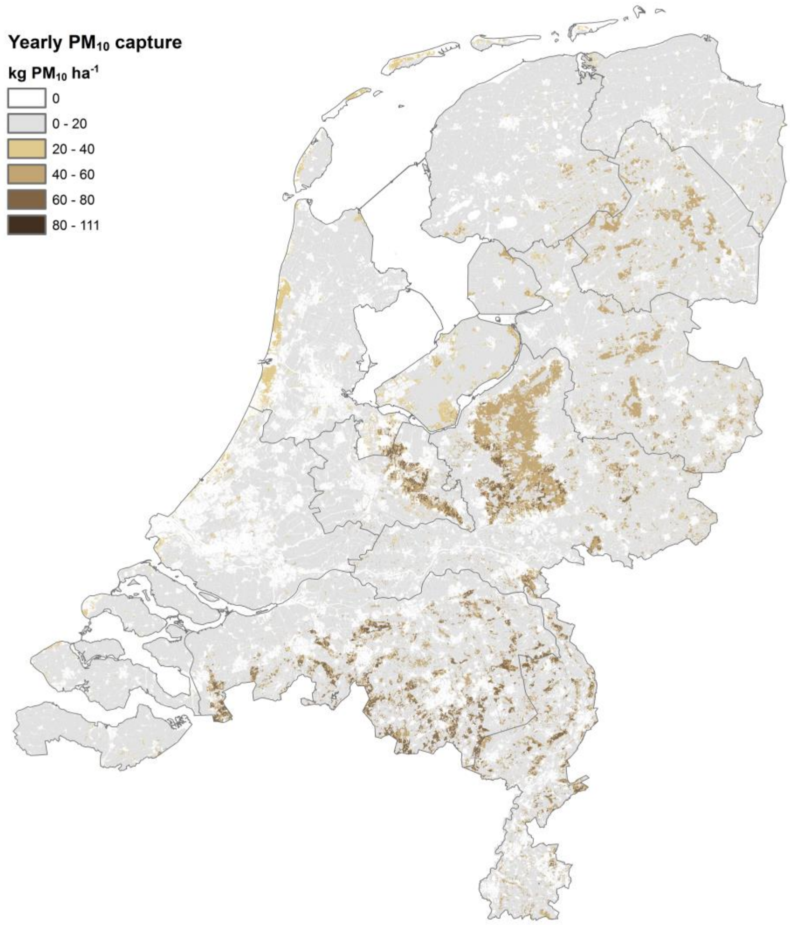

Figure 3.10.1 Mean yearly PM_{10} capture (kg PM_{10} per ha) by vegetated ecosystems

The deposition of PM_{10} can be compared to the national PM_{10} emissions, which are 33 million kg in 2013. In other words, seemingly an amount equal to some 70% of the national emissions is captured by the vegetation. However, first, it needs to be noted that the PM_{10} concentration in the Netherlands is also influenced by emissions in Belgium, Germany and the United Kingdom, part of which is transported to the Netherlands. Hence, the total amount of emitted PM10 that contributes to air pollution in the Dutch atmosphere is considerably higher than 33 million kg (in 2013). Second, it is possible and perhaps likely that PM10 emissions in the Netherlands are underestimated in the national air emissions inventory. In particular emissions of in-house fireplaces are estimated with a model that has not been updated in the last 10 years, and potential increases in emissions due to increasing popularity of wood burning in fire places are not considered in the current emission registration. Third, it needs to be acknowledged that there is considerable uncertainty in our estimate of the capture of PM_{10} by vegetation. There are relatively few numbers that indicate the precise amount of capture by plants and trees. Hence, the service of air filtration through the capture of PM_{10} by vegetation should be interpreted with caution, and improvements of the current model will be done when new or better data become available.

3.11 Protection against flooding due to intense rainfall

Flooding due to intense precipitation may occur when rainfall intensity exceeds soil infiltration capacity (in rural areas) or sewage capacity (in urban environments). Both the current and rapid increase in urbanisation and the increase of impervious surfaces within urban environments, such as paved gardens, lead to decreased infiltration capacity and hence an increased flooding risk.

In addition, it is already observed that due to climate change not only the occurrence of heavy rainfall increases, but also the intensity of the heavy rainfall. The Royal Netherlands Meteorological Institute (KNMI) reports that the occurrence of heavy rainfall events (more than 50 mm per 24 hour in the months June, July or August) have increased from on average 5 days with heavy rainfall early 1950s to about 10 days now (KNMI, 2017). Furthermore, in recent years heavy rainfall has also occurred in May, September and October.

Due to the large fraction of paved surfaces in urban areas, a correspondingly large fraction of the precipitation runs off to the sewage system. Whenever the capacity of this system is exceeded, flooding may occur in the form of flooded streets, tunnels or basements.

In cities, unpaved areas and vegetation play an important role in the protection from flooding. A small part of the precipitation is intercepted by the vegetation, the remaining part infiltrates in the soil. Soil type and the presence of vegetation affect the infiltration rate. Furthermore more water can infiltrate in dry soils than in moist soils as long as the soil is permeable. .

For the calculation of infiltration capacity of rain water in urban areas we combined the Ecosystem Type map (gridded to at 10 meter spatial resolution) with three vegetation maps (RIVM, 2017a, 2017c, 2017e) of trees, shrubs and grass (10 meter grid) and a soil map that includes soil types in urban areas (RIVM, 2017d). To calculate infiltration capacity for different degrees of urbanization, we used an urbanisation level map per neighbourhood of 2013 (Statistics Netherlands, 2017e). Infiltration capacity depends on soil type, soil moisture and the presence of vegetation. We used a look up table approach to combine the soil map with infiltration rates calculated with the Horton model for water infiltration in dry soils and for dense and no vegetation (Horton, 1933; see also Appendix 2, table A2.11.1). We use the three earlier mentioned vegetation maps to assess the fraction of the cell that is vegetated. To calculate interception by the vegetation, we used a look-up table in combination with the three vegetation maps; tree map, shrub map and grass map (Appendix 2, table A2.11.3).

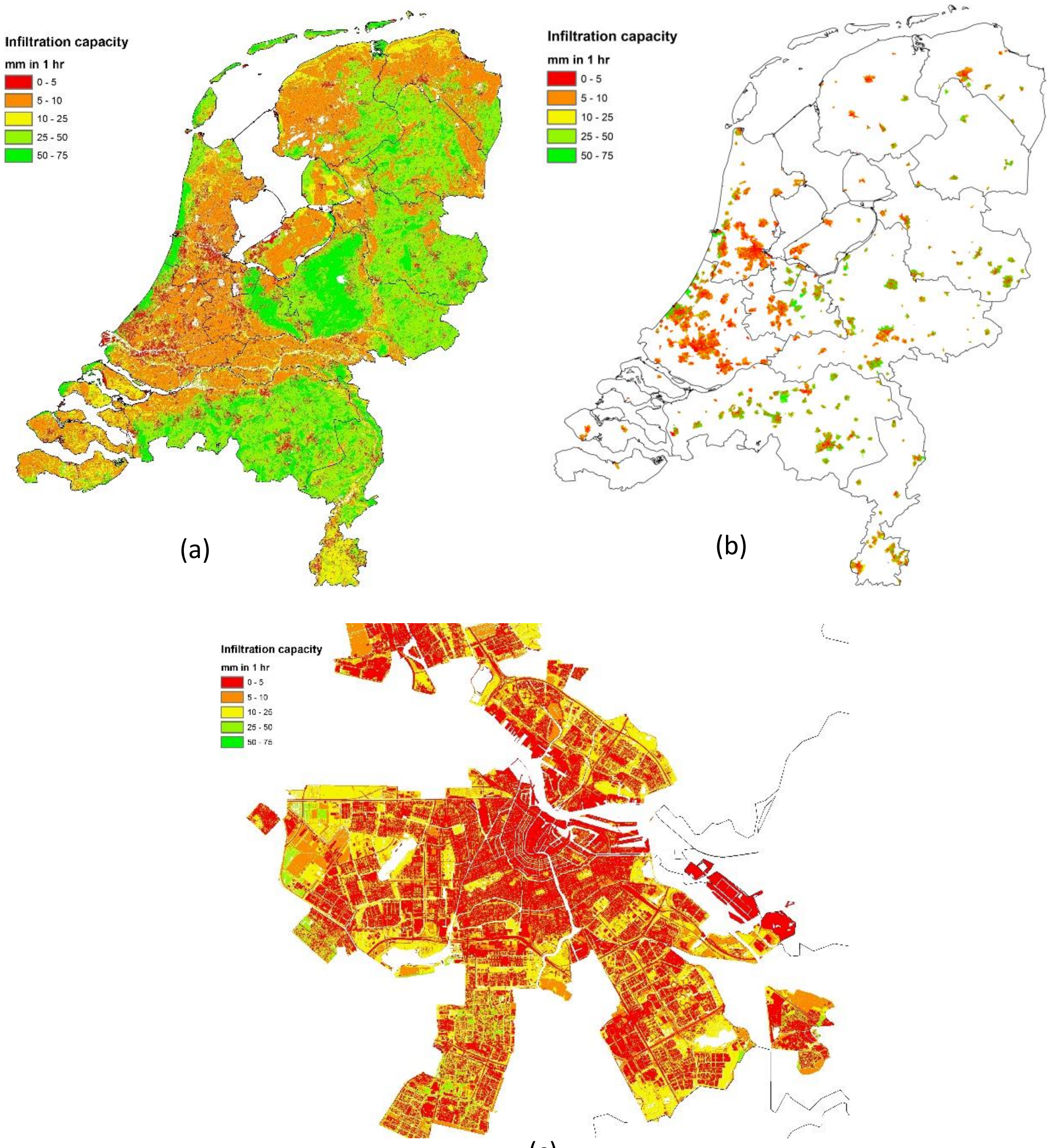

Figure 3.11.1 Total potential infiltration in one hour in **a)** the Netherlands, **b)** cropped to urban areas (urbanity levels intermediate, strong and very strong) in the Netherlands, and **c)** for the Amsterdam area. Based on dry soils, soil type and tree, shrub and grass cover and paved surfaces.

Table 3.11.1 Mean potential infiltration capacity in 60 minutes per urbanity level and interception by vegetation

Urbanity level	Mean infiltration (mm in 60 min)				Interception (mm)
	All soils	Low[1]	Inter-mediate[2]	High[3]	
Very strong	10.7	5.5	12.5	25.7	1.4
Strong	17.6	7.1	17.5	33.3	1.5
Intermediate	21.5	8.2	19.6	38.9	1.5
Moderate	23	8.5	22	44	1.5
No	26.8	8.6	26.3	54.2	1.3

[1]Soils with low initial infiltration capacity; clay, heavy clay and peat
[2]Soils with intermediate initial infiltration capacity; loam, sandy loam and loamy sand
[3]Soil with initial high infiltration capacity; sand.

In the Horton model, soil type is the main driver of infiltration capacity (figure 3.11.1). Urbanisation has a negative effect on total infiltration (figure 3.11.1). Strong urbanisation reduces the infiltration of all soils (table 3.11.1). The effect of the degree of urbanisation is, however, stronger in areas with soils with intermediate and high initial infiltration capacity; e.g. loamy sand, sandy loam and sand. On sandy soils for example, mean infiltration capacity decreases from on average 54.2 mm in one hour in rural areas to on average 25.7 mm in one hour in very urbanized areas (table 3.11.1 and figure 3.11.2). To place these values in perspective, a rainfall event with 54 mm precipitation in one hour has a recurrence interval of less than once per 100 years and in a rural area with a sandy soil, this would not cause a flooding under normal circumstances. For the same soil and same rainfall event in an urban area this event will likely result in flooding. In areas where the initial infiltration is already low due to soil type (e.g. most clayey and peaty soils) even 10 mm/yr showers (recurrence rate of once per half year) will result in floodings, for all degrees of urbanisation. Hence the degree of urbanisation may drastically increase the risk of flooding, in particular in areas with naturally permeable soils.

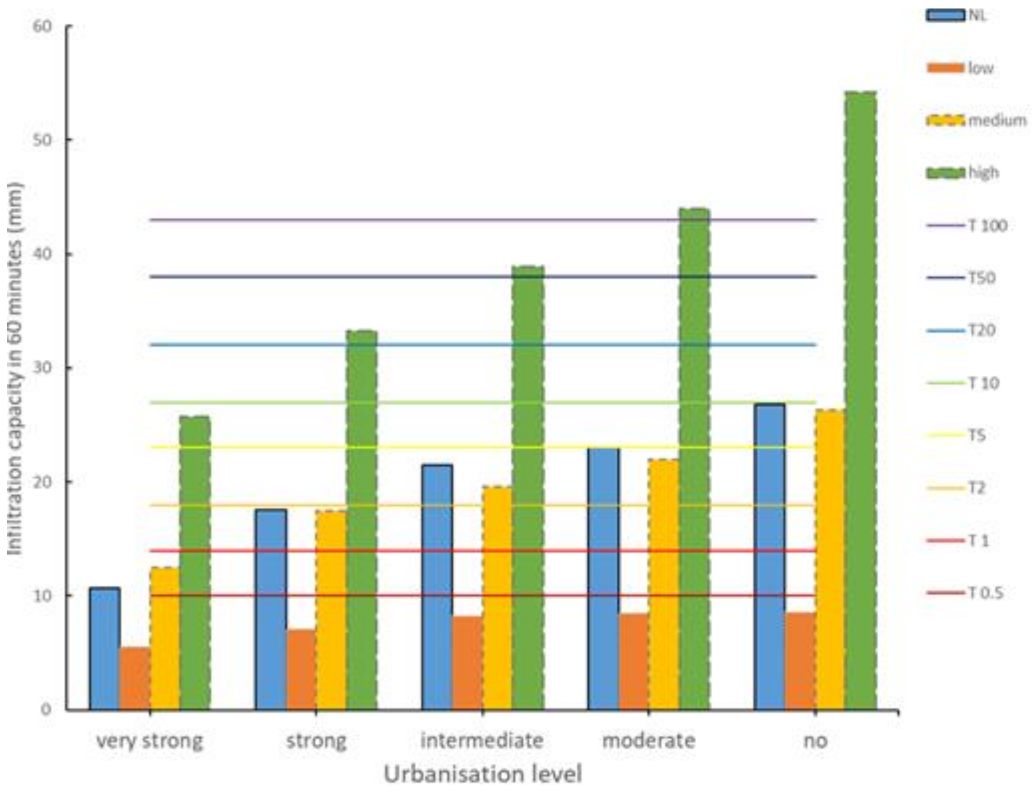

Figure 3.11.2 Effect urbanisation level on total infiltration in 60 minutes in dry soils, depicted for the Netherlands (blue bar) and for soils with low (orange bars), medium (yellow bars) or high infiltration capacity (green bars) (see table 3.11.1). Horizontal lines depict for recurrence times (T) from 0.5 year to 100 year the associated mm rainfall in one hour (Buishand and Wijngaard, 2007).

Degree of urbanisation has an effect on total infiltration of heavy rainfall (table 3.11.2). However, this is mainly in the built-up areas. In built-up ecosystems (residential areas, offices and companies, and roads) mean infiltration is lower in intermediate to very strong urbanized areas than for the mean for the Netherlands (including both urban areas and rural areas), not only for sandy soils with high infiltration capacity but also for all soil types combined. Such an effect is not found in the agricultural and natural and semi-natural ecosystems that are present in the periphery of urban areas. As expected, built-up areas (paved areas) in general, including green houses and built-up agricultural terrain, have a lower mean infiltration rate than the vegetated and unpaved ecosystems (table 3.11.2).

The total infiltration in one hour in water saturated soil is much lower than the total infiltration that is possible in dry soil. Differences between built-up terrains and vegetated and unpaved terrains are smaller, but also for saturated soils, vegetated and unpaved terrains have a higher infiltration rate. This account shows where risks of local flooding occur because the infiltration rates are lower than the amount of rainfall that can fall during high intensity rainfall events. This account is also particularly relevant when developed for multiple years. In this case the account shows where potential problems may occur with sewage systems because of insufficient infiltration of rain water.

Table 3.11.2 Mean infiltration capacity (mm in 60 minutes) per ecosystem type. Given for all areas, and for only the urban areas (urbanisation levels intermediate, strong and very strong), for all soils and sandy soils

	Mean infiltration (mm in 60 min)				
	Dry soil				Saturated soil
	All soils		Sandy soil		All soils
Ecosystem type	**All areas**	**Urban areas**	**All areas**	**Urban areas**	**All areas**
Non-perennial plants	22	22.5	46.2	46.9	8
Perennial plants	30	33	52.3	49.6	10.2
Greenhouses	8.1	8.3	15.9	16.9	1.4
Meadows (grazing)	20.9	18.2	47.1	48.2	7.6
Bushes and hedges bordering	22.4	18.9	51.1	52.3	7.4
Farmyards and barns	14.1	11.1	24.5	22.6	3
Dunes with permanent vegetation	68.3	67.9	69.8	69.6	19.5
Active coastal dunes	49.5	60.9	59.4	63.2	16.5
Deciduous forest	44.1	42.5	72.4	72.7	10.3
Coniferous forest	70.1	72	72.8	72.4	19.2
Mixed forest	67.4	71.4	73.1	73.2	18.1
Heath land	57.9	58.6	65.8	58.7	17.3
Inland dunes	49.1	52.5	50.9	54.7	19.1
Fresh water wetlands	20.8	13.8	62.8	65.5	5
(semi) Natural grassland	31.2	33.8	62.6	66	8.3
Public green space	38.6	32.3	67.4	67.1	9.4
Other unpaved terrain	33.2	31.7	62	65.5	9
River floodplains	19.5	17	57.6	54	4.4
Salt marsh	27	22.6	64.4	-	4.5
Residential area	21	14.7	33.9	25.7	4.9
Industy: offices and businesses	9.5	7.5	18.2	15.3	2.1
Services: offices and businesses	16.1	10.3	28.5	19.9	3.7
Public administration: offices and businesses	13	10.8	23	19.9	2.8
Roads, parking lots, runways, other	19.4	13.7	36.4	27.3	4.3
Forestry: offices and businesses	32	19.7	40.7	22.2	8
Fishery: offices and businesses	18.6	9.1	30.1	10.1	3.9
Non-commercial services: offices and businesses	18.2	13.7	30.4	25	4.2

3.12 Nature recreation

Ecosystems play an important role in outdoor recreation, by providing attractive environments for leisure activities. The ecosystem service nature recreation covers all nature-related recreational activities. Hiking is the most popular outdoor recreational activity in the Netherlands, ranging from short strolls in the neighbourhood to day long hikes along long distance hiking paths (NBTC-NIPO, 2015b). For that reason, we use hiking as the indicator for nature recreation in this study. As the activity revolves around interaction with the direct environment, the provision of an attractive surrounding for hiking is considered to be the ecosystem service. This ecosystem service is measured by the number of hikers passing through each individual hectare of an ecosystem.

Table 3.12.1 Number of recreational hikes per surrounding for the Netherlands. Source: NBTC-NIPO (2015b).

Hiking surrounding	Hikes (million)	Hikes per ha
Agricultural areas	83	213
Forest	86	444
Heath and sand	13	681
Urban parks	40	844
Wetlands and marshes	7	1,022
Seaside, beach and dunes	29	1,144
Inland water	17	494
Other areas	53	290
Total	430	335

The recreational hiking model was developed as an allocation model, based on outdoor statistics for 2015 (NBTC-NIPO, 2015b; table 3.12.1). Statistics for 2015 were used as these were the closest available data to 2013 (the accounting year for this report). The CVTO statistics contain information on the number of hikers for nine types of surroundings per province. A number of hikers indicated that they hiked in built-up areas. In the context of hiking as an ecosystem service, it is questionable whether this type of recreational hiking should be considered as an ecosystem service. Therefore, in the current analysis hikes in built-up areas were omitted. The remaining eight surroundings were linked to their equivalent ecosystem types in the Ecosystem Type map (see also table A2.12.1 in Appendix 2). The category 'other areas' contains the ecosystem types '(semi) natural grasslands', 'river floodplains, 'other unpaved terrain' and 'unknown'. Hikers were assumed to stick to footpaths, or to the beach, as this is frequently used for hiking. Ecosystem types within the direct surroundings of hiking paths (within 50 meter distance of the path) were assumed to contribute to the enjoyment of the hiker and therefore provide an ecosystem service. All hiking paths and roads less than 4 meter wide were selected from the Dutch road database (NWB) (Rijkswaterstaat, 2013) and buffers of 50 meter on each side of the roads were created. These buffers were used as a mask for further analyses.

The hikers were allocated equally over the nine types of surroundings according to the total area of each surrounding and the corresponding hiking statistics per province (table 3.12.2). A smoothing effect in a 100 meter neighbourhood was applied to the resulting map, to minimalize differences between the two sides of each path. Note that the applied indicator is a hiking 'intensity', i.e., the number of hikers that passes through individual hectares in the landscape.

Table 3.12.2 Hiking intensity (average number of hikers, x1000, passing through an individual hectare) per environment and province.

	Mean number of hikers (x1000/ha)											
Environment	Groningen	Friesland	Drenthe	Overijssel	Flevoland	Gelderland	Utrecht	Noord-Holland	Zuid-Holland	Zeeland	Noord-Brabant	Limburg
Sea, beach and dunes	21	13	0	0	0	0	0	71	197	187	0	0
Inland water	27	21	11	25	38	37	43	49	59	49	25	52
Agricultural areas	10	11	7	8	4	12	30	35	38	13	15	19
Wetlands and marshes	93	37	65	54	11	357	168	119	211	15	61	138
Forest	36	31	19	33	40	24	40	99	110	42	27	45
Heath and inland dunes	12	20	32	53	20	28	43	132	244	23	55	153
Public green space	47	23	17	55	55	62	107	97	115	23	50	51
Other areas	21	17	10	17	15	16	34	40	43	14	16	20

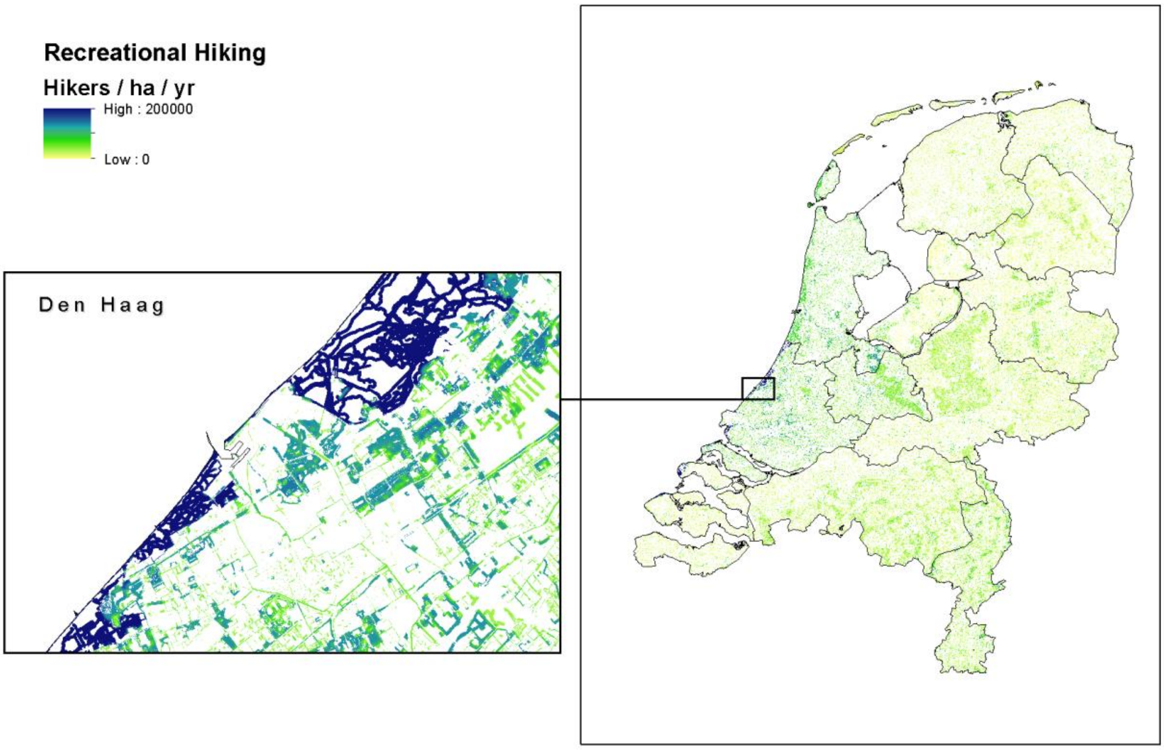

Figure 3.12.1 Recreational hiking in the Netherlands in 2013. The inset shows the city of The Hague and the surrounding coastal area in more detail.

On average beaches and dunes, wetlands and marshes and public green spaces are the most popular areas for hiking, although in total most recreational hikes are made in forests and agricultural areas (table 3.12.1 and figure 3.12.1). The beach and dune areas, especially in Noord- and Zuid-Holland, are popular for hiking (e.g. table 3.12.2 and inset figure 3.12.1). The densely populated provinces Noord-Holland, Zuid-Holland, Utrecht and Limburg have the highest number of hikers per ha (table 3.12.2).

For further development of the hiking model for ecosystem accounting, several improvements can be made. The current hiking model does not take into account accessibility of areas and distance from people's homes. In addition the NWB road database may not be the most suitable dataset to distinguish footpaths, as it does not indicate the availability of pavement along larger roads or cycling paths. The visibility of the surroundings from a footpath depends for a large part on the height of surrounding objects and the topography of the surroundings. Developing a model based on view shed would give a better indication of which ecosystems affect the attractiveness of certain areas. Finally, it is important to realize that hikers may be especially attracted to heterogeneous landscapes, where e.g. forests, heath land and inland dunes can be enjoyed during a single hike. In such areas, the attribution of a hike to one type of surrounding is not meaningful and this may cause misrepresentation of in particular small ecosystem types (e.g. inland dunes) in the CVTO dataset. Given the importance of the Dutch landscape for recreation it is crucial that this service can be considered in spatial planning (e.g. of new infrastructure). A national dataset that presents a first indication of the importance of individual sites for recreation is an important input for such plans.

Pilot project: Using Strava heatmap data to improve hiker allocation

In the original hiking ESS model and map, presented above, the number of hikers per province and per ecosystem type is known (from a survey) and allocated to the set of likely hiking paths. In this model, all roads and paths wider than 4 meter wide are excluded, and the hikers are distributed uniformly on all remaining (i.e. < 4m wide) roads and paths. In practice, this means than within a given environment, designated hiking routes in popular areas have the same probability to be hiked as dead-end paths on private property.

To solve this problem, we used a Big Data source on outdoor activity like bicycling and running. More specifically, the aggregated activity of *Strava* users, as depicted in so-called heat maps. These heat maps are available on the web (https://labs.strava.com/heatmap) as tiled images in multiple resolutions and activity types, resolutions and color schemes. While these heat maps do not show any actual numbers of hikers (the actual activity distribution is histogram-equalized on a 5x5 tile scale) more `heat' does locally correspond to more user activity.

Given these limitations, and the fact that certainly not all hikers will use Strava, we use the Strava heatmaps to distinguish between just a few classes: 'no hikers', 'low-intensity' and 'high-intensity'. Strava heatmaps are combined with the road and path networks derived from the official 1:10.000 topographic maps to obtain hiking intensity per road or path segment.

Figures 3.12.2 and 3.12.3 show the resulting ('Strava-based') map as compared to the original ('Allocation') hiking map. While there are a lot of similarities between the who maps, especially regarding the hiking intensity in the western coastal dunes and forested area, there are a couple of noteworthy differences.

1. In the Allocation model, all roads < 4 m wide where excluded from hiking. In the Strava-based map, this censoring was not applied, because it was judged to be not always appropriate. Sometimes designated hiking routes follow short stretches of wide, but quiet, roads. If deemed appropriate, censoring of road segments based on width, or similar characteristics, could easily be combined with the Strava-based analysis.

2. In the Allocation model, *all* small roads get their share of hikers, even if they are dead-ended or are on private property or restricted areas. In the Strava-based map these are excluded automatically because in practice no, or very few, users go there.
3. Beaches are a popular hiking destiny on Texel. In the Allocation map this is visible because the known amount of hikers (based on surveys) are allocated to these areas, even if there are no registered paths here. In the Strava-based map, the road network is used as starting point for the analysis, resulting in empty beaches (because there are no roads here). Note that the original Strava heatmaps themselves *do* show hiking activity on the beaches, obviously. Again, this omission of the Strava-based approach can easily by repaired by either allocation hikers to the beach areas directly, or using the Strava heatmap images using an polygon approach (i.e. beach areas) supplementing the current polyline approach (i.e., the road network).

Summarizing, we conclude that the Strava-based approach, when used in a more qualitative way, has some definite advantages (eliminating roads and paths that are not in actual use), while all the disadvantages (compared to the Allocation model) can be dealt with.

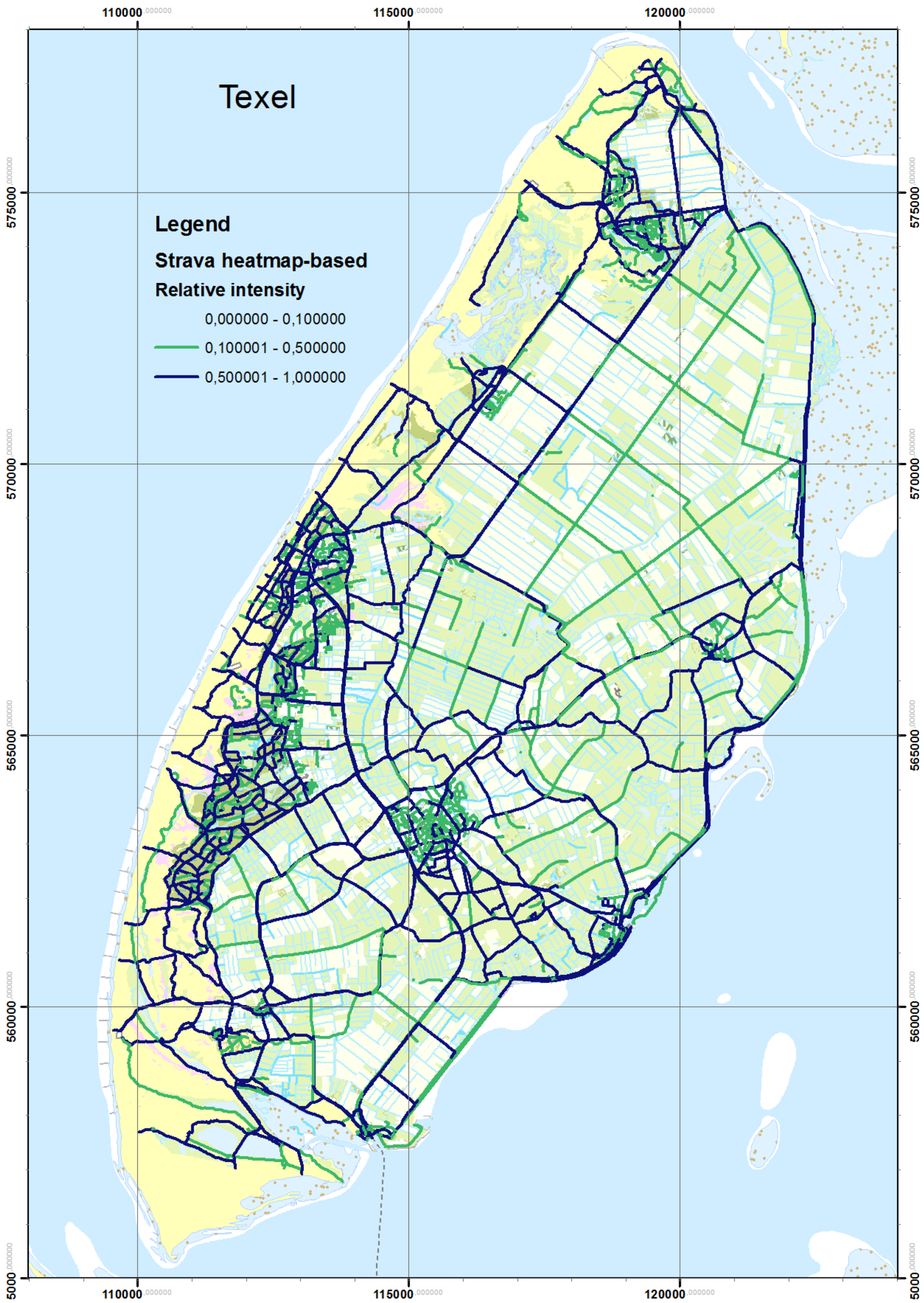

Figure 3.12.2 Hiking intensity on the island of Texel, derived from Strava heatmaps and the road network as published by the Netherlands Mapping Agency (Kadaster)

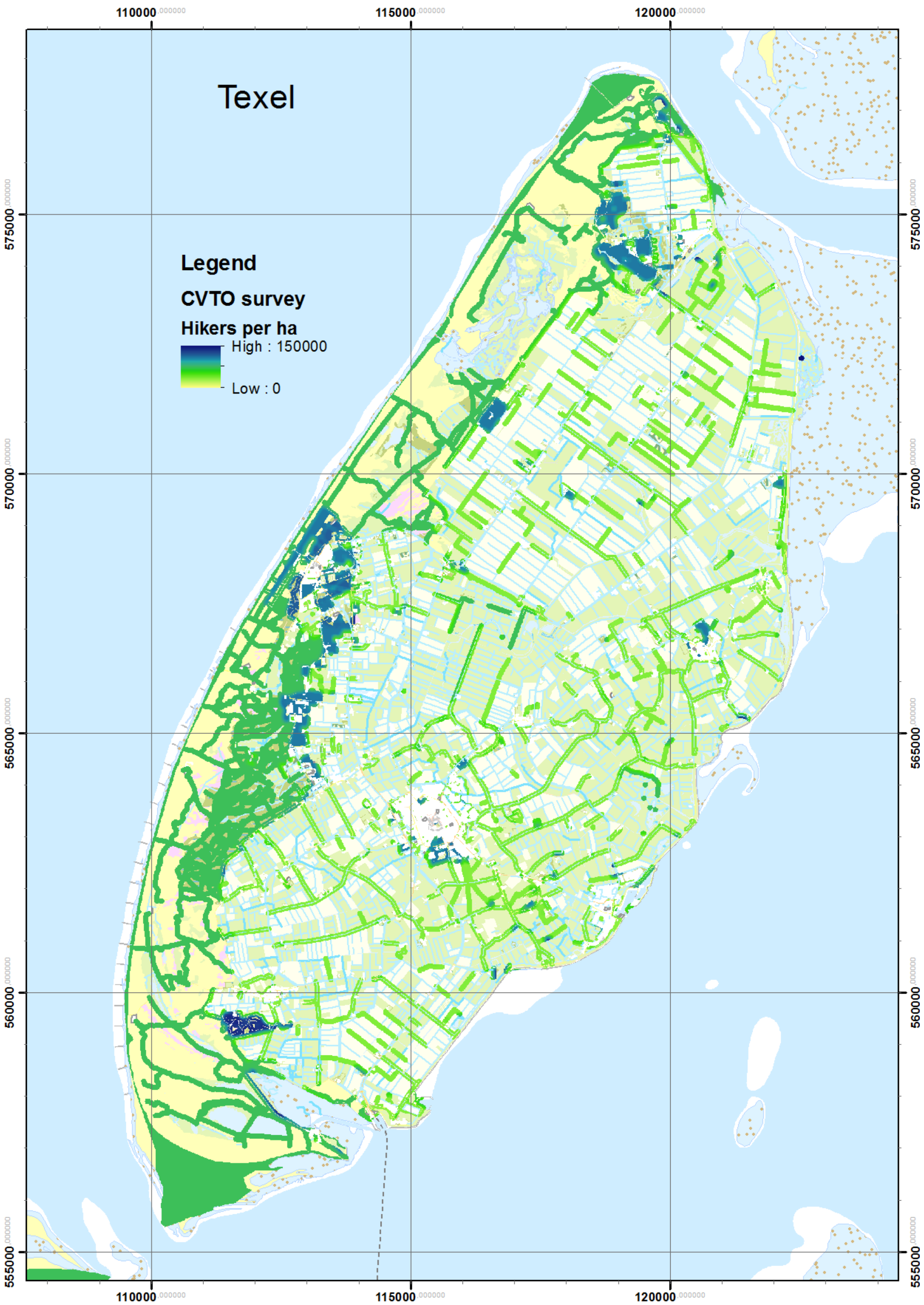

Figure 3.12.3 Hiking intensity on Texel, derived from the original allocation model using CVTO survey data.

3.13 Nature tourism

Nature tourism is an important ecosystem service in the Netherlands, as many areas of the country are frequently used for various leisure activities. Nature tourism is also an important component of the overall tourism sector, that accounts for around 4% of Dutch GDP. This account specifies the contribution of nature tourism to the overall tourism sector, and it indicates which areas contribute most to nature tourism. Nature tourism encompasses all tourist activities related to nature that involve overnight stays, both on land and on inland waters. Activities include visits to nature areas, outdoor activities such as hiking, cycling or boating, and beach holidays. Included accommodations are hotels, camp-sites, bungalows and group accommodations. Nature tourism differs from the ecosystem service recreation, as recreation considers only single day activities, whereas nature tourism includes only multiple day activities away from home (with at least one overnight stay at an accommodation).

The ecosystem service nature tourism was modelled based on Dutch tourism statistics for provinces and tourism areas, for domestic tourists (see table 3.13.1) (NBTC-NIPO, 2015a). International tourists are not included in the analysis, as they were not included in the dataset. Statistics were available for three main types of nature tourism: nature and active tourism, beach tourism, and water sports. It can be assumed that these types of tourism are directly dependent on the presence of (semi) natural ecosystems. Tourism statistics were combined with data on densities of beds in tourist accommodations (for land activities) and marinas (for water sports) for spatial disaggregation. Tourist activities were assumed to take place in the vicinity of accommodations and marinas. For accommodations a radius of 5 km was assumed within which the tourists undertake nature related activities. For marinas a radius of 10 km was assumed within which boats sail. Overnight stays was used as an indicator for the ecosystem service. The number of overnight stays was calculated based on the number of booked vacations and the average length of a vacation per province (Statistics Netherlands, 2017f).

Table 3.13.1 Number or tourists per province for different nature related types of tourism and the average length of their stay. Sources: NBTC-NIPO, 2015a and Statistics Netherlands 2017f .

Province	Number of tourists (x1000)			Average length of stay (days)
	Active and nature tourists	Beach tourism	Water sports tourism	
Groningen	66	0	1	2.5
Friesland	263	129	66	3.1
Drenthe	378	0	0	3.8
Overijssel	353	0	5	3.4
Flevoland	61	0	8	3.7
Gelderland	797	0	0	3.3
Utrecht	151	0	0	2.3
Noord-Holland	293	327	6	2.3
Zuid-Holland	151	126	18	2.2
Zeeland	145	386	16	4.5
Noord-Brabant	278	0	0	3.3
Limburg	446	0	9	3.1
Netherlands	3,382	968	129	3.0

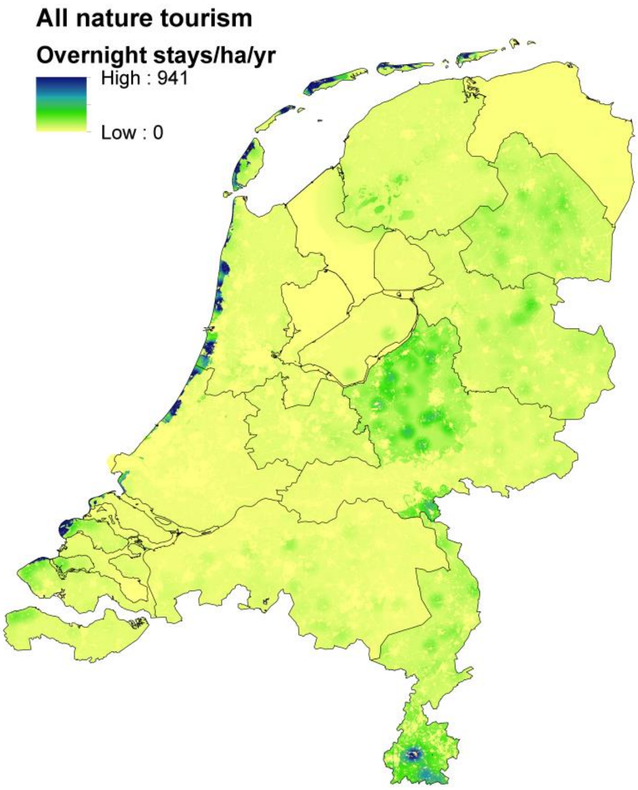

Figure 3.13.1 Map of nature tourism in the Netherlands.

The different forms of nature tourism were combined to produce a final map of nature tourism in the Netherlands (figure 3.13.1). The results show that especially the coastal areas are important for nature tourism. This is largely due to the high values for beach tourism, compared to the other forms of tourism, as becomes evident from figure 3.13.2. Where nature and active tourism and water sports tourism vary between 0-46 overnight stays per ha, beach tourism peaks at 922 overnight stays per ha. Southern Limburg and the Veluwe have relatively high nature tourist densities, while Groningen and the largest water bodies have low tourist densities.

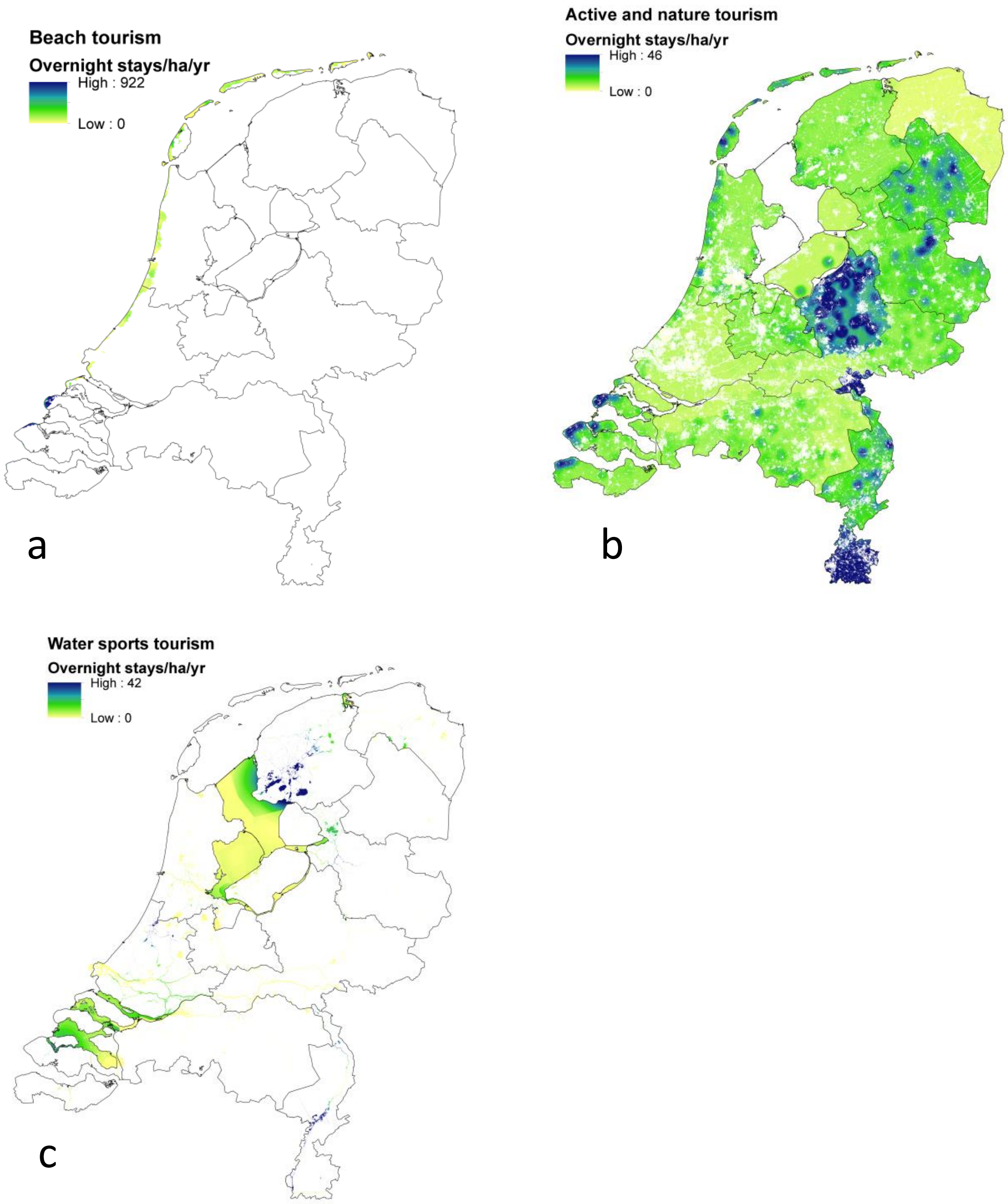

Figure 3.13.2 Overnight stays related to **(a)** beach tourism, **(b)** nature and active tourism and **(c)** water sports tourism in the Netherlands.

4. Biophysical ecosystem service supply-use account

4.1 Biophysical ecosystem service supply per ecosystem type

Here we present the results of the different physical supply models in a supply account. Following the SNA and the SEEA EEA technical recommendations (UN et al., 2009; UN et al., 2017), supply must equal use and therefore, physical supply cannot, by definition, exceed use. A (final) ecosystem service is defined as a flow between an ecosystem type and an economic unit, which means that only the actual flows are taken into account for which there is always a user. As described in the previous chapter, in this study we have attempted to model each ecosystem service so that this condition can be met. For example, pollination was modelled to represent pollination of pollination-dependent crops in the economy only. Air filtration was based on the capturing capacity of vegetation, as well as on actual PM_{10} concentrations. It was assumed that the air filtration service was fully used; in the Netherlands, with its high population density and absence of truly remote areas, this was considered a likely assumption. We thus assume that all supplied services as modelled in this study *for the Netherlands* are used in the economy

Table 4.1.1 shows an overview of the supply of ecosystem services as delivered by the different ecosystem types, showing totals for the Netherlands (year 2013). Note that ecosystem types that cover large areas (mostly agricultural types) generate correspondingly large quantities of services. To correct for the effect of size, table 4.1.2 shows the average delivery of services per ecosystem type per hectare. Note that for this analysis the full national extent of each ecosystem type has been used for the analysis.

The supply tables show which (and how much) ecosystem services are provided by each ecosystem type. For example, non-perennial crop land produces not only crops (93% of the total Dutch production) and fodder (59%), it also provides air filtration (11% of the total), and cultural services (recreation 8%, tourism 18%). However, because non-perennial cropland is also the largest ecosystem type in the Netherlands, this should not be surprising. As expected for e.g. air filtration, the capacity to deliver this service is much higher per ha in forests (ranging from 37-61 tons PM_{10}/ha depending on the forest type; table 4.1.2) than in non-perennial cropland (3.5 tons PM_{10}/ha). Forest and dunes provide relative high amounts of services per hectare. For forest areas this is the case for wood production, air filtration, pollination (especially deciduous forests), pest control and protection against flooding from rainfall. Additionally, dunes and beaches provide relative high amounts of drinking water, protection against flooding from rainfall and cultural services (hiking and tourism). Other unpaved terrain contributes services in biomass production, erosion control and protection against flooding from heavy rainfall.

Ecosystems that deliver few ecosystem services are built-up areas such as residential areas, offices and roads, both in absolute and relative terms. Note that we did not study ecosystem services provided by marine areas – even though overnight stays generated on land by recreational opportunities on sea were partly included.

Most provisioning services are only delivered by a very limited number of ecosystems each (agricultural land or forests), whereas most regulating and cultural services are provided by nearly all ecosystems to some extent. Pest control is not accounted for in table 4.1.1, as the model was based on a relative unit that cannot be summed up per ecosystem type.

4.2 Biophysical ecosystem service supply account per province

In this section the ecosystem services delivered per province are summarized in supply tables. Table 4.2.1 summarizes the total ecosystem services delivered by province and table 4.2.2 shows the values per ha.

From table 4.2.1, it is clear that the size of the province to a large degree determines the total amount of services delivered. The largest provinces (Gelderland and Noord-Brabant) supply the highest amounts of ecosystem services, while the smallest (Utrecht and Flevoland) generally supply the lowest total amounts of services. There are some notable exceptions. Flevoland produces the highest amounts of crops and Zuid-Holland has most hiking recreation.

Table 4.2.2 indicates that most provinces show distinctly different patterns in ecosystem service supply. Utrecht, Noord-Holland and Zuid-Holland show similar patterns in ecosystem service supply per hectare. These provinces have biomass production, drinking water production and nature recreation services that are higher than the national average and substantially lower supply of natural pest control per hectare than the national average. Table 4.2.2 also gives insight in the relative supply of ecosystem services of certain provinces, where we define relative supply of ecosystem service as the supply of ecosystem services in value per hectare. Table 4.2.3 summarizes these results, identifying the provinces with relative high and low ecosystem services supply.

Tables 4.2.2 and 4.2.3 show that Limburg province provides relatively high quantities of nearly all ecosystem services per ha (all quantities per ha are equal to or higher than the national average). Noord-Brabant supplies relatively large amounts of fodder, natural pest control and air filtration. Zuid-Holland scores relatively low for most ecosystem services, with the exception of biomass production, drinking water production and hiking recreation. These low scores per ha are likely related to the high population density and a corresponding high proportion of paved surfaces (buildings, roads etc.) (Statistics Netherlands, 2017g). Friesland and Groningen supply quantities of ecosystem services per ha that are often below the national average (for those services included in this study). This is likely related to the lower overall percentage of forested areas in these provinces; forests contribute substantially to all ecosystem services except fodder, crop, wood and other biomass production. It should thus be kept in mind that the comparisons in table 4.3.2 are biased towards provinces with a higher percentage of forest cover. Furthermore, a higher flow does not necessarily imply a ‘better’ supply of ecosystem services: high crop yields, for example, may be related to very intense land use that may not be sustainable in the long term.

Table 4.1.1 Biophysical ecosystem service supply account 2013 for the Netherlands, with total biophysical supply per ecosystem type

Ecosystem service \ Ecosystem unit	Unit	null	Non-perennial crops	Perennial crops	Greenhouses	Meadows	Hedgerows	Farmyards and barns	Dunes with permanent vegetation	Active coastal dunes and beaches	Deciduous forest	Coniferous forest	Mixed forest	Heath land	Inland dunes	Fresh water wetlands	(semi) Natural grassland
Area	ha	379	781,401	79,228	11,790	927,216	36,492	35,491	15,943	33,946	109,142	81,923	118,571	40,813	2,364	34,346	54,010
Crop production	ktons	0	15,177	1,081	0	0	0	0	0	0	0	0	0	0	0	0	0
Fodder production	ktons	0	9,517	0	0	6,181	0	0	0	0	0	0	0	0	0	0	0
Wood production	1000 m^3	0	0	0	0	0	0	0	50	0	289	348	398	0	0	0	0
Biomass production	ktons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Drinking water production	mln m^3	0	30	5	0	48	2	1	31	77	15	3	38	14	1	1	4
Carbon sequestration in biomass	ktons	0	0	30	0	167	6	0	30	0	206	155	224	8	0	8	10
Pollination[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural pest control[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Erosion control	ktons soil	0	57	34	6	893	77	50	197	13	480	316	518	175	4	39	195
Air filtration	tons PM_{10}	0	2,725	287	0	3,266	127	0	463	0	4,063	5,014	5,835	145	0	114	192
Protection against heavy rainfall	mln ltr in 1 hour	134	171,646	23,705	953	193,289	8,160	5,019	10,820	16,407	48,090	57,059	79,118	23,571	1,160	7,066	16,824
Nature recreation (hiking)	mln hikers	0	2,041	408	47	2,973	149	245	811	1,199	2,068	1,807	2,360	836	52	453	436
Nature tourism	1000 stays	0	2,327	266	0	2,870	127	0	967	2,134	430	494	706	264	19	103	224

Ecosystem service \ Ecosystem unit Cont'd	Unit	Public green space	Other unpaved terrain	River floodplains	Salt marshes	Residential area	Industry: offices and businesses	Servies: offices and businesses	Public administration: offices and businesses	Roads, parking lots and other paved areas	Forestry: offices and businesses	Fishery: offices and businesses	Non-commercial services: offices and businesses	Sea	Lakes and ponds	Rivers and streams	unknown	Total
Area	ha	68,416	294,931	73,306	11,139	250,417	66,518	89,774	1,093	111,811	206	115	19,723	381,509	123,277	297,559	1,231	4,154,080
Crop production	ktons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16,259
Fodder production	ktons	0	0	340	0	0	0	0	0	0	0	0	0	0	0	0	0	16,039
Wood production	1000 m^3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,085
Biomass production	ktons	0	357	0	0	0	0	0	0	0	0	0	0	0	0	0	0	360
Drinking water production	mln m^3	12	32	12	0	24	6	8	0	10	0	0	3	0	7	2	0	413
Carbon sequestration in biomass	ktons	18	53	15	45	0	0	0	0	0	0	0	0	0	0	0	0	975
Pollination[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	534[1]
Natural pest control[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Erosion control	ktons soil	159	787	112	12	251	75	93	1	325	0	0	16	0	2	0	0	4,888
Air filtration	tons PM_{10}	252	1,071	290	0	0	0	0	0	0	0	0	0	0	0	0	0	23,843
Protection against heavy rainfall	mln ltr in 1 hour	26,412	97,808	14,269	2,856	52,531	6,299	14,439	142	21,671	66	21	3,591	0	0	0	0	903,128
Recreation: hiking	mln hikers	3,251	3,135	342	37	0	0	0	0	0	0	0	0	15	1,294	94	6	24,060
Nature tourism	1000 stays	256	1,066	257	22	2	0	1	0	9	0	0	0	0	142	230	0	12,916

[1] Pollination and pest control cannot be added in this table due to set-up of the indicator. They are added in table 4.1.2, however.

Table 4.1.2 Biophysical ecosystem service supply account 2013 for the Netherlands, with mean biophysical supply per ha per ecosystem type

Ecosystem service \ Ecosystem unit	Unit	null	Non-perennial crops	Perennial crops	Greenhouses	Meadows	Hedgerows	Farmyards and barns	Dunes with permanent vegetation	Active coastal dunes and beaches	Deciduous forest	Coniferous forest	Mixed forest	Heath land	Inland dunes	Fresh water wetlands	(semi) Natural grassland
Area	ha	379	781,401	79,228	11,790	927,216	36,492	35,491	15,943	33,946	109,142	81,923	118,571	40,813	2,364	34,346	54,010
Crop production	tons/ha	0	19	14	0	0	0	0	0	0	0	0	0	0	0	0	0
Fodder production	tons/ha	0	12	0	0	7	0	0	0	0	0	0	0	0	0	0	0
Wood production	m^3/ha	0	0	0	0	0	0	0	3.1	0	2.6	4.2	3.4	0	0	0	0
Biomass production	tons/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04
Drinking water production	m^3/ha	0	3,828	5,717	854	5,226	4,146	3,974	195,637	228,071	13,983	33,934	32,124	34,417	34,960	4,170	8,034
Carbon sequestration in biomass	tons/ha	0	0	0.4	0	0.2	0.2	0	1.9	0	1.9	1.9	1.9	0.2	0	0.2	0.2
Pollination	tons/ha	0	0	0	0	0.9	1.6	0	0.5	0.1	2.0	0.6	0.8	0.6	0.1	0.6	1.5
Natural pest control	%	0	0	0	0	0	0	0	2.1	0	17.7	9.6	11.2	0	0	0	0
Erosion control	tons soil/ha	0.1	0.1	0.4	0.5	1.0	2.1	1.4	12.4	0.4	4.4	3.9	4.4	4.3	1.6	1.1	3.6
Air filtration	kg PM_{10}/ha	0	3	4	0	4	3	0	29	0	37	61	49	4	0	3	4
Protection against heavy rainfall	mm/m^2 in 1 hour	35	22	30	8	21	22	14	68	48	44	70	67	58	49	21	31
Nature recreation (hiking)	1000 hikers/ha	0	3	5	4	3	4	7	51	35	19	22	20	20	22	13	8
Nature tourism	stays/ha	1	3	3	0	3	3	0	61	63	4	6	6	6	8	3	4

Ecosystem service \ Ecosystem unit Cont'd	Unit	Public green space	Other unpaved terrain	River floodplains	Salt marshes	Residential area	Industry: offices and businesses	Servies: offices and businesses	Public administration: offices and businesses	Roads, parking lots and other paved areas	Forestry: offices and businesses	Fishery: offices and businesses	Non-commercial services: offices and businesses	Sea	Lakes and ponds	Rivers and streams	unknown	Total
Area	ha	68,416	294,931	73,306	11,139	250,417	66,518	89,774	1,093	111,811	206	115	19,723	381,509	123,277	297,559	1,231	4,154,080
Crop production	tons/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Fodder production	tons/ha	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Wood production	m^3/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3
Biomass production	tons/ha	0	1.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09
Drinking water production	m^3/ha	17,502	10,926	15,983	0	9,718	8,740	9,395	7,725	9,227	14,805	1,900	16,483	0	5,639	559	520	9,945
Carbon sequestration in biomass	tons/ha	0.3	0.2	0.2	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0.2
Pollination	tons/ha	0.8	1.2	1.8	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0.5
Natural pest control	%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
Erosion control	tons soil/ha	2.3	2.7	1.5	1.1	1.0	1.1	1.0	0.9	2.9	1.8	1.5	0.8	0	0	0	0	1.2
Air filtration	kg PM_{10}/ha	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Protection against heavy rainfall	mm/m^2 in 1 hour	39	33	19	26	21	9	16	13	19	32	19	18	0	0	0	0	22
Nature recreation (hiking)	1000 hikers/ha	48	11	5	3	0	0	0	0	0	0	0	0	0	10	0	5	6
Nature tourism	stays/ha	4	4	4	2	0	0	0	0	0	0	0	0	0	1	1	0	3

Table 4.2.1 Biophysical ecosystem service supply account 2013 for the Netherlands, with total biophysical supply per province

Ecosystem service \ Province	Unit	Groningen	Friesland	Drenthe	Overijssel	Flevoland	Gelderland	Utrecht	Noord-Holland	Zuid-Holland	Zeeland	Noord-Brabant	Limburg	Netherlands
Area[1]	ha	238,959	352,786	268,033	340,527	146,609	511,786	144,291	285,761	305,507	183,387	505,311	220,967	3,503,923
Crop production	ktons	2,178	590	1,950	310	2,605	611	71	1,067	1,241	2,429	2,010	1,199	16,259
Fodder production	ktons	786	1,839	1,258	2,657	216	2,879	557	591	562	330	3,353	1,012	16,039
Wood production	1000 m3	16	48	122	106	75	292	54	46	18	9	209	88	1,085
Biomass production	ktons	23	25	24	25	21	41	19	43	46	19	47	26	358
Drinking water production	mln m3	1	14	32	49	0	77	31	67	75	3	32	31	413
Carbon sequestration in biomass	ktons	38	90	81	100	36	216	47	60	41	30	163	73	975
Pollination	ktons	6	4	6	3	48	118	38	47	24	51	94	95	534
Natural pest control	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Erosion control	ktons soil	171	334	243	374	82	1,053	248	392	293	170	545	978	4,885
Air filtration	tons PM10	777	1,258	1,861	2,417	877	5,650	1,209	1,165	982	629	4,902	2,107	23,834
Protection against heavy rainfall	mln ltr in 1 hour	44,842	67,017	80,544	107,805	23,926	176,331	33,035	53,929	37,205	30,710	181,528	67,806	904,677
Nature recreation (hiking)	mln hikers	818	1,125	893	1,675	583	3,151	1,672	3,370	4,263	1,007	3,240	2,264	24,060
Nature tourism	1000 stays	134	1,288	1,134	1,073	184	2,391	302	1,259	582	2,166	834	1,364	12,711

Table 4.2.2 Biophysical ecosystem service supply account 2013 for the Netherlands, with mean biophysical supply per ha per province

Ecosystem service \ Province	Unit	Groningen	Friesland	Drenthe	Overijssel	Flevoland	Gelderland	Utrecht	Noord-Holland	Zuid-Holland	Zeeland	Noord-Brabant	Limburg	Netherlands
Area[1]	ha	238,959	352,786	268,033	340,527	146,609	511,786	144,291	285,761	305,507	183,387	505,311	220,967	3,503,923
Crop production	tons/ha	9.1	1.7	7.3	0.9	17.8	1.2	0.5	3.7	4.1	13.2	4.0	5.4	4.6
Fodder production	tons/ha	3.3	5.2	4.7	7.8	1.5	5.6	3.9	2.1	1.8	1.8	6.6	4.6	4.6
Wood production	m^3/ha	0.1	0.1	0.5	0.3	0.5	0.6	0.4	0.2	0.1	0.0	0.4	0.4	0.3
Biomass production	tons/ha	0.10	0.07	0.09	0.07	0.14	0.08	0.13	0.15	0.15	0.10	0.09	0.12	0.10
Drinking water production	m^3/ha	223	4,012	11,958	14,370	0	15,111	21,500	23,576	24,424	1,841	6,398	14,217	11,791
Carbon sequestration in biomass	tons/ha	0.2	0.3	0.3	0.3	0.2	0.4	0.3	0.2	0.1	0.2	0.3	0.3	0.3
Pollination	tons/ha	0.03	0.01	0.02	0.01	0.33	0.23	0.26	0.16	0.08	0.28	0.19	0.43	0.15
Natural pest control	%	0.8	0.3	2.2	1.2	1.7	1.0	0.5	0.3	0.2	0.6	2.1	2.7	1.2
Erosion control	tons soil/ha	0.7	0.9	0.9	1.1	0.6	2.1	1.7	1.4	1.0	0.9	1.1	4.4	1.4
Air filtration	kg PM_{10}/ha	3.3	3.6	6.9	7.1	6.0	11.0	8.4	4.1	3.2	3.4	9.7	9.5	6.8
Protection against heavy rainfall	mm/m^2 in 1 hour	19	19	30	32	16	34	23	19	12	17	36	31	26
Nature recreation (hiking)	1000 hikers/ha	3	3	3	5	4	6	12	12	14	5	6	10	7
Nature tourism	stays/ha	0.6	3.7	4.2	3.2	1.3	4.7	2.1	4.4	1.9	11.8	1.7	6.2	3.6

[1] The surface area is excluding large water bodies such as the sea and the IJsselmeer since this report focusses on terrestrial ecosystem services. Including large water bodies in the total area would distort the average rates per province. For this reason, differences in extent are present between this table and table 4.1.1 and 4.1.2 which are based on the Ecosystem Type map (which includes large water bodies).

[2] Pest control cannot be added in this table due to set-up of the indicator. It is added in table 4.2.2, however.

Table 4.2.3 Summary of relative supply in providing ecosystem services per province.

	Highest	Second highest	Lowest	Second lowest
Crop production	Flevoland	Zeeland	Utrecht	Overijssel
Fodder production	Overijssel	Noord-Brabant	Zeeland	Zuid-Holland
Wood production	Gelderland	Flevoland	Zeeland	Zuid-Holland
Biomass production	Noord-Holland	Zuid-Holland	Friesland	Overijssel
Drinking water production	Zuid-Holland	Noord-Holland	Flevoland	Groningen
Carbon sequestration in biomass	Gelderland	Limburg	Zuid-Holland	Groningen
Pollination	Limburg	Flevoland	Overijssel	Friesland
Natural pest control	Limburg	Drenthe	Zuid-Holland	Noord-Holland
Erosion control	*(erosion control is only delivered by specific areas)*			
Air filtration	Gelderland	Noord-Brabant	Zuid-Holland	Zeeland
Protection against heavy rainfall	Noord-Brabant	Gelderland	Flevoland	Zeeland
Nature recreation (hiking)	Zuid-Holland	Noord-Holland	Friesland	Drenthe
Nature tourism	Zeeland	Limburg	Groningen	Flevoland

For a more balanced comparison of ecosystem services per province and the explanations for these differences, it would be necessary to compare not only services supply (per ha), but to also include information on a range of ecosystem condition indicators, the carbon balance and biodiversity, as well as data on e.g. population density and the density and distribution of paved surfaces (buildings, roads, other structures)[4].

4.3 Biophysical use account

The ecosystem services that are supplied by different ecosystems in the Netherlands are used by a variety of economic sectors (table 4.3.1).

The Agriculture, forestry and fisheries sector (ISIC sector A) uses the largest number of ecosystem services. Five ecosystem services are fully allocated to this sector (crop production, fodder production, wood production, pollination and pest control), and the sector is the largest user of the ecosystem service erosion control. Pollination and pest control cannot be quantified in the use account, as these ecosystem services have been modelled using a relative measure. We assume that biomass production is used entirely by the Energy production sector (ISIC sector D), although some biomass can also be used for other purposes. The ecosystem service drinking water production is used entirely by the Water supply sector (ISIC sector E) to produce clean drinking water. Some industries, such as the beverage industry also use groundwater to produce drinking water. However, this often comes from private wells that were not included in our model. Carbon sequestration is considered as a global good that has a global benefit. Therefore, the use of this ecosystem service was allocated to a separate column.

The ecosystem services erosion control and protection against flooding due to heavy rainfall were allocated spatially, based on land ownership. The Agriculture, forestry and fisheries sector and

[4] Compilation of these data is currently well underway within the context of the current project, as well as in two related project funded by Eurostat.

Government own the largest land areas (agricultural land and most forest and nature areas), and therefore use over 80% of both these services.

Use of the ecosystem services air filtration and recreational hiking was allocated entirely to households, as the inhabitants of the Netherlands are the prime beneficiaries of these services. Tourism was allocated to the Accommodation and Recreation sector (ISIC sectors I and R), as these economic sectors benefit from tourists staying overnight.

Table 4.3.1 Biophysical ecosystem service use account 2013 for the Netherlands, with total biophysical use per economic user (ISIC)

Ecosystem service \ Economic users (ISIC)	Unit	A - Agriculture, forestry and fishing	B,C - Mining and manufacturing	D - Electricity	E - Water supply	F-H - Contruction, wholesale and transportation	I,R - Accommodation and food service, culture, sports and recreation	Other sectors	Export	Households	Government	Investments	Inventories	Environment (Global goods)	Total
Crop production	ktons	16,259													16,259
Fodder production	ktons	16,039													16,039
Wood production	1000 m3	1,085													1,085
Biomass production	ktons			360											360
Drinking water production	mln m3				413										413
Carbon sequestration in biomass	ktons													975	975
Pollination	ktons	534													534
Natural pest control	-	x													x
Erosion control	ktons soil	1,880	30	0	26	158	129	60		277	2,328				4,888
Air filtration	tons PM10									23,843					23,843
Protection against heavy rainfall	mln ltr in 1 hour	505,633	2,001	43	689	13,665	22,352	12,255		59,861	286,629				903,127
Nature recreation (hiking)	mln hikers									24,060					24,060
Nature tourism	1000 stays						12,916								12,916

4.4 Accounting for supply over time - pilot

To test whether ecosystem services can be monitored over time using the current models, two ecosystem services models were applied to data for the year 2006; wood production and air filtration.

The regulating service air filtration depends on the concentration of air pollutants and the total leaf area on which PM_{10} can be captured. Between 2006 and 2010 the mean yearly ambient PM_{10} concentration reduced from 27.0 µg m^{-3} to 19.7 µg m^{-3}. Consequently, the service air filtration was lower in 2013 than in 2006 (table 4.4.1 and figure 4.4.1). In 2006 a total of 32,740 thousand kg PM_{10} was captured, while in 2013 23,789 thousand kg PM_{10} was captured by vegetation in the Netherlands. This resulted in a total reduction in the capture of PM_{10} of approximately one third, which was present in all provinces and in all ecosystem types. This is a highly interesting result; the data show that less of the service is provided, which –without knowledge on the processes behind the numbers – may be interpreted as a negative development. However, the reduction in the service supply is due to improved air quality, which is generally considered a positive development. However, a similar result would have been achieved if the reduction of the air filtration service would have been caused by deforestation (under constant ambient PM_{10} concentrations). This poses an interesting challenge to the accounting approach, because in a full set of ecosystem accounts, reduced service supply may result in a lower value of the delivered services and hence of the total stock of natural capital. This example highlights the importance of transparency in the applied models, so that causes underlying trends can be analysed and interpreted in a meaningful way.

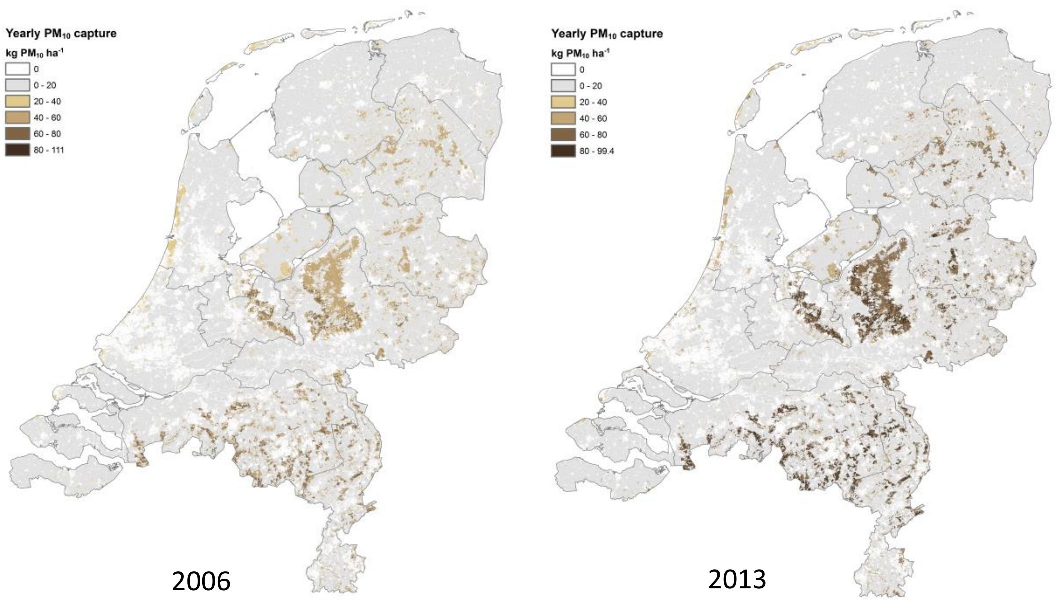

Figure 4.4.1 Capture of PM_{10} in kg PM_{10} per hectare by vegetation in the Netherlands in 2006 (left) and 2013 (right).

Harvest of timber (used as a proxy for wood production) in the “meetnet functievervulling” MFV (forest monitor between 2001-2005) and “Zesde Nederlandse bosinventarisatie” NBI6 (forest monitor between 2012-2013) was estimated based on size, age and species of trees in the sampled plot (Schelhaas et al., 2014). The mean harvest and total harvest for the Netherlands as a whole was relatively stable (table 4.4.2 and figure 4.4.2). Both in the MFV and in the NBI6 harvest of coniferous trees was approximately one-third more than the harvest of deciduous trees. Hence, the wood production service is stable in the years considered here.

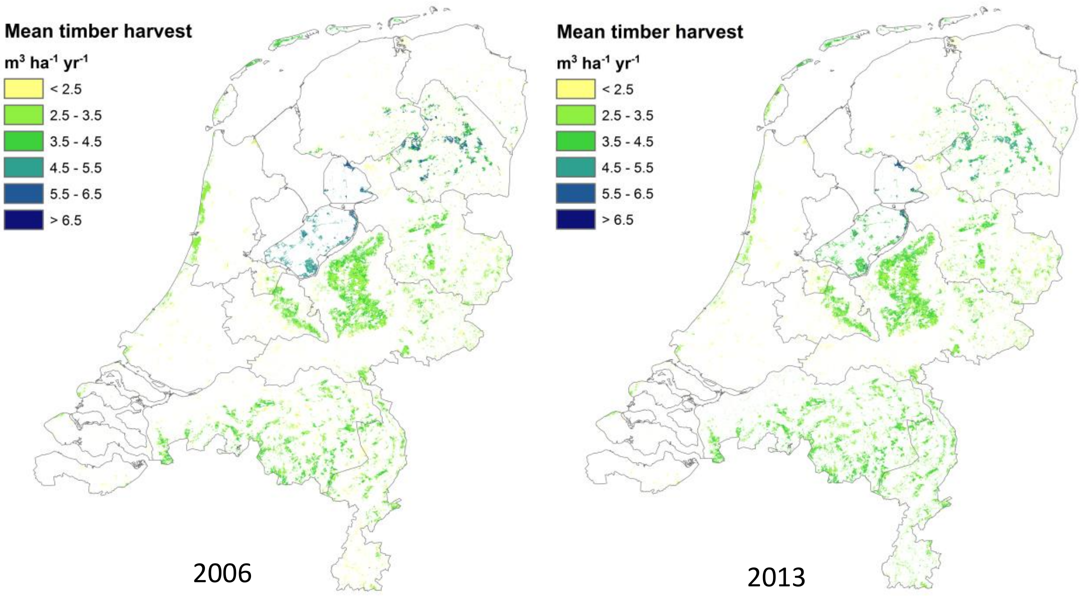

Figure 4.4.2 Mean timber harvest in m^3 timber per hectare in 2006 (left) and 2013 (right). Based on the estimated harvest of the MFV, respectively the estimated harvest of the NBI6.

Table 4.4.1 Mean yearly capture op PM_{10} (kg/ha)) and total yearly capture of PM_{10} (1000 kg) per **a)** province and per **b)** ecosystem type

(a)	**Mean**		**Total**	
Province	**2006**	**2013**	**2006**	**2013**
Groningen	4.7	3.2	1,130	772
Friesland	5.1	3.6	1,792	1,254
Drenthe	10.1	7.1	2,694	1,893
Overijssel	10	7.1	3,389	2,403
Flevoland	8.7	6.1	1,280	898
Gelderland	14.9	11	7,615	5,607
Utrecht	11.4	8.3	1,644	1,197
Noord-Holland	5.6	4.1	1,605	1,165
Zuid-Holland	4.4	3.1	1,330	951
Zeeland	4.8	3.5	877	638
Noord-Brabant	13.1	9.7	6,640	4,894
Limburg	12.4	9.6	2,745	2,116
Netherlands	9.3	6.8	32,740	23,789

(b)	**Mean**		**Total**	
Ecosystem type	**2006**	**2013**	**2006**	**2013**
Non-perennial plants	4.8	3.5	3,841	2,732
Perennial plants	4.9	3.6	362	287

Greenhouses	0	0	0	0
Meadows (grazing)	4.8	3.5	4,615	3,241
Bushes and hedges bordering	4.8	3.5	77	127
Farmyards and barns	0	0	0	0
Dunes with permanent vegetation	41.4	29.1	567	463
Active coastal dunes	0	0	0	0
Deciduous forest	50.9	37.2	5,604	4,063
Coniferous forest	83.6	61.2	7,580	5,013
Mixed forest	67.2	49.2	7,217	5,834
Heath land	4.9	3.5	187	144
Inland dunes	0	0	0	0
Fresh water wetlands	4.6	3.3	142	114
(semi) Natural grassland	4.8	3.5	205	190
Public green space	5	3.6	345	250
Other unpaved terrain	4.9	3.6	1,647	1,066
River flood basin	4.9	3.8	365	276
Salt marsh	0	0	0	0
Build-up and paved areas	0	0	0	0
Water	0	0	0	0

Table 4.4.2 Mean yearly timber harvest (m^3/ha) and total yearly timber harvest (1000 m^3) per **a)** province and per **b)** forest ecosystem type.

(a)	**Mean**		**Total**	
Province	**2006**	**2013**	**2006**	**2013**
Groningen	2.3	2.7	13	16
Friesland	3.1	3.4	40	48
Drenthe	3.6	4.0	108	122
Overijssel	3.2	3.1	109	106
Flevoland	4.6	5.3	68	75
Gelderland	3.4	3.3	298	293
Utrecht	3.3	3.2	56	54
Noord-Holland	2.8	2.7	44	46
Zuid-Holland	2.6	2.4	19	18
Zeeland	2.7	2.4	9	9
Noord-Brabant	3.6	3.2	237	209
Limburg	3.5	3.0	99	88
Netherlands	3.4	3.3	1,100	1,085

(b)	**Mean**		**Total**	
Ecosystem type	**2006**	**2013**	**2006**	**2013**
Coniferous forest	4.3	4.2	392	348
Broad-leaved forest	2.7	2.7	295	289
Mixed forest	3.5	3.4	372	398
Dunes with permanent vegetation	3.1	3.1	42	50

5 Discussion

Here we present a spatially explicit, national scale biophysical supply and use account for ecosystem services for the Netherlands. It follows the SEEA EEA and SEEA EEA TR and as such, it is the first national scale application of this method. The study shows that many ecosystem services can be modelled in a manner that is consistent with SEEA EEA requirements, based on available data but, in several cases, requiring additional models in order to develop national scale maps and accounts.

This report builds on the experiences of an earlier pilot project in Limburg (funded by both the European Research Council and the Ministries of Economic Affairs and Infrastructure and Environment), and it shows marked improvements from the pilot project. A larger number of ecosystem services have been modelled (13 compared to 8 in the case of Limburg, 2 of which were discontinued (meat from game, cycling recreation); here we introduce 7 completely new models), at the national (and not provincial) scale. In all models we have used better data and improved the models. This was partly possible because of other national ecosystem service modelling efforts such as the Atlas of Natural Capital, the National Forest Inventory update and access to higher quality data (including satellite data) than in the pilot study. Data from these studies were used to produce the pilot national scale ecosystem services supply and use accounts of this report.

5.1 Interpretation of results

Discussion of ecosystem service models and uncertainties

We strived to develop models with the best available data and models, by using existing statistics and available maps. For instance, the map Basisregistratie Gewaspercelen 2013 for the location of specific crops in the Netherlands and regional statistics on harvest were used to map the ecosystem service crop production. For some services, such as air filtration and pollination, detailed information was not available. Here, we used models based on relevant data from scientific literature and Dutch reports to map the service. The uncertainty in these models is therefore higher, however, they are still very useful, for example as a tool to compare changes in ecosystem services between years. Some of the models presented here represent a first attempt at modelling these services. An example is the model for pest control. When new information, maps or models become available maps and tables of these services can be updated. This was already done for e.g. biomass production and fodder production, where Net Primary Productivity (based on remote sensing data) was implemented in the models.

Almost all maps cover the whole of the Netherlands, which means that data is available at national, provincial and regional level. However, uncertainties increase when the results are analysed at a local scale. For example, the models for fodder production and tourism have input data which were only available on provincial level. By applying modelling techniques a map was created with a higher level of spatial detail. However, downscaling of information creates uncertainty. All models presented here are based on the Ecosystem Type map, or use the Ecosystem Type map to attribute services to ecosystem types. Hence, uncertainties and error sources that are present in the Ecosystem Type map are incorporated in all models. However, the level of detail in the Ecosystem Type map was assumed to be sufficient to allow for interpretations at the national down to regional scale. Interpretation of maps and results at the regional – local scale are prone to a higher uncertainty, due to uncertainties in the map, and moreover, due to the lower spatial resolution of a range of other data used to calculate all the different models. As stated before, downscaling of data creates unknown uncertainties when looking at local scales. It is beyond the scope of the current report to discuss these uncertainties in detail, because they differ per ecosystem service model and per ecosystem type.

Finally, not all existing ecosystem services in the Netherlands could be included in this study. First, we only include services delivered in the terrestrial realm; services provided by inland and coastal waters were not included. Next, for practical reasons, a number of services could not be included here, such as recreation (other than hiking), bird watching, berry and mushroom picking and educational services. Symbolic or religious ecosystem services were not included either. The ecosystem services selected in this study therefore do not present the full range of ecosystem services in the Netherlands. As more data and models become available, the number of ecosystem services that can be included in future studies will increase.

Discussion of ecosystem services supply and use account

Presentation of the results in the supply and use tables gives a good overview and allows for detailed comparison between different ecosystem types, regions and ecosystem services. However, there are a few drawbacks from such tables. First, not all ecosystem services can be analysed in a set up that fit the table. For example, pest control uses an indicator based on percentage coverage. Therefore, they cannot be added in the tables that present the total services (tables 4.1.1 and 4.2.1) and can only be shown in the tables with average production rates (tables 4.1.2 and 4.2.2). Currently, efforts are made to improve these ecosystem service models so they can be included in the tables.

The supply tables of the account record the average rates of supply of ecosystem services per ha (tables 4.1.2 and 4.2.2). First, it should be noted that the average supply rates are influenced by the ecosystem types present in each province. Specific ecosystem types generate specific services. As mentioned previously, a large number of ecosystem services are primarily delivered by woodland areas. Hence, the total delivery of ecosystem services is strongly biased towards regions with high proportions of woodland.

Tables 4.1.2 and 4.2.2 do not show how effective ecosystem types in a specific province are in generating ecosystem services in comparison to other provinces. Such information can be provided based on the currently developed account, in case this would be requested by provinces. However, to interpret these provincial differences in 'effectiveness', it would be necessary to also provide provincial scale data and maps on ecosystem extent, condition, and biodiversity; regions may 'score' relatively low on food and fodder production due to less efficient agricultural practices, which may be accompanied by a much higher biodiversity (and possibly, but not necessarily a higher 'score' for nature tourism). Thus, comparisons of ecosystem services supply between regions need to be interpreted with great caution, and using the full array of data that will become available within this project.

Ecosystem services and the SNA

Further clarification on the concept of ecosystem services is relevant for two specific aspects;1) the way ecosystem services underpinning the production of commodities including crops and timber have been analysed, and 2) the way biodiversity is included in the account and the relation between biodiversity and ecosystem services. Both are complex topics which have been subject to major debate in the context of the SEEA EEA development. Given the state of these discussions, choices had to be made for this Dutch account. These choices are clarified below.

In terms of ecosystem services in relation to the production of crops, timber, etc., the SEEA (and the SNA) distinguish between SNA and non-SNA benefits, i.e. benefits that are already measured in the national accounts (such as crop production) and benefits that are not (such as air filtration). There is also a distinction between natural (e.g. a natural forest) and managed ecosystems (e.g. a plantation). Discussions on how to define ecosystem services in this context are on-going in the SEEA community. In the Dutch study, it was chosen not to differentiate between natural and managed ecosystems because more or less all ecosystems in the Netherlands are (strongly) managed by people. We also follow the definition of an ecosystem service very strictly, i.e. a service is the contribution of the ecosystem to a benefit. In the case of crop production, the service involves the regulation of water and nutrient flows in the farmer's field, so that the farmer has a conducive environment for crop production. Unfortunately, the overall number of soil, hydrological and biological processes involved is very large (including absorption and release of nutrients, rain worm activity, in-situ insect activity, etc.) – and this myriad of processes cannot be individually measured and aggregated, especially not at the national scale. Therefore, the production of crops (expressed in tons of produce) is used as a proxy for the service (in line with the SEEA EEA TR).

Ecosystem services and biodiversity

On biodiversity, this has also been a much debated topic in the SEEA community. Even though discussions are not yet finalised, the most recent thinking as expressed in the various drafts of the SEEA EEA TR is that biodiversity is akin to a stock and not a service, since conservation or enjoyment of biodiversity does not involve consumption, nor any kind of flow. As widely acknowledged, valuing the non-use value of stocks of biodiversity is challenging, and there are further challenges in integrating such value estimates into an accounting setting. Therefore, while recognising that discussions are on-going, the Dutch approach has been that biodiversity is not included in the services supply and use account but that, in line with the SEEA EEA TR, a separate biodiversity account was developed. This account is only in physical not in monetary units. It aims to express biodiversity in indicators that highlight the aspects that are important for the conservation of biodiversity, with specific reference to the non-use values of biodiversity (because use values are captured in the ecosystem services supply and use account, e.g. values related to recreation or tourism). In addition, it will be examined if there are specific functional aspects of biodiversity that can be included in the ecosystem condition account (e.g. presence of keystone species, or species indicative of environmental quality).

Data availability and reproducibility

All models can be run for future years, provided that updated data are available. The reproducibility of the models is high, many of the models use data and maps that are updated yearly (e.g. Basisregistratie Gewaspercelen, harvest projections, Landelijk Grondwater Register, ambient PM_{10} concentration, tourism accommodations and beds). In some cases datasets are not freely available and require sufficient funding for regular updates (e.g. recreation and tourism data [CVTO and CVO]). Other data is only available in longer time cycles. For example, the forest monitor takes place once every five to six years. Therefore, data is not always available for the exact year of the account. However, models are available on the expected change in forests that would allow updating the accounts also in intermediate years, and alternatively, remote sensing may be a future source of high-quality data on vegetation (forest, fodder production, biomass, etc.) development.

We also used several maps that are produced for the Atlas of Natural Capital (ANK). The map of the Net Primary Production (remote sensing data) was used for the services fodder production and biomass production, and the tree, shrub and grass cover maps were used for the service protection from flooding. In addition, for one of the analysed services a model from the ANK was used (erosion control), even though we believe this model requires further updating.

For some models, there is a need to consider how they can be improved in the future, also on the basis of potential new data. For example, the model on biomass production could be extended if more data are available. The current method focusses on biomass as a whole, from areas which that have limited economic or ecological purpose. Further data on where specific types of biomass are produced, and for what purposes they are used (e.g. raw material for production, building purposes or fuel) would increase the information content of the biomass production model in the ecosystem accounts.

5.2 Future developments for the supply and use account

It is important to place the development of this pilot ecosystem services account into context. There is a global drive (including in the EU) towards better accounting for natural capital, changes therein over time, and its uses in the economy. The reason for this is that it is increasingly recognised that natural capital is becoming scarcer with on-going degradation of ecosystems and that this will have economic consequences (and in many situations, is already having economic consequences). In a comparable fashion, the national accounts were developed as off the 1930s following the major economic and financial crisis that hit the world at the time. Development of the national accounts took several decades, but building upon the experiences with accounting (and the modelling of ecosystem services) to date the development of ecosystem accounts, and a standard for this, should take much less time (UNSD hopes to produce a standard for ecosystem accounting by 2020). However, to produce such standards, the experience gained in specific case studies is critically important. The experiences gained in this project are therefore relevant for all other countries interested in the same approach.

From the experience of this first national study, we have several recommendations on where improvements can be made. The supply account is generally more advanced than the use account, as most ecosystem service models focus on modelling supply. With regards to use, ecosystem service use has now generally been attributed to a single user group, while in practice other user groups may also profit. As the use table presents an important link to the system of national account, this should be further developed in the future. With the current account, already the contribution of goods and services (in biophysical units) to the Dutch economy can be analysed. However, true integration (i.e. connecting natural capital and national accounts) requires also their analysis in monetary terms, which will be experimented with in the coming phase of this project.

For the current report, we decided to incorporate crop production as an 'overarching service' contributing to agricultural production, and to present pollination as an intermediate service. This is in line with the forthcoming SEEA EEA TR. Hence the study not only includes final ecosystem services but also tests how intermediate ecosystem services (pollination, pest control) can be included in the accounts. This is important because spatial planning tends to overlook the benefits derived from small landscape elements that provide these intermediate services. The present account shows that small landscape elements such as hedgerows and small forest patches are very important for crop production because of the pollination and pest control services that they provide. Further intensification of the Dutch landscape may jeopardize these services.

A number of ecosystem services that are (potentially) important for the Netherlands were not modelled for this report, for various reasons. A highly relevant ecosystem service for the Netherlands is protection against flooding from rivers and the sea (dunes, floodplains). Flooding in the Netherlands is highly regulated through an intricate man-made protection system, consisting of sluices, dykes and dams. Ecosystems play a role in the protection against flooding from rivers by providing space between the dykes for water to drain to the sea. The exact protection by the ecosystems in a certain location is, however, complex to quantify and to separate from human management, which is omnipresent in the Dutch river system. Further discussion with the relevant authorities is necessary for this ecosystem service, to determine a useful and practical indicator.

Another water related ecosystem service that is not included in this report is coastal protection (by dunes). This ecosystem service was planned to be adopted from the ANK. However, at the time of writing the model was not fully finished and could therefore not be used for analysis. This model will be available for future supply and use accounts.

Additionally, compared to the report for Limburg, the ecosystem service hunting was not included. Data for hunting is not collected at national scale, and is only available if they are collected by local hunting associations and wildlife units. To develop a reliable national model considerable effort would need to be made to assemble a representative dataset on hunted species. Data would need to be collected for each hunting association (and be dependent upon the willingness of each association to provide the data). It was therefore decided not to include this service at the national scale. However, given that hunting (using nature areas to produce organic meat) and the collection of various fruits and nuts are services that facilitate connecting people to nature (and that thereby also have recreational and educational value) it is recommended to consider them in potential future updates of the accounts.

In future accounts, additional ecosystem services can be incorporated with the help of other national projects carried out by large Dutch institutes (RIVM, PBL, RVO).

Finally, this study has brought to light that improvements can be made on the Ecosystem Type map and the underlying classification. The current ecosystem type classification contains a broad set of classes for offices and built-up areas, while some important distinctions in more natural ecosystem types are missing. For example, in dune areas a differentiation between forest on dunes and shrubs on dunes would improve all forest-related ecosystem service models, whereas they are now taken together as non-active (vegetated) dunes and active (sand) dunes. In addition, detailed maps on tree cover (including individual trees) have now become available (in the ANK, developed by RIVM), whereas CBS is currently developing a detailed map showing all paved surfaces (including e.g. paved terraces on private property). The incorporation of such information in the Ecosystem Type map would greatly improve the level of detail to which individual ecosystem models can be relied upon.

5.3 Policy applications

During the development of the supply and use account, discussions were held with the Ministry of Economic Affairs, the Ministry of Infrastructure and Environment and a stakeholder group, in part to address potential policy applications. These discussions will continue throughout the further duration of the Dutch ecosystem accounting project. Discussions with a variety of stakeholders are essential to better understand the uncertainties and accuracies of the accounts and will be facilitated by the on-going production of the various accounts. In this section a first overview of potential policy applications is presented. Note that policy applications will further increase with the publication of the monetary ecosystem services supply and use account, in which case also for instance trade-off analyses will be facilitated. This will be reported on when that account is also finalised.

A major factor driving the applicability of the information is how the information is made available to potential users. In addition, the applicability of the information depends upon if it is available for one year only, or if there are also time series of natural capital. Following the SEEA EEA TR, having data for multiple years greatly enhances policy uses. Time series (which can be developed on national but also on smaller spatial scales) can be compared to policy measures as well as economic and social developments and indicate how ecosystem services and natural capital are changing over time (and if we are currently using them in a sustainable manner). Nevertheless, clearly, also the current account has a number of important policy uses (all to be determined and tested with stakeholders during the course of the Dutch ecosystem accounting project).

The data on services supply and use for a single year, as presented in this study, help to identify economic dependencies on ecosystem services and the location and relative importance of contributors to ecosystem service supply. More specific, the data from the physical supply and use tables could be used for the following purposes. It should be noted that this list is by no means extensive:

a. Identifying important ecosystem types that supply services and important user groups

The primary application of the biophysical supply and use tables is to identify how much of each ecosystem service is being supplied by the different ecosystems and who are using these services. Providing a comprehensive overview of both supply and use of ecosystem services gives a range of stakeholders a basis for a broad pallet of potential decisions. Discussions with stakeholders revealed that several provinces, for instance, have an interest in better understanding natural capital within their province boundaries. This information is directly relevant for planning purposes, for example in the context of discussions on further agricultural intensification. Regarding ecosystem service supply, the ecosystem types that are most important for supplying the services can easily identified, both with regard to the total services provided as the amount of service provided per hectare. As an example for supply, the number of hikers for different ecosystem types (nature recreation) is shown in figure 5.3.1. (Semi) natural environments attract most hikers in the Netherlands, followed by forests. However, dunes and beaches, forests and heath and inland dunes have the highest number of hikers per hectare. Agricultural lands have a low number of hikers per hectare.

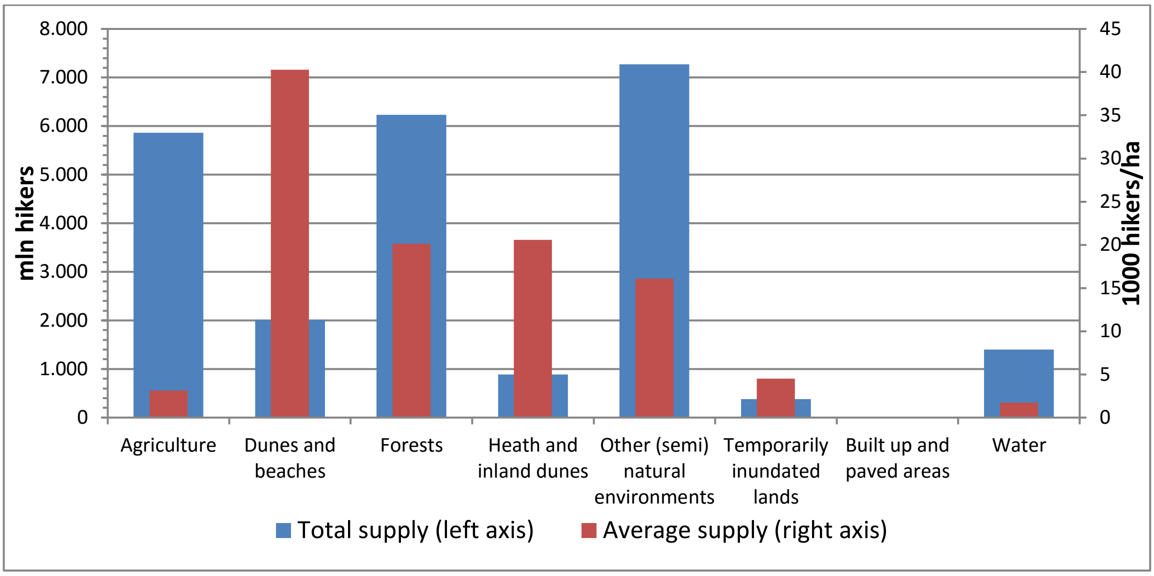

Figure 5.3.1 Number of hikers per ecosystem type, in absolute amount and hikers per hectare (see also table 4.1.1 and table 4.1.2).

Data from the biophysical use tables indicates who benefits from the ecosystem services that are provided. This is important to determine stakeholders in decision making processes, among others. Also, this information will indicate what economic sectors will be affected when the supply of these services might, for whatever reason, decrease. Figure 5.3.2 shows which economic sector benefit most from erosion protection. Agriculture and government are the main 'users' of this service, as they own most of the land that is affected by the service, followed by households and the service sector.

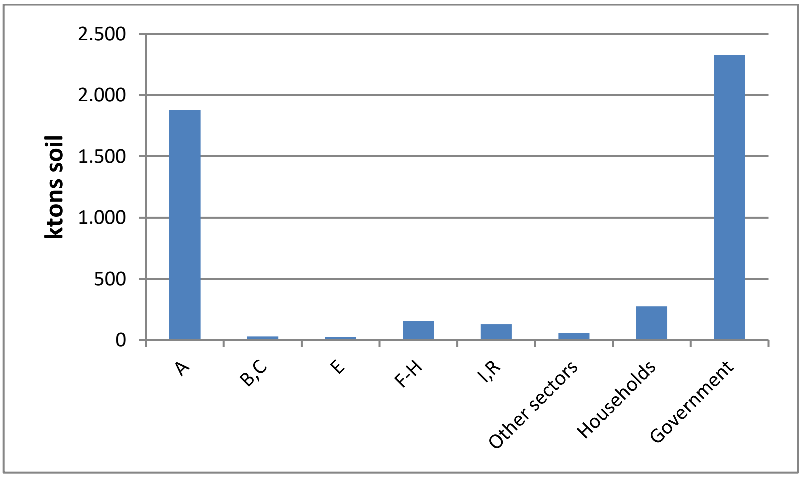

Figure 5.3.2 Economic sectors that are users of the ecosystem service erosion control (see also table 4.3.1).

b. Supporting spatial planning at different scales.

For large national infrastructure projects, provincial infrastructure projects, nature conservation programs, or for municipal infrastructure or residential projects the accounts show which areas *currently* provide a great number of ecosystem services and thereby contain high stocks of natural capital, and which should as much as possible be avoided in planning new investments involving land use change. The accounts also provide base information, for example, for comparing different trajectories of a highway in terms of their impacts on natural capital and thereby on people and the economy. For both examples, it is essential to include the biodiversity maps and accounts that are being produced in the current project. An additional concrete example of how the accounts present new insights is in the contribution of small landscape elements to crop production, through the supply of pollination and pest control services. Such information should be considered in spatial planning in rural areas, since maintaining these types of natural capital is very relevant for economic production.

c. The accounts show the specific contributions that different (economic) sectors receive from ecosystems.

The biophysical supply table shows how much services are supplied by the different ecosystems. Accordingly, the ecosystem types that are most important for providing ecosystem services can easily be identified, both with regard to the total services provided as the amount of service provided per hectare. For example, there is a high awareness that pollination and natural pest control are important for agriculture, and that forests and dunes are important in support of tourism. However *how* important the ecosystems that provide these services are was, until publication of these accounts, unknown. For instance, the accounts show how many overnight stays are generated in coastal municipalities because of the presence of the dunes as an area for recreation and tourism. And – once the monetary accounts have been developed (in 2018) – for example what the costs would be of converting these areas to other uses (e.g. building houses in the dunes). For instance, the accounts specify the dependency of the tourism sector on ecosystems. The maps specifies in physical units (number of overnight stays) the contribution the various ecosystems in the landscape provide to hotels, camping places, etc. – if these ecosystems would be lost or converted this would have immediate consequences for the sector. The monetary accounts under development will also show subsequent economic implications. The accounts also permit identifying areas that have an underdeveloped potential for tourism, e.g. a high attractiveness for tourism and recreation and a relatively low number of hotels. Because of their high level of detail, the accounts facilitate a large number of policy applications – for instance a possible application would be to identify where the construction of new holiday houses would have minimal impact on ecosystems and the services they provide, and where such construction would have major impacts and new recreational complexes should be avoided.

d. **The accounts present opportunities to move towards a circular economy.**

Developing a circular economy is becoming an increasingly important policy goal. Insight in the supply and use of ecosystem services can provide extra knowledge on whether these goals are being reached through use of natural capital. Provisioning services such as wood production and biomass production can contribute directly to the development of a circular economy and the supply and use of such services is monitored in this ecosystem account. For example, the accounts show potential areas where additional biobased materials can be harvested (e.g. biomass from roadsides or forest biomass) in sustainable manners (i.e. where the regrowth considerably exceeds current harvest rates). This shows where the flows from the ecosystems to the economy can be increased, without depleting the ecosystem for this particular ecosystem service[5]. For example, in the case of timber between 30% and 50% of the mean annual increment is harvested in the different provinces of the Netherlands. The account also specifies the amount of 'other biomass' e.g. from road sides that can be harvested, to be used for example for energy production from biomass. Appendix 3 presents a detailed explanation of how natural capital accounting contributes to moving towards a circular economy.

e. **The accounts facilitate comparison between different parts of the country, e.g. identifying areas that are particularly successful in protecting natural capital, or extracting revenue from natural capital.**

The supply account shows that Limburg provides relatively high amounts of nearly all ecosystem services per ha, while supply in Friesland is lower than the national average for nearly all ecosystem services. This shows that the spatial constitution of Limburg, with small agricultural parcels, relatively many forest areas and many landscape elements, provides a better environment for the supply of ecosystem services than the open landscape of Friesland. To improve the supply of multiple ecosystem services, Friesland could profit from increasing the amount and density of landscape elements such as hedgerows and forest patches. Nevertheless, the supply of ecosystem services will always remain somewhat different between Friesland and Limburg, given the topographical differences. Also, information from the supply and use account is not the only type of information required for planning the use of natural resources. For instance, people in Friesland (and other parts of the country) may appreciate the open landscapes rather than the more heterogeneous landscape of Limburg. Also some parts of biodiversity (e.g. farmland birds (*weidevogels* in Dutch)) may benefit from open landscapes without forest patches. Hence, the information in the accounts should always be put in context, and seen as covering one specific element of the various criteria in decision making.

Finally, it is important to note that the biophysical supply and use tables for ecosystem services are part of the overall framework of ecosystem accounting. These tables should thus also be analysed in combination with other accounts, such as the condition account, biodiversity account, asset account and monetary supply and use tables, which provides additional policy applications. These analyses will be done during a later stage of the Dutch ecosystem accounting project.

[5] The potential impact of increased harvest on other ecosystem services is not taken into account in this study.

6 Conclusion

This report shows that a national biophysical supply and use account for a wide range of ecosystem services can be developed, and many ecosystem services can be modelled in a manner that is consistent with SEEA EEA requirements. In this report 13 terrestrial ecosystem services were accounted for with high resolution spatial models. The breadth and depth of the ecosystem service models has improved compared to the pilot project for Limburg, often with improved input data. This has in part been possible because of other national ecosystem service modelling and data collection efforts such as the Atlas of Natural Capital, and the National Forest Inventory update. Given continued developments in (national) ecosystem service models, more ecosystem services can be accounted for in the near future.

A complete biophysical supply and use account was developed for the Netherlands, were supply equals use by definition. Biophysical supply tables were developed that account for ecosystem services for 32 ecosystem types and for all Dutch provinces. The biophysical supply tables show that forests and agricultural land supply the highest total quantities of ecosystem services, in part because agricultural ecosystem types cover the largest extents. More natural ecosystem types (e.g. dunes, heath and deciduous forest) supply higher average quantities of ecosystem services (per ha). The supply of ecosystem services from Dutch provinces is highly heterogeneous, with each province providing a different set of services, in part due to differences in dominant ecosystem types. Limburg has the highest supply of ecosystem services, on a per hectare basis.

The biophysical use table reflects which economic sectors are most important for using each ecosystem service. The use of ecosystem services erosion control and protection against flooding from heavy rainfall could be allocated to sectors based on land ownership. The ISIC sector Agriculture, forestry and fisheries uses the most ecosystem services (seven), followed by households (four). The ecosystem service models that were developed for the biophysical supply and use account form an important basis for other ecosystem service accounts, such as the monetary supply and use account and the ecosystem asset account

Not all ecosystem services could be fully incorporated in all supply and use tables in their current modelled form. For example, the indicators for natural pest control were modelled as relative quantities, and could therefore not be summed up. The indicator for protection from flooding by heavy rainfall was quantified as an hourly value. To fully include these ecosystem services in all accounting tables indicators may need to be adapted in future ecosystem accounts.

The ecosystem service models that were developed for the biophysical supply and use account form an important basis for other ecosystem service accounts, such as the monetary supply and use account and the ecosystem asset account. The results from the biophysical supply and use account can also be used for multiple policy applications, providing information for spatial planning, developing a circular economy, assessing particular sectors, and providing a basis for monitoring existing policies.

The accounts also show the importance of some aspects of natural capital that have generally been taken ‘for granted’ such as pollination and pest control, and how these services can be maintained in the future. The various policy applications have been explored in the current report in general terms, but they will be further tested in the future.

An important additional benefit of the approach is that it presents information on the various ecosystem services side-by-side, in a coherent manner. Some of the information is new, and other parts of this information were, to date, only available in separate datasets which made it difficult to consider them in an integrated manner (as is required for decision making on natural resources such as in the case of spatial planning). Hence, an important part of the added value of the approach is its integrated treatment of ecosystem services. Furthermore, it is important that an international guideline is followed (the SEEA EEA). The results of the SEEA ecosystem account of the Netherlands are therefore comparable with those of, for example, the United Kingdom or the accounts in development in among others Australia or the United States. At this point in time, however, the Dutch ecosystem account can be considered as internationally the most comprehensive and methodologically advanced.

Acknowledgements

This report has been produced as part of the Dutch national ecosystem accounting project and the research has been made possible by the Dutch Ministry of Economic Affairs and Ministry of Infrastructure and Environment. Data were kindly provided by RIVM (Atlas Natural Capital) and Alterra, Probos and NBTC-NIPO Research. We would like to thank the members of our advisory group for providing useful feedback.

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Appendices

Appendix 1 – Ecosystem extent account for 2006 and 2013

In this Appendix the ecosystem extent accounts for the Netherlands for 2006 and 2013 are presented, based on the Ecosystem Type maps (Statistics Netherlands, 2017a; van Leeuwen et al., 2017). The gross changes are presented in table A1.1; this table summarizes the total extent per ecosystem type in both years in absolute and relative values. For example, the total extent of all heath land in 2006 added up to 394 km2, whereas in 2013 this total extent had increased to 427 km2 (thus showing a net increase of 33 km2). Similarly, agricultural land use (types 1-6 combined) decreased from 46% to 45% of all land cover in the Netherlands. However, because all analyses are based on detailed maps, it is also possible to determine where the 'extra' heath land came from and what happened to the 'lost' agricultural land. This detail is presented in table A1.2.

Table A1.1 Ecosystem extent account for 2006 and 2013 for the Netherlands in km^2 and percentage of total area[6].

Ecosystem Type	Area 2006 (km2)	Area 2013 (km2)	% in 2006	% in 2013
Agriculture	19,174	18,811	46.2	45.3
Forest	3,207	3,216	7.7	7.7
Heath	394	427	1.0	1.0
Sand	356	358	0.9	0.9
Wetlands	461	580	1.1	1.4
Other unpaved terrain	4,061	4,007	9.8	9.7
Public green areas	710	708	1.7	1.7
Built-up and paved	5,236	5,410	12.6	13.0
Inland water	4,088	4,199	9.8	10.1
Sea[7]	3,846	3,815	9.3	9.2
Unknown/null	6	8	0.01	0.02
The Netherlands	41,539	41,539		

Table A1.2 can be interpreted as follows. For agriculture, the right most column indicates that in 2006 (rows represent 2006) the total extent of agricultural land use types was 19,174 km^2. The column total for agriculture in 2013 (columns represent 2013) shows that in that year, 18,811 km^2 of agricultural land remained. To know what happened to the 'missing' agricultural land, one needs to first look at the row for agriculture: 17,350 km^2 was agricultural land in 2006 and remained so in 2013. Thus, a total of 19,174 – 17,350 = 1,824 km^2 of agricultural land was changed into a different type of land use: (look at the rows) 81 km^2 were turned into forest, 7 to heath land, 11 to inland dunes, 97 to wetlands, 1,349 to other unpaved terrain, etc. Thus, agricultural land was primarily changed into the ecosystem types other unpaved terrain, built up and paved surfaces, wetlands and forest. However, in 2013, 18,811 ha of agricultural land were mapped; primarily already existing agricultural land (those same 17350 km^2), but in addition, 77 km^2 of forest had changed into agricultural land, as well as 10 km^2 heath land, 4 km^2 inland dunes, etc. On the other hand, ecosystem types that changed into agricultural land are primarily

[6] Calculations of extent are based on the more precise polygon maps. Therefore, small differences in extent are present between this table and table 4.1.1 where a raster map was used.
[7] Only the coastal zone was included here to allow for the analysis of changes in the coastline. The full Dutch Continental Shelf area is much larger at roughly 57.000 km^2

other unpaved terrain, built up and paved terrain, and forest. Thus, in summary: between 2006 and 2013 the extent of agricultural land decreased slightly. Agricultural land was changed into primarily other unpaved terrain and built-up and paved surfaces. At the same time, but on other locations, and representing a smaller extent, other unpaved terrain and forests were converted into agricultural land.

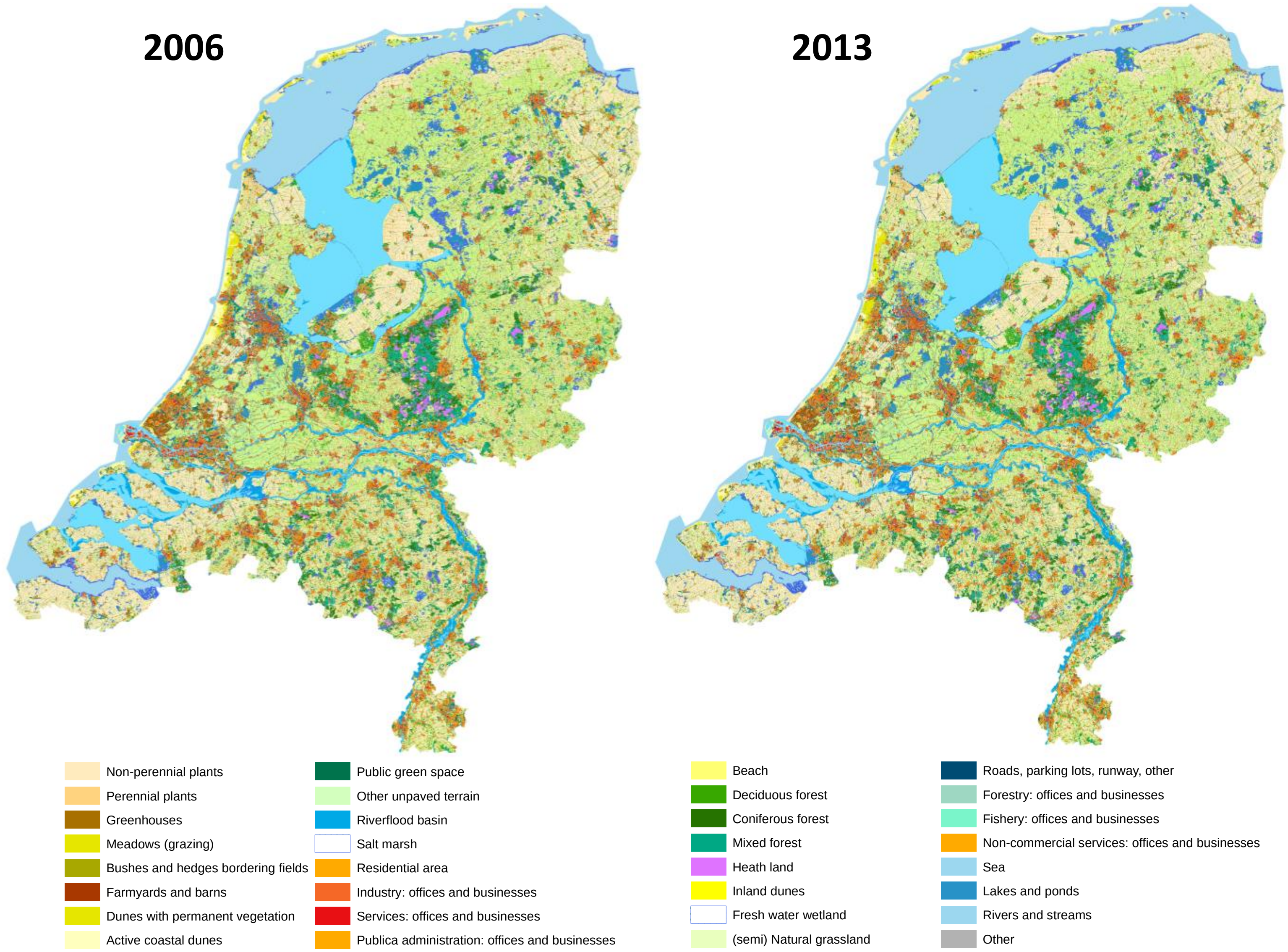


Figure A1.1 Ecosystem Types maps of the Netherlands for 2006 and 2013

Table A1.2 Changes in ecosystem extent for the main ecosystem types between the Ecosystem Type maps of 2006 (rows) and 2013 (columns) in km^2.

		2013											
Ecosystem Type		Agriculture	Forest	Heath	Sand	Wetlands	Other unpaved terrain	Public green areas	Built-up and paved	Inland water	Sea	Unknown/null	The Netherlands (totals 2006)
2006	**EU classes**	*1-6*	*21- 23*	*24*	*25*	*26*	*27 / 29*	*28*	*41 - 48*	*52 - 53*	*51*	*999 / 0*	
Agriculture	*1-6*	17,350	81	7	11	97	1,349	18	205	53	0	2	19,174
Forest	*21 - 23*	77	2,952	32	4	4	96	10	24	6	0	0	3,207
Heath	*24*	10	20	337	2	17	5	0	1	1	0	0	394
Inland dunes	*25*	4	5	8	303	6	5	1	3	3	20	0	356
Wetlands	*26*	14	5	24	1	388	16	0	0	9	3	0	461
Other unpaved terrain	*27 / 29*	1,150	125	15	4	52	2,288	54	314	56	1	2	4,061
Public green areas	*28*	7	13	0	1	1	38	603	42	5	0	0	710
Built-up and paved	*41 - 48*	186	12	1	2	3	182	20	4,811	16	0	1	5,236
Inland water	*52 - 53*	10	2	2	2	6	19	2	8	4,035	1	2	4,088
Sea	*51*	1	0	0	29	5	9	0	1	12	3,790	0	3,846
Unknown/null	*999 / 0*	0	0	0	0	0	1	0	1	3	0	0	6
The Netherlands (totals 2013)		18,811	3,216	427	358	580	4,007	708	5,410	4,199	3,815	8	41,539

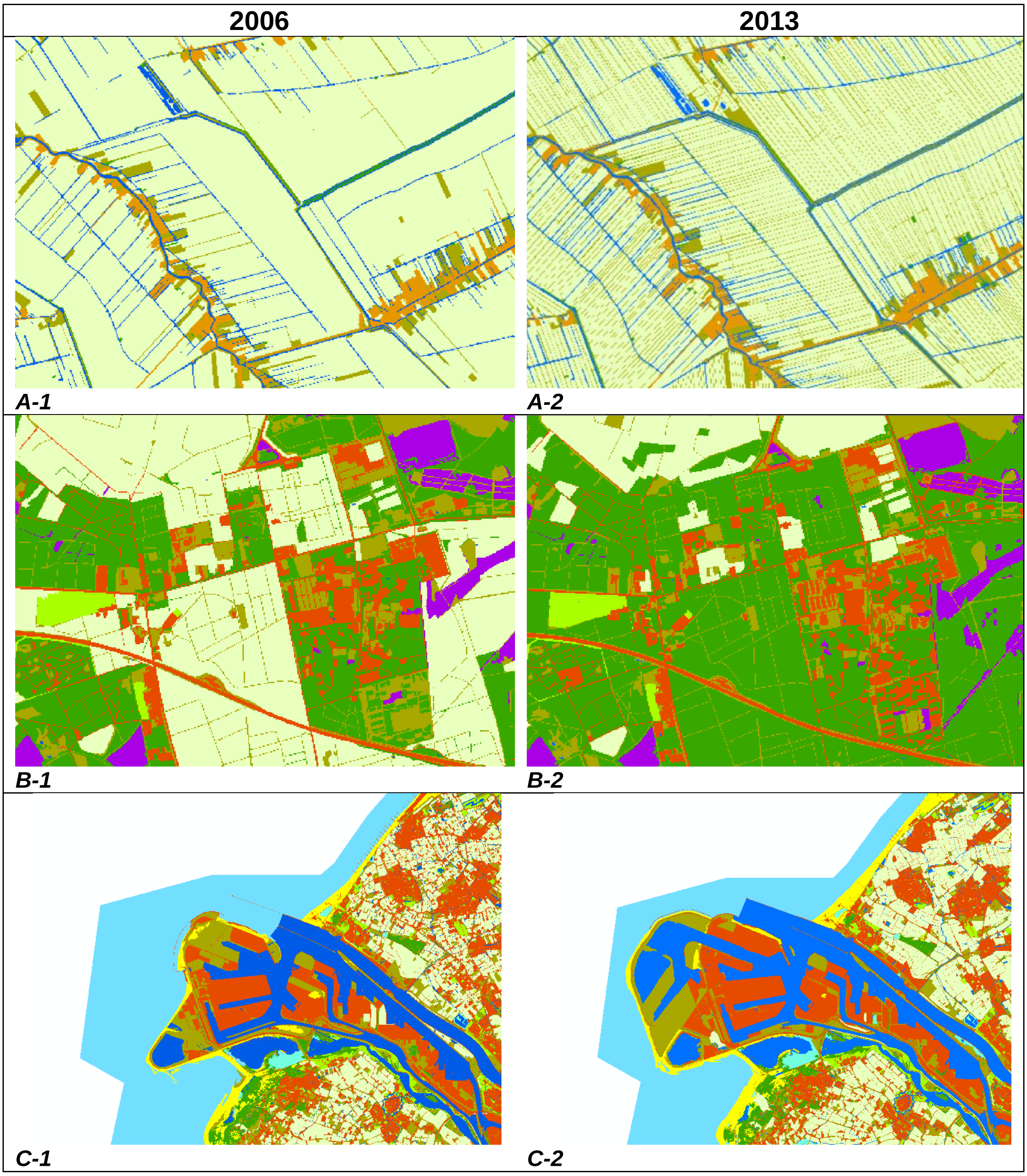


Figure A1.2 Examples of differences between the Ecosystem Type maps of 2006 and 2013. Example A shows the added detail of the 2013 map (A-2) compared to the 2006 map (A-1): ditches and edges of fields have been added in greater detail. Example B shows differences in classifications between the two years. The maps are for the Veluwe area just north of Arnhem. In 2013 much more area was classified as forest [dark green areas] (B-2) compared to 2006 (B-1), where much of the area was classified as grassland [light green areas]. Example C shows actual developments that occurred between 2006 (C-1) and 2013 (C-2), in this case for the 2nd Maasvlakte.

Table A2.1 thus shows the full detail of land conversions in the Netherlands between 2006 and 2013. When summing the diagonal values (which represent the extent of unchanged land for each ecosystem type) it becomes clear that between these years, 36,857 km2 of land remained unchanged, whereas (total extent of the Netherlands) 41,539 – 36,857 = 4,682 km^2 (or 11%) of the total Dutch surface had changed into a different ecosystem type. However, these 11% represent actual changes (e.g. development of urban areas on former agricultural lands), gradual changes (e.g. the gradual change of heath land into forest land or grassland), and changes due to classification differences and mapping details (figure A1.2).

Appendix 2 – Ecosystem service modelling methodology

This Appendix provides detailed descriptions of the models that were used to develop maps per ecosystem service.

The look-up table (LUT) approach was used in several cases, see Remme et al. (2014) for the pilot study in province Limburg where this method was also applied. LUT weigh different land-use or land-cover classes according to their capacity to provide ecosystem services. These LUT were combined with the Ecosystem Type map for the Netherlands (van Leeuwen et al., 2017; Statistics Netherlands, 2017a). In a LUT approach, each spatial unit (in our case each ecosystem type) in the map was attributed a specific value for a given process or property.

1. Crop production

Input data

Name dataset	Data type	Source
Basisregistratie gewaspercelen	Spatial data	RVO.nl
Harvest projections	Statline table	Statistics Netherlands

Main assumption: Crop production was used as a proxy for the ecosystem services that together allow for agricultural production. Higher crop yields are thus interpreted as a higher supply of these ecosystem services. Clearly, a large number of services, such as pollination and pest prevention by e.g. insects, quality and state of soils and soil life and the water balance better represent the actual supplied ecosystem services. Due to a lack of data, however, crop production is generally used as a proxy for this ecosystem service. Clearly, crop yields also depend on climate and weather and farming practices such as use of fertilizers, crop rotation and tillage methods etc.

Method description

For the analyses of crop production on agricultural land data, harvest projections (Statistics Netherlands, 2017c) and the registry on agricultural parcels (*Basisregistratie gewaspercelen (BRP)*) (RVO.nl, 2017) were combined. All relevant crops for human consumption were taken into account (Table A2.1.1).

From the registry on agricultural parcels both the geographical location and the type of crop grown on each parcel on May 15, 2013 are known. A selection of relevant parcels lead to a total of 137 thousand parcels taken into account in the analysis.

The second data source are the harvest projections. Each year, Statistics Netherlands produces harvest projections. Data are collected from surveys filled out by crop producers (Statistics Netherlands, 2017b). For the majority of crops data are published on average production (in kg) per ha per province. For some crops, such as potatoes, the harvest projection additionally takes into account soil type and the specific type of crops. In some cases, especially for crops that are produced in smaller quantities, average production is only available on the national level. Additionally, some crops, mostly legumes, are not a separate category in the harvest projections and the average production of an aggregated category is used. This information is indicated in the table below.

Table A2.1.1 Crops taken into account in crop production analysis

Crops	Region in harvest projections
Wheat	Province
Barley	Province
Rye	Province
Oats	Province
Triticale	Province
Other grains	Province†
Red kidney beans	Province
Rape	Province
Chicory	Province
Ware potatoes (on clay and sandy or peat soil)	Province
Seed potatoes (on clay and sandy or peat soil)	Province
Starch potatoes	Province
Other potatoes	Province†
Sugar beets	Province
Seed onions	Province
Other onions	National
Broad and field beans	National†
Peas	National†
Capuchins	National†
Soy beans	National†
Caraway seeds	National†
Lupine	National†
Other vegetables in open field	National
Fruit	4 regions†

† Not directly taken from the harvest projections: rather an average of other categories or an aggregate of different crops is used.

2. Fodder production

Input data

Name dataset	Data type	Source
Basisregistratie gewaspercelen	Spatial data	RVO.nl
Harvest projections	Statline table	Statistics Netherlands
NPP map	Spatial data	Lorenzo Cruz (2017)

Main assumption; the production of grass and maize reflects the ecosystem service of fodder production. The same assumptions and limitations as for crop production are valid here.

Method description

In terms of methodology, the analyses are similar to that of crop production. Harvest projections (Statistics Netherlands, 2017c; Statistics Netherlands, 2017d; see also section A2.1) based on surveys were linked with a selection of relevant parcels from the registry on agricultural parcels (Basisregistratie Gewaspercelen) (RVO.nl, 2017). Table A2.2.1 shows the list of selected fodder crops. Because harvest projections of grass are available on a lower spatial level compared to the harvest projections of crops, another data source was added. Net primary productivity (NPP) based on remote sensing (Lorenzo Cruz, 2017; see also sections 3.4 and A2.4) can be used to calculate a detailed map of annual carbon uptake. By using this map it is possible to allocate harvest projections per crop and per region at a much higher spatial level of detail. It is noted that the indicator used in this analysis remains ton/ha, however. The following formula shows how the grass production rates are deviated around their means with the use of the NPP:

$$production_{\,i} = \frac{NPP_i}{\overline{NPP}_{p,g}} * HP_{p,g}$$

where $production_i$ is the production per parcel (in ton/ha), NPP_i is the net primary productivity of that parcel, $\overline{NPP}_{p,g}$ is the average NPP per region and crop and $HP_{p,g}$ the average harvest projection per region and crop.

Table A2.2.1 Crops taken into account in the fodder production analysis

Crops	Region in harvest projections
Grass (permanent and temporary)	5 regions
Grain maize	Province
Green maize	Province
Corn cob mix	Province

3. Wood production

Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Zesde Nederlandse Bosinventarisatie (NBI6)	Monitoring data	Probos
EEA 1km reference grid the Netherlands	Spatial data	European Environmental Agency (EEA)

Main assumption: data for total harvested timber (specified for coniferous and deciduous trees) were available. To allows for a spatial allocation (actual locations of harvest are not known) of these totals, a spatial allocation model was developed based on inverse linear regression.

Method description

For the timber account we used data that were collected in 2012 and 2013 for the sixth Dutch Forest Monitor (Zesde Nederlandse Bosinventarisatie, NBI6) (Schelhaas et al., 2014). The collected data and background information were available online (Probos, 2017). Data were collected at 3190 sample points, of which 1235 were also sampled in the 2001-2005 Forest Monitor (Meetnet Functievervulling, MFV). At 203 other random sample points data could not be collected because either the point was inaccessible, or permission to collect data was not granted. For privacy reasons, the exact coordinates of the sample points are not available in the public database. Instead, it is noted in which 1x1 km grid cell the coordinate is located (EEA, 2013).

For each sample point, the characteristics of the forest were determined. Combined with the total area forest, observations can be used to estimate the areal with a certain characteristic. A prerequisite is that a sample point is representative for the whole forest. The sample points for data collection were randomly assigned and therefore it is assumed that they are representative. To calculate timber stock, stock change and harvest, only the visited sample points could be included. The total area of forest in the Netherlands in the Ecosystem Type map for 2013 is 325,579 ha, therefore each sample point represents 325,579/3190 = 102.06 ha.

Statistics

First, we applied a linear regression model to test which variables explain timber harvest best. A combination of dominant tree type and province could explain harvest best (R^2=0.34, p-value < 0.001); adding information on tree age did not improve model performance statistics significantly and therefore the most parsimonious model was selected. However, in absence of detailed information about local tree species, a model that includes whether the dominant tree group in a forest is deciduous or coniferous also explains harvest in combination with province. However, the predictive power for a certain location is much lower (R^2=0.09). Hence we can use this model to calculate harvest for deciduous and coniferous forests at province level, but we cannot use it to predict harvest at a local scale. Thus, we used an inverse linear regression model where timber harvest is predicted by the dominant tree group (data at provincial level) and the province.

4. Biomass production from non-agricultural and non-forest sources

Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
NPP map	Spatial data	Lorenzo Cruz (2017)
Root-to-shoot ratio	Reference values	IPCC
Carbon-to-biomass ratio	Reference values	ECN

Main assumptions; Biomass produced on semi-natural grasslands and other unpaved terrain can be approximated by using NPP (remote sensing) data when corrected for belowground production of carbon in roots.

Method description

In the applied methodology the focus was primarily on biomass production from grassland, shrubs and tree litter. Agricultural areas and forests were excluded from the analysis, as biomass produced in those ecosystems is used for other purposes (food and timber), and are modelled as separate ecosystem services. For the biomass production model the ecosystem types 'non-agricultural grassland' and 'other unpaved terrain' from the Ecosystem Type map were used. These ecosystem types were clipped from the Ecosystem Type map for further analysis. Biomass may be produced in other ecosystem types as well (e.g. 'hedgerows' and 'public green space'), however many of these areas also constitute artificial surfaces, and biomass unsuitable for further use.

To model the amount of biomass grown on the selected parcels annual net primary productivity (NPP) was calculated. Using the remote sensing based NPP map developed by RIVM for the Atlas of Natural Capital (Lorenzo Cruz, 2017), the annual carbon uptake in the ecosystem types was extracted. In the NPP map, NPP was averaged per parcel from the Ecosystem Type map.

As a large part of the NPP occurs below ground in grasslands and shrubs, a root-to-shoot ratio of 2:1 was applied in accordance with the LULUCF Good Practice Guidance (IPCC, 2003). Hence, 33% of NPP was assumed to be applicable as biomass for further economic use. To revert the carbon content of biomass (NPP) to weight of the vegetation an average conversion rate of 20% carbon content was applied, based on 108 samples of biomass types related to grass and shrubs from the Phyllis2 database (ECN, 2012; figure A2.4.1).

Averages

108 samples selected.

Property	Unit	Minimum	Maximum	Median	Mean	Std dev		Samples
▾ Fuel Properties								
▾ Proximate Analysis								
Moisture content	wt% (ar)	0.43	66.14	18.90	24.42	18.89	77%	43
Ash content	wt% (dry)	0.00	39.40	7.95	9.35	9.01	96%	58
Volatile matter	wt% (daf)	72.20	88.43	79.75	79.93	3.46	4%	42
Ash content at 550°C	wt% (dry)	0.55	43.77	8.64	10.55	10.65	101%	15
Ash content at 815°C	wt% (dry)	0.20	43.20	7.49	9.05	9.99	110%	17
Fixed carbon	wt% (daf)	11.57	27.80	20.25	20.07	3.46	17%	42

Figure A2.4.1 Screenshot from Phyllis2 database for the fixed carbon percentage in fodder, applied to the calculations.

The final map shows the biomass by weight (tons/ha), for the ecosystem types that have sufficient biomass production, but no predefined end purpose for this biomass.

5. Drinking water production

Input data

Name dataset	Data type	Source
Grondwaterbeschermingsgebieden	Spatial data	Interprovinciaal Overleg
Landelijk Grondwater Register (LGR)	Table	Bij12 / LGR

Main assumptions: the ecosystem service was spatially confined to the locations where active or passive filtering of water (through river banks, dunes or as groundwater) is used by water production plants. Filtering of river water in streams and rivers is therefore currently not included as a service in this model. Moreover, the actual delivery of a certain quantity of water is not considered an ecosystem service here and hence the extraction points of water for dune filtration (where river water is tapped to be infiltrated in the dunes) are not included in the model.

Method description

The analysis was performed by combining geographical data on areas of water extraction near pumping stations and water protection (Interprovinciaal Overleg, 2013) with data on the amount of water extracted per well (LGR, 2016). As was explained in section 3.5, three different types of water extraction were taken into account: infiltrated surface water, river bank filtration water and phreatic groundwater. For the wells of these types the water extraction area and water protection areas were merged. In some cases there is no protection area and only the extraction area was used to determine the location of ecosystem service supply. These geographical areas were then matched with the extraction data from the LGR and evenly distributed over the area.

6. Carbon sequestration in biomass and soil

Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
-	Reference values	Literature

Main assumption: the values in the LUT provide reasonable estimates of nett carbon sequestration and are applicable to vegetation types and climatic conditions in the Netherlands.

Method description

The methodology was based upon a qualitative look-up table (LUT) approach. Each spatial unit (i.e. ecosystem type) in the map was attributed a specific value for carbon sequestration. These values were based on values used for greenhouse gas reporting of the LULUCF sector in the Netherlands (Arets et al., 2015) and scientific literature. The look-up table for carbon stock in above ground biomass is provided in table A2.6.1.

Table A2.6.1 Look-up table for carbon sequestration in above and below ground biomass in the Netherlands

Ecosystem type	Carbon sequestration (ton C/ha/yr)	Reference
Non-perennial plants	0	Kuikman et al. (2003)
Perennial plants	0.38	0.2*forest, Schulp et al. (2008)
Greenhouses	0	Schulp et al. (2008)
Meadow	0.18	Janssens et al. (2005)
Hedgerows	0.17	Janssens et al. (2005)
Farmyards and barns	0	Schulp et al. (2008)
Dunes with permanent vegetation	1.89	Mostly forest, therefore same value as for forest[1]
Active coastal dunes	0	Schulp et al. (2008)
Beaches	0	Schulp et al. (2008)
Deciduous forest	1.89	Coenen et al. (2016)
Coniferous forest	1.89	Coenen et al. (2016)
Mixed forest	1.89	Coenen et al. (2016)
Heath land	0.19	Janssens et al. (2005)
Inland dunes	0	Schulp et al. (2008)
Fresh water wetlands	0.22	Janssens et al. (2005)
Natural grassland	0.19	Janssens et al. (2005)
Public green space	0.27	0.05*forest + 0.95*other unpaved terrain
Other unpaved terrain	0.18	Janssens et al. (2005)
River flood basin	0.20	Janssens et al. (2005)
Tidal salt marshes	4.00	Callaway et al. (1996), Oenema and De Laune (1988)
Paved surfaces (urban area, infrastructure)	0	Schulp et al. (2008)
Sea	0	Coenen et al. (2016)
Lakes and ponds	0	Coenen et al. (2016)
Rivers and streams	0	Coenen et al. (2016)

[1] The outline of dunes with permanent vegetation was defined by the presence of shrubs and bushes

7. Pollination

Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Basisregistratie Gewaspercelen	Spatial data	RVO.nl
Pollination requirements	Table	Klein et al. (2007)
Habitat suitability for pollinators	Table	Kennedy et al. (2013)

Main assumptions: the model assumes that pollinators are indeed present in habitats that are suitable for them (actual observation data of wild bees and other pollinators are not available), and that they all contribute to the pollination of nearby planted crops. Pollination by honey bees is *not* included in the analyses.

Method description

Crops differ in pollination requirements. Klein et al. (2007) divided crops, depending on degree of production dependence, in five classes (table A2.7.1). These are used to assign pollination demand to crops in the Netherlands (table A2.7.2).

Table A2.7.1 Classes for dependence of crops on pollination, based on yield loss in absence of pollinators. Between brackets the class mean that is used to generate maps of pollination demand of crops. Source: Klein et al. (2007).

Degree of dependence	Production reduction in absence of pollinators	Crops
Essential	> 90%	Courgette, pumpkin
Great	40% - 90% (65)	Raspberries, blackberries, other berries, annual fruit cultivation, perennial fruit cultivation (e.g. pear, apple, cherry) and summer rapeseed, and winter rapeseed
Modest	10% - 40% (25)	Strawberries, eggplant, redcurrants, blackcurrants, summer oilseed rape, winter oilseed rape, and sunflower
Little	0% -10% (5)	Other beans and other oilseeds
No increase	no reduction (0)	Other crops

Table A2.7.2 Look-up table for pollination demand of pollination dependent crops classes in the basic registration of crops in the Netherlands (*Basisregistratie Gewaspercelen*). Based on the classification used for the pollination requirements for the Atlas Natuurlijk Kapitaal (ANK) and the classification of Klein et al. (2007).

Crop code	Description	Pollination demand (%)
175	Flower cultivation	5
176	Flower bulbs and tubers	5
212	Fruit	65
242	Beans (bruine bonen)	5
243	Field beans	25
258	Alfalfa	5
515	Sunflower	25
663	Lupine	5
664	Rapeseed	65
665	Soybeans	5
666	Linseed	5
672	Vegetables open field	25
853	Broad beans (tuinbonen, droog)	5
854	Broad beans (tuinbonen, groen)	5
1922	Oilseed rape, winter	25
1923	Oilseed rape, summer	25

Most studies on natural pollination are focussed on wild bees and bumble bees. Historically, pollination demand was fulfilled by wild pollinators that live in the agricultural landscape. Nowadays, beekeepers place hives with cultivated honey bees, *Apis mellifera*, close to pollination demanding crops. Many crops, however, are also effectively pollinated by wild bees. Furthermore, honey bees are not always the most efficient pollinator; for some crops wild bees are more efficient than honey bees. As an ecosystem service, we map pollination by wild organisms such as wild bees, bumble bees, butterflies, and hoverflies. Managed honey bees were excluded. Wild pollinators require sufficient resources in the agricultural landscape. These resources include suitable nesting habitats (e.g. tree cavities, or suitable soil substrate) as well as sufficient floral (food) resources (i.e. pollen and nectar). Bees are central place-foragers. This means that they return to their nest site after foraging. The availability of nesting habitats close to agricultural fields is critical for bee-pollinated crops (Ricketts et al., 2006). Ecosystems differ in the suitability for pollinators, because there are differences in the presence of tree cavities or suitable substrates for nesting, and differences in the availability and suitability of floral resources (Kennedy et al., 2013). We used indicators for total nesting and floral resource availability for the suitability of the ecosystem types (table A2.7.3). These indicators were based on a meta-analysis of 39 studies that was conducted by Kennedy et al. (2013). Note that private gardens, whether in rural (farmyards and barns) or in urban areas (residential areas), are set to zero suitability due to the lack of information and the spatial heterogeneity of all ‘paved and built- up areas’.

Table A2.7.3 Look-up table for an indicator of combined nesting suitability and floral resource availability for ecosystem types in the Netherlands, on a 0 - 100 scale, with 100 indicating most suitable, and 0 unsuitable (based on Kennedy et al., 2013). *total nesting and floral suitability for economic crops were not used in the model (assumed value = 0), because these are considered to be the recipients of the pollination service.

Code	Ecosystem type	Total nesting and floral suitability
1	Non-perennial plants	30*
2	Perennial plants	58*
3	Greenhouses	0
4	Meadows / pasture	53
5	Hedgerows	80
6	Farmyard and barns	0
11	Dunes with permanent vegetation	80
12	Active coastal dunes	26
21	Deciduous forest	89
22	Coniferous forest	44
23	Mixed forest	66
24	Heath lands	100
25	Inland dunes	26
26	Fresh water wetlands	48
27	Natural grassland	80
28	Public green space	41
29	Other unpaved terrain	41
31	River flood basin	48
32	Tidal salt marshes	36
41-48	Paved and built-up area	0
51	Sea	0
52	Lakes and ponds	0
53	Rivers and streams	0

The maps for the pollination account are generated based on the spatial location of crops that require pollination (Basisregistratie Gewaspercelen 2013) and the spatial location of ecosystems that are suitable for pollinators on the Ecosystem Type map 2013. We generated two maps; one map that plots the *use* of the pollination service of the ecosystems, based on the *demand of the crop* and the distance between the demanding crop to the pollination providing ecosystem, and one map that plots the *supply* of the pollination service of the ecosystems, based on the *suitability of the ecosystems for pollinators* and the distance between the suitable ecosystem and the demanding crop. Different species of pollinators move at different length scales. Large pollinators such as bumble bees forage over long distance (up to 1750 m; Walther-Hellwig and Frankl, 2000), while small pollinators such as solitary bees, forage over shorter distances (up to several hundred meter). We generate the suitability and demand maps for all natural pollinators. Ricketts et al. (2006) found in their meta-analysis on 13 studies in temperate biomes that visitation rates of pollinators declined to half its maximum at 1308 m distance between the nesting sites and the crop. The optimal model for visitation rate (scaled 0 – 1, with 1 the maximum visitation rate) in temperate biomes is $\exp(-0.00053d)$. Where d, is distance between the nesting sites and the crop in meters. This model includes both species that forage over long distances and species that remain close to their nesting site. In the model, pollination service is assigned to the nearest suitable habitat. Pollinators leave their nesting sites to forage in the surrounding landscape. We assume that pollinators from all suitable habitats in the local landscape contribute to pollination. To obtain the relative visitation rate (scaled 0 -100) in a crop in map unit *c* (Lonsdorf et al., 2009) we calculate

$$v_c = \sum_{h=1}^{H} S_h \frac{e^{-0.00053 d_{hc}}}{\sum e^{-0.00053 d}}$$

where S_h represents the relative pollinator abundance (scaled 0 – 100, where 100 marks maximum suitability) in map unit *h* (based on the suitability for nesting and foraging for pollinators of the habitat in map unit *h*), d_{hc} is the distance between map unit *h* and the crop in map unit *c*. Pollination is then a function of the relative visitation rate,

$$P_c = f(v_c)$$

Rader et al. (2016) find a relationship between visitation variation and fruit set variation, based on 39 studies. Variation in fruit set was measured in 14 crops. They found that both bees (not including honey bees) and non-bee pollinators had a positive relationship between fruit set and pollination. Furthermore, studies show that often more pollen are deposited than needed for successful fruit set, 10 to 40 times more pollen have been reported in Sáez et al. (2014) and Pfister et al. (2017). Therefore, we model the function of pollination based on visitation rate as $P_c = 5v_c$, v_c between 0 and 20 and 100 for $v_c \geq 20$. This is a starting assumption, there can be differences between crops, but we do not take that into account here.

Next, we generate a potential production reduction map in absence of pollination based on the spatial location of crops in 2013 (Basisregistratie Gewaspercelen 2013) (RVO.nl, 2017) and table A2.7.3. Pollination service can be calculated as the difference between the production reduction in absence of pollinators and the production reduction in presence of pollinators.

To calculate pollination reduction in presence of pollinators, we combine the pollination map that is based on the Ecosystem Type map and spatial relationships of visitation rates by pollinators with the production reduction map, using the following equation:

"Avoided production reduction" = "potential production reduction" * ("pollination")/100

The avoided production reduction represents the use of the pollination service by the crops. Next, we calculate the contribution (supply) of the ecosystems to the avoided production reduction, APR_h,

$$APR_h = \sum_{c=1}^{C} APR_c \frac{\sum_{h=1}^{H} S_h \frac{e^{-0.00053 d_{ch}}}{\sum e^{-0.00053 d}}}{\sum_{h=1}^{H} S_h}$$

Where APR_c is the avoided production loss in the crop in map unit *c*, d_{ch} is the distance between the crop in map unit *c* and the ecosystem in map unit *h*. The relative contribution of all ecosystems in a 6 km square around the crop is weighted by the sum of the relative pollinator abundances, S_h. Contribution to avoided production loss in crop fields by the ecosystem in map unit *h* is based on all crop fields that require pollination in a 6 km square around map unit *h*. This is calculated for all map units that contain an ecosystem that is suitable for pollinators.

8. Natural pest control

Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands

Main assumptions: Ladybirds hibernate in and (initially) disperse from forests exclusively, and all ladybirds that reach agricultural crops and fruit trees contribute to pest control.

Method description

For natural pest control we use a look-up table approach in combination with a spatial model to model movement from the providing ecosystem type (forests) to the receiving ecosystem type (agricultural fields and orchards). We model pest control service provided by the seven-spot ladybird (*Coccinella septempunctata*) a very common ladybird in the Netherlands. Ladybirds forage on aphids that are a common pest of agricultural crops and fruit trees *C. septempunctata* hibernates in forests in litter, on pine trees or between leaves of broad-leaved trees. In spring, adults awake from hibernation and start feeding on aphids. We assume that ladybirds only hibernate in forests and start dispersing to the surrounding from these forests in spring. We assume that annual crops and perennial crops potentially profit from pest control. We have no information that indicates that forest types differ in their potential for ladybird hibernation, therefore we assume that forests are all equal suitable for hibernation (table A2.8.1).

Bianchi et al. (2007) use a dispersal parameter of 60 meter for a model that calculated short distance trivial flight per day for *C. septempunctata*. We calculated that spatial distribution in 3 months can be approximated with exp(-0.002*d*). Where *d*, is distance between the hibernation area and the crop in meters. The resulting long distance model, agrees with the study of Woltz et al. (2012) who found that landscape composition in a 1.5 km and 2km radius had an effect on *coccinellid* abundance, while landscape composition with a shorter radius did not explain *coccinellid* abundance. This indicates that *coccinellids* provide pest control over an area of at least 2 km.

To obtain the relative visitation of *C. septempunctata* (scaled 0 -100) in a crop in map unit *c* we calculate

$$v_c = \sum_{h=1}^{H} L_h \frac{e^{-0.002 d_{hc}}}{\sum e^{-0.002d}}$$

where L_h represents the relative *C. septempunctata* abundance in map unit *h* (based on the suitability for hibernation of the habitat in map unit *h,* with 100 indicating a suitable habitat and 0 indicating an unsuitable habitat), d_{hc} is the distance between map unit *h* and the crop in map unit *c*.

Table A2.8.1 Suitability for hibernation of ladybirds per ecosystem type

Code	Ecosystem type	Suitability for hibernation
1	Non-perennial plants	0
2	Perennial plants	0
3	Greenhouses	0
4	Meadows	0
5	Hedgerows	0
6	Farmyards and barns	0
11	Dunes with permanent vegetation	100
12	Active coastal dunes	0
21	Deciduous forest	100
22	Coniferous forest	100
23	Mixed forest	0
24	Heath land	0
25	Inland dunes	0
26	Fresh water wetlands	0
27	Natural grassland	0
28	Public green space	0
29	Other unpaved terrain	0
31	River flood basins	0
32	Salt marshes	0
41-48	Built-up and paved areas	0
51-53	Water	0

Next, we calculate the contribution (supply) of the ecosystems to the visitation by *C. septempunctata* in the field, v_h,

$$v_h = \sum_{c=1}^{C} v_c \frac{\sum_{h=1}^{H} L_h \frac{e^{-0.002 d_{ch}}}{\sum e^{-0.002 d}}}{\sum_{h=1}^{H} L_h}$$

Where v_c is the relative visitation by *C. septempunctata* in the crop in map unit *c*, d_{ch} is the distance between the crop in map unit *c* and the ecosystem in map unit *h*. The relative contribution of all ecosystems in a 2 km square around the crop is weighted by the sum of the relative *C. septempunctata* abundances, L_h. Contribution to visitation by *C. septempunctata* in the crop fields by the ecosystem in map unit *h* is based on all crop fields in a 2 km square around the ecosystem in map unit *h*. The contribution to visitation is calculated for all map units *h* that contain ecosystems suitable for *C. septempunctata* hibernation.

9. Erosion control

To model erosion control the methodology developed by RIVM and VITO for the Atlas of Natural Capital was applied (RIVM, 2017b). Technical documentation on this model is available at RIVM, and can be requested via info@atlasnatuurlijkkapitaal.nl.

The model uses the Universal Soil Loss Equation (USLE), based on land cover, slope and slope length. Cropland is used as a benchmark for comparison with other land cover types. Land cover types with higher or more permanent vegetation cover (such as grassland or forest) prevent more soil loss than cropland, while bare soil (such as sand areas) prevent less soil loss.

10. Air filtration

Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Yearly average PM_{10} 2013	Spatial data	RIVM
PM_{10} capture parameters	Reference values	Powe and Willis (2014)
Tree phenology	Observations	Nature Today
Rain days	Statistics	Environmental Data Compendium

Main assumptions: the model uses yearly average PM_{10} concentration data. Hence an underlying assumption of the model is that PM_{10} concentrations are normally distributed over a year. Timing of foliage as well as precipitation are accounted for in the model.

Method description

Particulate matter is captured through deposition on leaf and bark surfaces. The process of deposition depends on tree type and meteorological conditions (Powe and Willis, 2004). Deposition varies depending on density of the foliage and leaf form (the leaf area index, LAI).

For the calculation of PM_{10} capture by vegetated ecosystems (e.g. forests, natural grasslands, cropland, heath) we combined the Ecosystem Type map with a 10m spatial grain with a map of yearly average PM_{10} in µg m^3 (based on 24 hour daily averages) for 2013 on a 1000 m spatial grain (RIVM, 2013). PM_{10} capture was estimated using the following equation (as in Powe and Willis, 2004):

$$\text{ABSORPTION} = \text{SURFACE} * \text{PERIOD} * \text{FLUX}$$

where:

ABSORBTION = dry pollution deposition on vegetation cover (PM_{10} *capture* in µg m^{-2})

SURFACE = area of land considered (A in m^2) * surface area index (S in m^2 per m^2 of ground area)

PERIOD = period of analysis (t in s (i.e. 31536000 s)) * proportion of dry days per year (p_{dry})* proportion of in-leaf days per year ($p_{on\text{-}leaf}$)

$$\text{FLUX} = \text{deposition velocity } (v_d \text{ in m s}^{-1}) * \text{ambient PM}_{10} \text{ concentration } (C_{PM10} \text{ in µg m}^{-3})$$

Or,

$$\text{PM}_{10}\, capture_{on\text{-}leaf} \text{ (in } kg \text{ ha}^{-1}) = A * S_{on\text{-}leaf} * t * p_{dry} * p_{on\text{-}leaf} * v_d * (10^{-9}/10^{-4}) * C_{PM10}$$

$$\text{PM}_{10}\, capture_{off\text{-}leaf} \text{ (in } kg \text{ ha}^{-1}) = A * S_{off\text{-}leaf} * t * p_{dry} * (1 - p_{on\text{-}leaf}) * v_d * (10^{-9}/10^{-4}) * C_{PM10}$$

We take,

$$M_{on\text{-}leaf} = A * S_{on\text{-}leaf} * t * p_{dry} * p_{on\text{-}leaf} * v_d * (10^{-9}/10^{-4})*0.5$$

And,

$$M_{off\text{-}leaf} = A * S_{off\text{-}leaf} * t * p_{dry} * (1 - p_{on\text{-}leaf}) * v_d * (10^{-9}/10^{-4})*0.5.$$

where the factor 0.5 denotes the resuspension rate of particles coming back to the atmosphere (Zinke, 1967).

For each vegetated ecosystem type we add these multiplication factors $M_{year} = M_{on\text{-}leaf} + M_{off\text{-}leaf}$ to calculate PM_{10} *capture* in *kg* ha^{-1} based on ambient PM_{10} concentration, C_{PM10} in µg m^{-3}. The deposition velocities, the surface area index and multiplication factors per ecosystem type with vegetation cover are summarized in table A2.10.1. Values for deposition velocity are based on Powe and Willis (2004), however, for coniferous forest, we used a similar LAI as for in-leaf deciduous forest based on a meta-analysis by Asner et al. (2003).

Data on phenology of emergence of leaves until the end of leaf fall of trees in the Netherlands (Nature Today, 2017) was used to estimate the proportion of in-leaf days for deciduous forests, on average deciduous trees were on-leaf from mid-April to mid-November (i.e. $p_{\text{on-eaf}}$ = 7/12). Data on average number of rain days with ≥ 1.0 mm precipitation (Environmental Data Compendium, 2017) was used to calculate the proportion of dry days. The average number of rain days in the Netherlands in the period between 1981 and 2010 was 131 (i.e. p_{dry}=234/365).

Table A2.10.1 Deposition velocities ($m\ s^{-1}$), the surface area index ($m^2\ m^{-2}$) and yearly multiplication factors per ecosystem type with vegetation cover.

	Deposition velocity		Surface area		M_{year}
Ecosystem type	**On-leaf**	**Off-leaf**	**On-leaf**	**Off-leaf**	
Non-perennial plants	0.0010	0.0010	2	1.5	0.18
Perennial plants	0.0010	0.0010	2	1.5	0.18
Meadows	0.0010	0.0010	2	1.5	0.18
Hedgerows	0.0010	0.0010	2	1.5	0.18
Dunes with permanent vegetation					1.69[1]
Deciduous forest	0.0050	0.0014	6	1.7	1.87
Coniferous forest	0.0050	0.0050	6	6	3.03
Mixed forest					2.45[2]
Heath land	0.0010	0.0010	2	1.5	0.18
Fresh water wetlands	0.0010	0.0010	2	1.5	0.18
Natural grassland	0.0010	0.0010	2	1.5	0.18
Public green space	0.0010	0.0010	2	1.5	0.18
Other unpaved terrain	0.0010	0.0010	2	1.5	0.18
River flood basin	0.0010	0.0010	2	1.5	0.18

[1] Dunes with permanent vegetation is calculated as the average of the factors for coniferous forest, deciduous forest and other vegetation.

[2] Mixed forest is calculated as the average of the factors for coniferous forest and deciduous forest.

11. Protection against flooding due to heavy rainfall

Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Tree cover map: bomen 10m	Spatial data	RIVM
Shrub cover map: struik 10m	Spatial data	RIVM
Grass cover map: gras 10m	Spatial data	RIVM
Soil map urban areas: bofek_10m_v2	Spatial data	RIVM
CBS buurt 2013 (v2)	Spatial data	Statistics Netherlands
Infiltration capacity data	Reference values	Akan et al. (1993)
Interception of precipitation by vegetation	Reference values	Nedkov and Burkhard (2012)

Main assumptions; it is assumed that the infiltration capacity per soil- and vegetation type provided in the tables below represents reality in the Netherlands reasonably well. Local soil compaction and the possible influence of tilling and ploughing was not taken into account here though. In addition the occurrence of e.g. clayey and loamy deposits at greater depths below the surface were not taken into account, possibly leading to local errors where these deposits do occur.

Method description

For the calculation of infiltration capacity of rain water in urban areas we combined the Ecosystem Type map with a 10 m spatial grain with three vegetation maps (RIVM, 2017a; RIVM 2017c; RIVM 2017e) of trees, shrubs and grass with a 10 m spatial grain and a soil map that contains soil types in urban areas (RIVM, 2017d). These present the percentage of the cell that is covered with trees, shrubs and grass, respectively. In the 10 m grain cells, 1% cover equals 1 m^2 cover. To calculate infiltration capacity for different degrees of urbanization, we used an urbanisation level map per neighbourhood of 2013 (Statistics Netherlands, 2017e). Infiltration capacity depends on soil type, soil moisture and the presence of vegetation. We used a look up table approach to combine the soil map with initial infiltration rates in moist and dry soils and for dense and no vegetation (table A2.11.1). In unpaved areas, rain water can infiltrate both in vegetated and in open areas, while in paved areas, rain water can only infiltrate in vegetated areas. In dry soils, vegetation enhances infiltration capacity.

Infiltration capacity for each 10m x 10m cell was calculated as:

$$\text{Infiltration}_{\text{dry,unpaved}}(x,y,t) = p_{\text{vegetated}}(\text{x,y}) * \text{infiltration}_{\text{vegetated}}(\textit{soil type}(x,y),t) + p_{\text{open}}(x,y) * \text{infiltration}_{\text{open}}(\textit{soil type}(x,y),t)$$

for dry soils in unpaved areas,

$$\text{Infiltration}_{\text{dry,paved}}(x,y,t) = p_{\text{vegetated}}(\text{x,y}) * \text{infiltration}_{\text{vegetated}}(\textit{soil type}(x,y),t)$$

for dry soils in paved areas, respectively

$$\text{Infiltration}_{\text{saturated,unpaved}}(x,y,t) = \text{infiltration}_{\text{open}}(\textit{soil type}(x,y),t)$$

for saturated soils in unpaved areas, and

$$\text{Infiltration}_{\text{saturated,paved}}(x,y,t) = p_{\text{vegetated}}(\text{x,y}) * \text{infiltration}_{\text{saturated}}(\textit{soil type}(x,y),t)$$

for saturated soils in paved areas.

In these equations, $p_{\text{vegetated}}$ is the total fraction of the cell that is occupied by forest, shrubs and grass and p_{open} is the remaining fraction, i.e. soil without vegetation. We classified cells as paved or unpaved based on the ecosystem type (table A2.11.2).

Infiltration capacity in dry soil is calculated based on the Horton model that calculates current infiltration rate based on an initial infiltration capacity, f_0, and a final infiltration capacity, f_c, and the time since the start of the infiltration, t, and a constant k that models how fast the infiltration capacity declines. The Horton model (Horton, 1933):

$$f(t) = f_c + (f_0 - f_c)\, e^{-kt}$$

The Horton model can be integrated to calculate the total infiltration in time *t,*

$$F(t) = f_c\, t + ((f_0 - f_c)*(1 - e^{-kt})\,/k)$$

We use the total infiltration in 60 minutes for our calculations for infiltration (table A2.11.1).

To calculate interception by the vegetation, we used a look-up table in combination with the three vegetation maps; tree map, shrub map and grass map (table A2.11.3).

Table A2.11.1 Initial infiltration capacity, final infiltration capacity and total infiltration in 60 minutes, depending on soil type and presence vegetation (Akan et al., 1993).

	Infiltration (mm/h (per m^2))			Infiltration (mm in 1h (per m^2)	
	Initial infiltration capacity, f_0		Final infiltration capacity, f_c	Total infiltration in 60 minutes, $F(60)$	
	Dry soil		Saturated soil	Dry soil	
Soil type	**Vegetated**[1]	**Open**[1]		**Vegetated**	**Open**
Heavy clay soil	50	25	0.5	12.3	6.3
Clay soil	50	25	1.5	13.0	7.1
Organic soils	50	25	2.2	13.6	7.6
Loam soil	150	75	2.1	37.3	19.4
Sandy loam soil	150	75	6.0	40.2	22.4
Loamy sand soil	150	75	11.0	44.0	26.2
Sandy soils	250	125	20.0	74.7	45.0

[1] Based on a relationship between values of initial infiltration for moist and dry soils and sparse and dense vegetation proposed by Akan et al. (1993) (i.e. infiltration in soil with dense vegetation is 2 * infiltration in soil with sparse to no vegetation).

Table A2.11.2 Division in paved (impermeable for rain water) and unpaved (permeable for rain water) soil based on ecosystem type.

	Ecosystem types
unpaved	All agricultural ecosystems (except green houses and built-up farm yards), all dune ecosystems, all forest and other natural ecosystems and other unpaved terrain, river flood plains and tidal salt marshes
paved	All built up areas, green houses and built-up farm yards.

Table A2.11.3 Interception of precipitation of trees, shrubs and grass (Nedkov and Burkhard, 2012).

	Interception (mm)	
Vegetation type	**Vegetation**	**Litter**
Trees	3.0	5.8
Shrubs	1.0	
Grass	1.3	

12. Nature recreation

Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Provincial boundaries	Spatial data	Statistics Netherlands
National road database	Spatial data	Rijkswaterstaat
CVTO	Survey data	NBTC-NIPO

Main assumptions: the first method implies the assumption that within a province, hikers are distributed equally over areas with the same ecosystem types. Hence, all forests in one province are assumed to be equally popular for hiking. The pilot study using Strava data tackles this issue because the actual popularity of paths is taken into account. This second method assumes that the preferred choices of routes by Strava users (those that identify themselves as 'runners') are representative for all recreational hikers.

Method description

Recreational hiking was used as the indicator for nature recreation in this account. The recreational hiking model was developed as an allocation model, based on outdoor statistics for 2015 (NBTC-NIPO, 2015b). Hiking statistics for 2013 were not available for use. The CVTO statistics contain information on the number of hikers for nine types of surroundings per province. These nine surroundings were coupled to the ecosystem types in the Ecosystem Type map (Statistics Netherlands, 2017a). The reclassification is shown in table A2.12.1. Hikers were assumed to stick to footpaths, or to the beach, as this is frequently used for hiking.

Table A2.12.1 Reclassification of CVTO and Ecosystem Type classes for the recreational hiking model

'Surroundings' classes for model	CVTO classes	Ecosystem Type classes
Sea and dunes	On/at sea Dune areas	Dunes with permanent vegetation Active beaches Sea
Water	Water/river/pond/lake	Lakes, ponds and other inland water bodies Rivers
Rural and agricultural	Rural and agricultural	Non-perennial plants Perennial plants Greenhouses Meadows Hedgerows Farmyards and barns
Wetlands	Wetlands	Wetlands Salt marshes
Forest	Forest	Deciduous forest Coniferous forest Mixed forest
Heathland and inland dunes	Heathland and inland dunes	Heath land Inland dunes
Urban area	City/town	Residential area

		Industry: offices and businesses Services: offices and businesses Public administration: offices and businesses Roads, parking lots, runways, other Forestry: offices and businesses Fishery: offices and businesses Non-commercial services: offices and businesses
Public green space	Public green space	Public green space
Other surrounding, including recreation areas	Other surroundings Recreation area	(semi) Natural grassland Other unpaved terrain River flood basins Unknown

Ecosystem types within the direct surroundings of hiking paths (within 50 m distance of the path) were assumed to contribute to the enjoyment of the hiker and therefore provide an ecosystem service. All hiking paths and roads less than 4 meters wide were selected from the Dutch road database (NWB) (Rijkswaterstaat, 2013). Buffers of 50 m on each side of the roads were created. These buffers were used as a mask for further analysis.

The hikers were allocated equally over the nine types of surroundings according to the total area of each surrounding and the corresponding hiking statistics per province. For example, if there are 100 ha of forest available along hiking paths in province *x*, and 10000 hikers in forests in this province, forests receive a value of 10000/100 = 100 hikers/ha.

Given an average hiking distance of 7 km (based on the CTVO surveys), it was assumed that each hiker visits 70 individual hectares. The number of hikers per ha is thus multiplied by 70 to yield the hiking intensity, i.e. the number of hikers passing through a specific hectare. A smoothing effect in a 100 meter neighbourhood was applied to the resulting map, to minimalize differences between the two sides of each path.

Strava-based approach

Strava heatmap images were used as an indicator for hiking intensity, as outlined in Section 3.12. The procedure used is as follows:

1. The 'Top10NL' vector map of the Netherlands's topographic was used to extract geometries and characteristics of all roads segments.
2. For each road segment, the point halfway the road is determined. Coordinates for this point are converted to the pixelated georeferencing system used by the Strava heatmaps.
3. The corresponding heatmap tile, and the surrounding tiles, are downloaded from the Strava server.
4. RGBA color and transparency channels within a small search radius around the current point of interest are analyzed to obtain the hiking intensity for the current road segment. This procedure is repeated for all zoom levels, and the results are compared, to undo the regional normalization used by Strava.

Road segment hiking intensities are stored in a table and joined with the original road network attribute table to proceed with GIS postprocessing.

13. Nature tourism

Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Provincial boundaries	Spatial data	Statistics Netherlands
Tourism regions	Spatial data	Statistics Netherlands
Postal codes (4-digit)	Spatial data	Statistics Netherlands
Urbanisation classes	Spatial data	Statistics Netherlands
Accommodations and beds	Spread sheet	Statistics Netherlands
Marina locations from business register	Spread sheet	Statistics Netherlands
CVO	Survey data	NBTC-NIPO

Method description

The ecosystem service nature tourism was modelled based on Dutch tourism statistics available at aggregated scales (provinces and tourism areas) (NBTC-NIPO, 2015a). Statistics were available for three main types of nature tourism: nature and active tourism, beach tourism, and water sports. Each type of nature tourism was mapped separately, following slightly different methods. The methods will be described per tourism type.

Nature and active tourism:

For the analysis of active and nature tourism built-up and water ecosystem types were excluded. To partially disaggregate the data for nature and active tourism, the provincial boundaries have been supplemented with the boundaries for tourism regions where possible, providing 18 sub-regions for which tourism statistics were available (table A2.13.1).

Table A2.13.1 Active and nature tourists per analysed tourism region. Source: CVO.

Tourism region	Active tourists (x1000)	Nature tourists (x1000)	Active and nature tourists combined (x1000)
Achterhoek	67	64	131
Drenthe	178	200	378
Flevoland	27	34	61
Friesland	110	153	263
Gelders Rivierengebied	30	13	43
Groningen	28	38	66
Noord-Holland	133	160	293
Noord-Midden Limburg	99	106	205
Overig Gelderland	61	31	92
Overig Noord-Brabant	33	35	68
Overig Overijssel	19	18	37
Twente, Salland en Vechtstreek	173	143	316
Utrecht	74	77	151
Veluwe en Veluwerand	166	365	531
West en Midden-Brabant	98	112	210
Zeeland	92	53	145
Zuid-Holland	87	64	151
Zuid-Limburg	144	97	241

The above data was further disaggregated to four-digit postal codes, based on the density of beds in accommodations. The underlying assumption was that a higher availability of beds leads to a higher number of visiting tourists. Data on actual visitation rates by tourists per accommodation or postal code were not available.

A dataset on the number of accommodations and subsequent beds, available at Statistics Netherlands, was used to assess the density per postal code. A Point Density analysis was done in ArcGIS, using the centres of the 4-digit postal codes and the number of beds per postal code as a weighting factor. Because tourists potentially visit all areas in the Netherlands, 1 point was added to all pixels in the point density map. In order to exclude highly urbanized areas from the density analysis all areas with the highest CBS urbanisation class (1) were reclassified to zero. The density map was used to redistribute tourists per tourism region proportionally. Per tourism region the total number of nature and active tourists were divided by the summed density scores. These values were multiplied with the point density map and by 100 to obtain the number of nature and active tourists per ha.

Beach tourism:

For beach tourism the CVO data could be disaggregated into six tourism regions (table A2.13.2). For these regions only the categories 'Beach, sand and active dunes' and 'Dunes with permanent vegetation' from the Ecosystem Type map were used, as beach tourism only occurs in these areas.

Table A2.13.2 Number of beach tourists (x1000) per coastal region in 2015. Source: CVO.

Tourism region	Beach tourists (x1000)
Den Haag - Rotterdam	6
Friesland	129
Zuid-Holland	120
Noord-Holland	214
Texel	113
Zeeland	386

The point density map for beds per accommodation per four-digit postal code developed for nature and active tourism was used in this model as well. The same procedure as for nature and active tourism was followed to obtain the final map.

Water sports tourism:

By combining provincial boundaries and tourism regions, the CVO data for water sports tourism was disaggregated into 18 regions (table A2.13.3). For the model only inland water categories 'Lakes, ponds and other inland water bodies' and 'Rivers' from the Ecosystem Type map were used. For this model only large inland water bodies were selected, with a contiguous size of at least 1 km^2.

Table A2.13.3 Number of water sports tourists (x1000) per tourism region. Source: CVO.

Tourism region	Water sports tourists (x1000)
Drenthe	0
Flevoland	8
Friesland	66
Gelderland	0
Groningse Meren	1
Noord-Brabant	0
Noord-Holland	6
Noord-Midden Limburg	6
Overig Friesland	0
Overig Groningen	0
Overig Noord-Holland	0
Overig Zuid-Holland	0
Overijssel	3
Twente, Salland en Vechtstreek	2
Utrecht	0
Zeeland	16
Zuid-Holland	18
Zuid Limburg	3

To allocate the water sports tourists within the 18 tourism regions the availability of marinas were used as a proxy. Marinas were selected from the Dutch business register and mapped according to the centres of their six-digit postal codes (points). A kernel density analysis was done on the based on the point data for marinas, using a 10 km search radius. This was the distance within tourists were assumed to stay during their holidays. The kernel density map was normalised on 0-100 scale and summed per tourism region. The kernel density map was used to redistribute water sports tourists per tourism region proportionally. Per tourism region the total number of water sports tourists was divided by the summed density scores. These values were multiplied with the kernel density map to obtain the number of water sports tourists per ha.

All nature tourism:

The three output maps per tourism type were added up to create the final map for nature tourism in the Netherlands.

Links between Natural Capital, Natural Capital Accounting and the Circular Economy

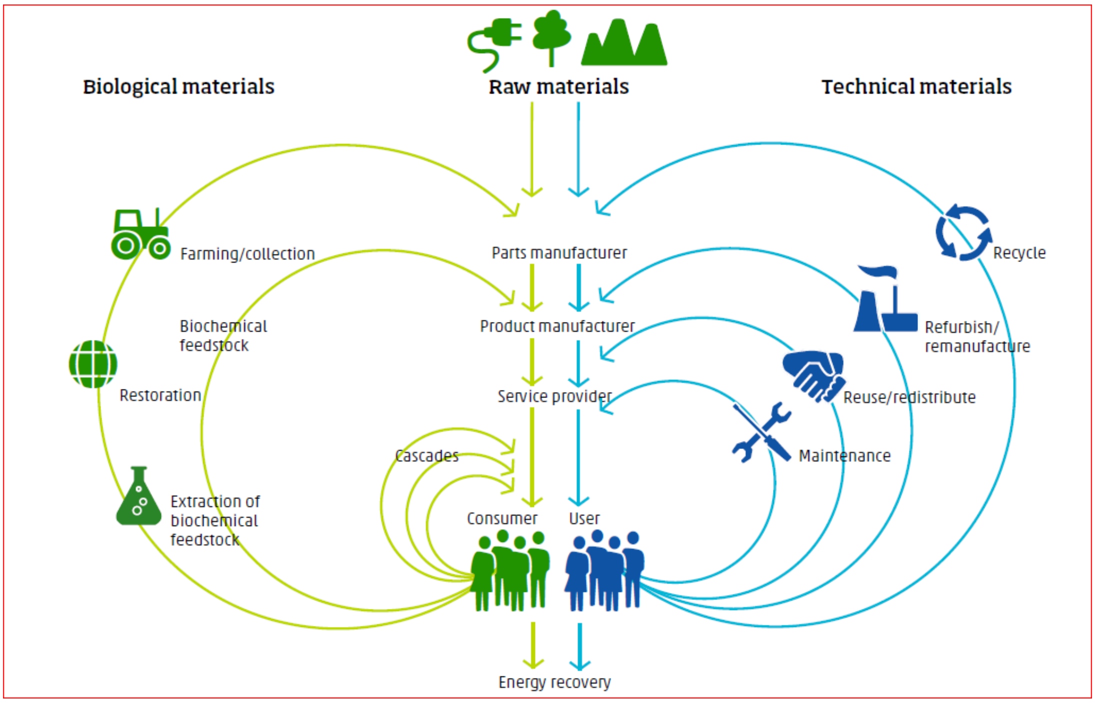
A transition to a more circular economy (CE) has received a lot of attention recently (e.g. EMF, 2014; EEA, 2016). A more circular economy would reduce environmental pressures and resource dependency while at the same time increasing economic growth. In the Netherland this had led to an interdepartmental programme on circular economy (Ministries of I&M and EZ, 2016). In this CE policy programme, natural capital is considered to play an important role. Here we briefly describe the role of natural capital accounting (NCA) in a CE. First, the concepts behind natural capital, natural capital (or ecosystem) accounting and CE are briefly explained. Second, the linkages between different aspect of both systems are described and discussed.

1. Circular economy

In a circular economy (CE) the value of products, materials and resources is maintained in the economy for as long as possible and the generation of waste is minimised (European Commission). The transition to a more CE should contribute to the developments of a sustainable, low carbon, resource efficient and competitive economy.

A linear economy is based on a take, make and dispose principle. In a CE the input of primary non-renewable resources and the output of waste are reduced to a minimum. As shown in the figure below this is achieved by bringing back end-of-life products into the economy by keeping the value of the product components as high as possible. This goes for both technical and biological materials. Resources are regenerated in the bio-cycle or recovered and restored in the technical cycle. Preserving and enhancing natural capital by controlling finite stocks and balancing renewable resource flows is an important principle of CE.

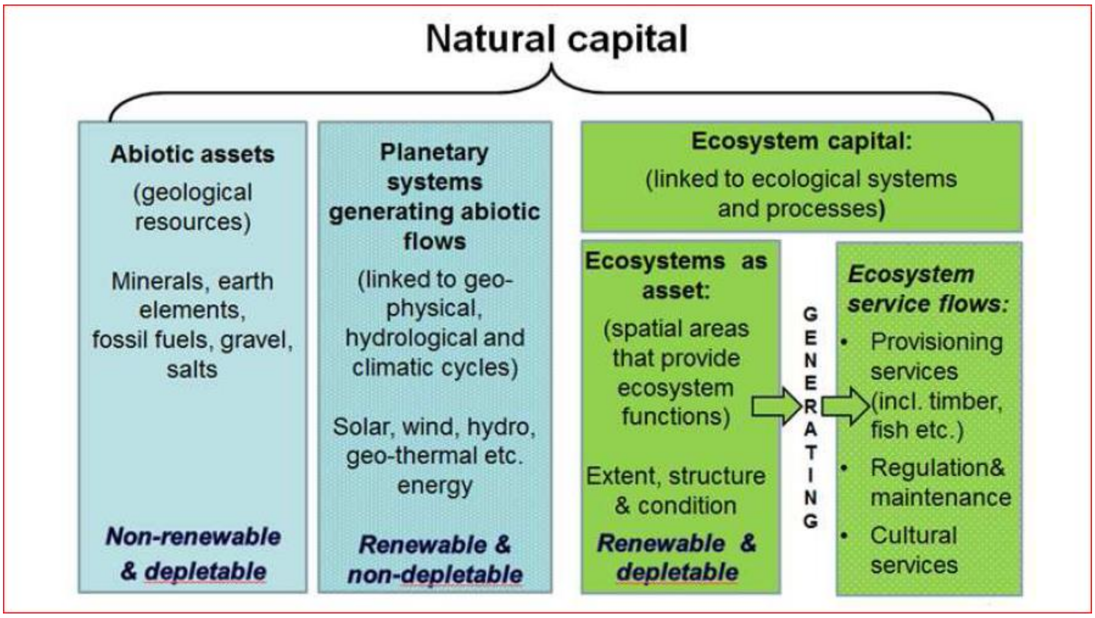
2.1: Outline of a circular economy (based on the Ellen MacArthur foundation)



2. Natural Capital and accounting

Natural Capital (NC) can be defined as the world's stocks of natural assets which include geology, soil, air, water and all living things. In addition, from this NC a wide range of services, often called ecosystem services, can be derived which make life possible. According to SEEA-CF (System of Environmental Economic Accounting – Central Framework) Natural Capital consist of three parts: 1) non-renewable and depletable abiotic assets such as mineral resources, 2) abiotic renewable and non-depletable resources such as solar energy and 3) renewable and depletable ecosystems assets, such as fertile soils and forests (see figure 3.1). The SEEA EEA and the Dutch Natural Capital Accounts focus strictly on the third form of natural capital, that is defined by its capacity to provide ecosystem services (and is also known as ecosystem accounting). Hence, following the SEEA CF definition of natural capital forms, geological reserves of oil and gas and mineral resources such as sand and gravel are not considered to be ecosystem services and they are therefore not considered in the SEEA EEA. However, data on the two other forms of natural capital are of course also available at Statistics Netherlands and can be included to generate a complete overview of all three forms of natural capital.

3.1: Different aspects of Natural Capital (based on Eurostat)



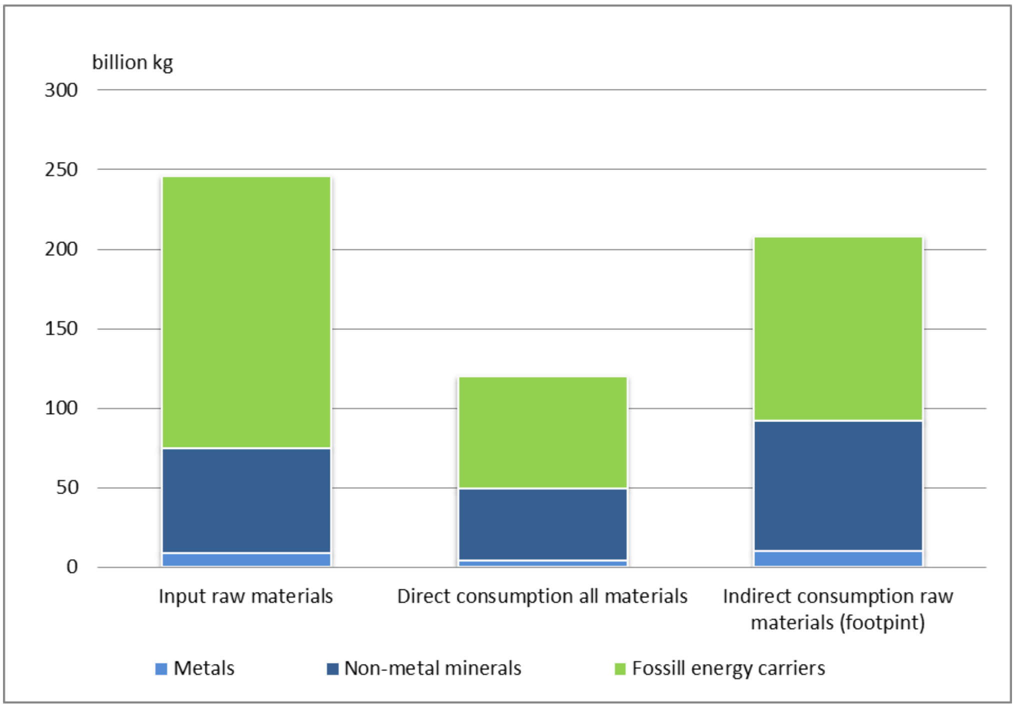
3. Link between natural capital and circular economy

In research and policy reports on the transition towards a circular economy (CE), natural capital plays an important role. The Dutch CE policy programme refers to an economy in which natural resources are used in a sustainable way. CE and natural capital (as depicted in Fig. 3.1, including all three types of natural capital) are broad concepts that are often interlinked(see e.g. CREM, 2016). This chapter describes the role of different aspects of natural capital in a CE. Focus is on the link between CE and ecosystem capital. The structure of this chapter is based on figure 3.1.

3.1 Abiotic assets (non-renewable, depletable)

Here we consider abiotic assets that are non-renewable and depletable, (fossil fuels and mineral resources). The extraction of these natural resources that flow from the environment to the economy are an important element in a CE. In a transition to a CE, the use of non-renewable and depletable resources is replaced by sustainable produced, renewable and commonly available resources derived from ecosystem services (for example in the form of biomass for energy). A truly sustainable CE can only be created if these alternative sources for energy production are also produced sustainably, and the capacity of ecosystem assets to generate these services is not exceeded (see Hein et al., 2017). If successful, this will make our economy more durable and less dependent on critical resources from other countries.

3.1: Direct input, direct consumption and indirect consumption of materials, 2014



There are different ways to look at the use of non-renewable, depletable materials in our economy. The left bar of figure 3.1 shows the input (domestic extraction plus imports) of raw materials in our economy. Large parts of these inputs consist of re-exports or are used to make products that are exported. With regard to fossil fuels a lot of our input consist of the domestic extraction of natural gas. Part of this gas is due for export. In the middle bar all materials (raw, semi processed and final products) that are used for Dutch consumption (domestic extraction plus imports minus exports) are presented. In this case, for example, "metals" refers to products that primarily consist of metals. The right bar shows all natural resources that are extracted worldwide in order to fulfil our consumption needs.

3.2 Abiotic assets (renewable, non-depletable)

Renewable assets such as wind, solar and hydro energy play an important role in a CE because the shift from fossil fuels to renewable non-depletable energy sources can attribute to the reduction of the use of non-renewable depletable resources. In the Netherlands the share of non-depletable gross energy use in the total energy use was only 1.9 percent in 2015.

With regard to the use of energy sources there are often (as is the case for the Netherlands) policy programmes active that stimulate the transition to more sustainable energy use. The progress made on energy transition is already monitored extensively (Schoots *et al*, 2016). Therefore with regard to CE the focus is less on energy use. However, the materials used to build solar panels and windmills do receive special attention in the CE. Some of the required materials are considered critical in a sense that they are crucial to our economy and not widely available. In a transition to a CE one of the goals is to be become less dependent of the critical materials by replacing them with more commonly available materials or by recycling these materials. The extraction of some critical materials can have considerable impact on natural capital and ecosystem services due to the way mining takes place (e.g. water pollution and disruption of ecosystems) and the amount of energy that is required.

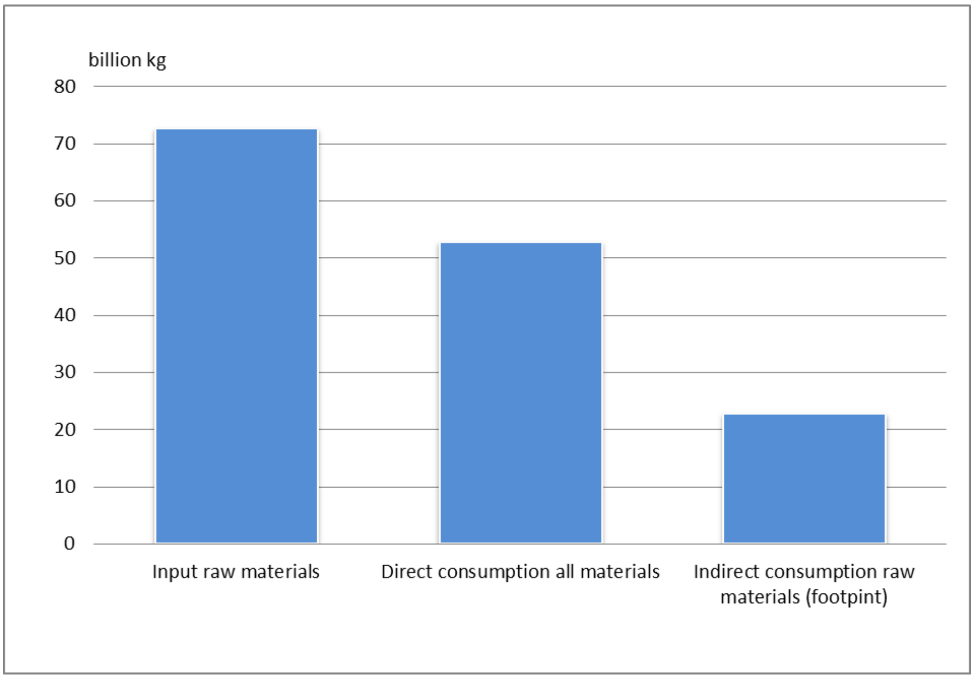
3.3 Ecosystem capital and ecosystem services

In natural capital acounting the ecosystem capital provides ecosystem services. Some of these services are also relevant for the CE. Here we will discuss the three ecosystem services flows as presented in figure 3.1: provisioning, regulating and cultural services.

3.3.1 Provisioning services

Provisioning services such as the extraction of crops, fish and timber (biomass) are part of both natural capital accounting and CE. Different ways to look at the use of biomass in our economy are presented in figure 3.3.1. In the left bar the input (domestic extraction plus imports) of raw biomass in our economy is given. Large parts of these inputs consist of re-exports or are used to make products that are exported. In the middle bar all products made of biomass (raw, semi processed and final products) that are used for Dutch consumption (domestic extraction plus imports minus exports) are presented. The right bar shows all natural resources that are extracted worldwide in order to fulfil our consumption needs. Indirect consumption is lower than direct consumption because The Netherlands export a relative high amount of high end biomass products such as meat. In order to produce these products a lot bulk biomass (animal feed) is used. In the right bar the export of high end products are converted to the raw biomass that was used to produce these products. In consequence the export flow is much higher than in the middle bar. This results in a lower indirect consumption.

3.3.1 Direct input, direct consumption and indirect consumption of biomass, 2014.



As mentioned before, provisioning ecosystem services play an important role with regard to the substitution of non-renewable and depletable resources with biomass (e.g. production of biobased plastics) or energy production. A higher demand for such ecosystem services requires more of the ecosystem assets that provide this service (in this case the production of biomass). In order not to deplete ecosystem assets they either have to produce more efficiently or more of these assets are required. More intense production per ha of agricultural land may lead to a deterioration of the assets condition, which would cause a decrease for the capacity of the asset to sustain production in the long term.

With regard to the production of biobased plastics, the substitution of fossil energy carriers for biomass is only part of the story in CE. Plastics including biobased plastics cause environmental problems of which the plastic soup in the oceans gets a lot of attention recently. Bringing disposed of plastics back in the production process will be one of the challenges in the transition to a circular economy.

3.3.2 Regulating services

A reduction of the quantity or quality of natural capital might lead to a decrease in the regulation and maintenance ecosystem services such as carbon sequestration, water purification or soil fertility. Fertile land is essential for agricultural activities. In the Netherlands, due to the intensive use of land for agricultural purposes there is a lot of pressure on soil quality. Maintenance of soil quality is important in order to preserve vital ecosystem services. The cyclical use of nutrients (like phosphorus and nitrogen) is important in this respect. These nutrients are essential to keep the soil fertile but at the same time their use, production and extraction can have negative impacts on (other) natural capital. For example, the use of phosphate can result in water pollution because not all phosphate is taken up by crops. Also, phosphate is made from phosphate rock, a non-renewable, depletable natural resource. Therefore it is important to use nutrients as efficient as possible and to regain nutrients from waste flows. These aspects are important for both natural capital accounting and CE. The Dutch CE policy programme also mentions the direct use of regulating services in order to reduce the use of primary resources. For example, in the case of flooding due to intense rainfall, instead of building large infrastructural systems to manage excess water, the natural water storage capacity of soils can be optimized by promoting the removal of paved surfaces. Another example is the use of green roofs. Among other advantages, green roofs are a natural way to insulate roofs for both heath and sound. In these cases non-renewable resources are replaced by ecosystem services.

3.3.3 Cultural services

The link between cultural services, like the amount of tourist that visit a nature park, and CE is not apparent. However, cultural services also contain intellectual benefits obtained from ecosystems through knowledge development.

3.4 Conclusions

Both natural capital accounting and circular economy are broad concepts in which all kinds of aspects are important. As a result both systems are linked together at different levels. With regard to the role of NCA in CE the following can be observed:

2) The use of non-depletable, renewable resources is an important aspect in both systems

3) The physical flows of provisioning services are recorded in both systems.

4) Regulating services play a role in CE if they reduce the amount of depletable, non-renewable resources.

5) Cultural services play a role in CE if they attribute to a solution to closing feedback loops in the CE.

A sustainable use of ecosystem services is one of the requirements in the transition towards a circular economy. Therefore the impact on ecosystem assets should be a prominent indicator while monitoring the transition towards a CE.

3.5 References

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