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Ecosystem accounting in the Netherlands

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ABSTRACT

In 2012, the Netherlands started the testing and production of high resolution, national scale ecosystem accounts following the methodology of the System of Environmental Economic Accounting – Experimental Ecosystem Accounting (SEEA EEA), in short 'ecosystem accounting'. The SEEA is endorsed by the United Nations Statistical Commission as a comprehensive system for analysing and recording physical and monetary information on ecosystems and human dependencies on ecosystems. Many other countries have been developing natural capital accounts following the SEEA EEA, but the Netherlands work was novel in the sense that a comprehensive set of accounts has been developed for the whole country, including high resolution maps and accounting tables of ecosystem type, condition, services, assets, carbon and biodiversity. The work involved over 10 man-years of work, and was carried out in a collaboration by the Netherlands Statistical Office (CBS) and Wageningen University. This paper presents the methodologies followed and results obtained, and reflects on the policy applications of the accounts. Some further testing and development of the SEEA EEA is needed and also the Netherlands accounts are not yet complete. Nevertheless, the lessons learned in the Netherlands are relevant for other accounting efforts world-wide.

1. Introduction

There is a general consensus that better and up-to-date information on the state and use of global ecosystems is needed in order to reduce and ultimately reverse their ongoing degradation (e.g. TEEB, 2010; Johnson et al., 2017). Furthermore, there is a widespread concern that decision making on renewable natural resources including ecosystems is biased by their lack of consideration in economic statistics including in indicators such as GDP (Van den Bergh, 2009; Guerry et al., 2015). This is the motivation behind the development of the System of Environmental Economic Accounting, or SEEA. The SEEA is a systematic statistical framework to measure and analyse natural capital, and the use of this capital by people. The SEEA is connected to the System of National Accounts, used by statistical agencies world-wide to record economic production and consumption and derive macro-economic indicators like GDP.

The SEEA is developed under auspices of the United Nations Statistical Commission and consists of two parts. The SEEA Central Framework was published in 1993 and updated in 2012 (UN et al., 2014a). It considers natural capital from the perspective of individual stocks of resources, and is generally used to measure non-renewable natural capital including water, oil, natural gas, and iron ore. The SEEA CF also measures physical flows between the economy and the environment and environmentally related transactions, such as environmental expenditures, within the economy. The SEEA Experimental Ecosystem Accounting (SEEA EEA), first published in 2014, takes a spatial and integrated perspective to measuring ecosystems and the services they provide (UN et al., 2014b). The SEEA EEA records ecosystem types, condition, use and asset value, as well as biodiversity and carbon contained in ecosystems and changes therein. A specific property of the SEEA EEA is that information is analysed and recorded both in the form of maps (of ecosystem types, a set of condition indicators, and a set of ecosystem services and asset indicators) and accounting tables.

Even though the SEEA EEA framework was published only recently, it is now being tested by statistical and environmental agencies in over 30 countries (UNCEEA, 2019). Comprehensive accounts of natural capital contained in ecosystems are being conducted in an increasing amount of regions, including but not limited to Andalusia (Campos et al., 2019), the Great Barrier Reef ecosystem, Australia (ABS, 2017),

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and the UK (e.g. Bright et al., 2019; Sunderland et al., 2018; ONS, 2016). However, there have been few tests of the complete system, i.e. involving all main accounts of the SEEA EEA, at high resolution and at national scale. In the UK, the Office for National Statistics (ONS) and the Department for Environment, Food and Rural Affairs (Defra) have made important progress in implementing the SEEA (Bright et al., 2019). Three types of SEEA EEA natural capital accounts were developed in the UK: (i) broad aggregate estimates of UK natural capital (estimates of physical and monetary ecosystem service flow and asset accounts); (ii) more detailed habitat-based ecosystem accounts, e.g. for woodland, freshwater, peatland and the urban environment, including the extent and condition of the habitat, as well as estimates of the ecosystem services provided; (iii) cross-cutting or enabling accounts for important natural assets such as land, carbon and water that feed into the habitat and aggregate accounts (ONS, 2016).

The approach taken in the Netherlands differs somewhat from that taken in the UK. The Netherlands SEEA EEA accounts were implemented in an integrated manner – covering all ecosystems – at the national scale, following a pilot in the province of Limburg conducted in 2010–2015 (Remme et al., 2014; Remme et al., 2015; de Jong et al., 2016; Remme and Hein, 2016). Hence, the Netherlands accounts are therefore the first accounts on a national scale that involve the complete testing of all six main accounts of the SEEA EEA. The objective of this paper is to present the accounts to a scientific audience inclusive of the scientific challenges encountered in the compilation of the accounts, and an explanation of how these challenges were addressed. We also present our experiences to date in connecting the accounts to policy makers and other users. Documentation of the development process at national scale was identified as a key necessity by a large body of experts (Bordt, 2018).

The novelty of the work is in the combination of spatial modelling and accounting, the work at high resolution (several meters for ecosystem type and most of the condition and services indicators) and at national scale, and in the strict adherence to statistical definitions postulated in the SEEA when defining and analysing ecosystem services and assets. Several types of mapping approaches and models are used to populate the accounts, including process based models and models to interpolate between data points. Models as well as valuation approaches bring uncertainties, which propagate through the accounts. The paper first sketches the methodologies followed in preparing the Netherlands ecosystem accounts, followed by an analysis of results obtained. In the Discussion we elaborate on uncertainties, methodological challenges, scientific implications of accounts as well as policy uses, and we end our paper with a concluding section.

2. Methodologies

The SEEA EEA framework comprises a set of interconnected accounts, see Fig. 1 below, covering the extent and condition of ecosystems (in biophysical terms), the supply and use of ecosystem services (in biophysical and monetary terms) and ecosystem assets (in monetary terms). Thematic accounts can be developed for specific policy relevant issues, such as biodiversity and carbon. In the Netherlands, we have developed all SEEA EEA core accounts and in addition two thematic accounts, namely the biodiversity account and the carbon account. Water accounts, including water supply and use tables and water asset accounts, were already developed in the Netherlands (Edens and Graveland, 2014), and the land accounts are less detailed than the extent accounts.

The development of the accounts was undertaken in close consultation with an advisory group including key stakeholders and potential users of the accounts. The advisory group comprised several senior policy makers and advisors from the Ministry of Agriculture, Nature and Food Quality and Ministry of Infrastructure and Water Management, as well as government research agencies including the National Institute for Public Health and the Environment (RIVM), Wageningen Environmental Research (WENR) and the Netherlands Environmental Assessment Agency (PBL).

2.1. Development of the ecosystem extent account

An ecosystem extent account was developed for the years 2006 and 2013, currently being updated to 2018. The ecosystem extent account includes a vector-based map of the ecosystem types of the Netherlands (Fig. 2) as well as a table showing the area of each ecosystem type in ha, and changes therein between 2006 and 2013. Ecosystem types were defined on the basis of (i) land cover; (ii) land use; and (iii) ecosystem services supply. The latter criterion implied that areas of particular relevance for the supply of specific ecosystem services were singled out. The main example of this is grasslands in and outside diked areas. The grassland outside dikes (i.e. along rivers) were classified as floodplains, in view of their importance for regulating water flows. In particular, such areas act as buffer areas during peak river flow. Clearly, land use, condition and ecosystem services supply are related, the flood plains are temporarily flooded (as opposed to grasslands within dikes), and are used mostly for seasonal grazing. Such ecosystem types thus still provide multiple services, as is in principle the case for all ecosystem types. Note that the methodology for defining ecosystem types is currently being defined in more detail in the revision of the SEEA (as managed by the UN Statistics Division) and that current thinking is that the focus for defining ecosystem types should be their key ecological characteristics.

Once the units (ecosystem types) were established, in consultation with the stakeholders represented in the advisory board, different map layers available at Statistics Netherlands were combined to produce the extent account. These data layers included: (i) the Digital Cadastral map; (ii) Crop plots (PBL, 2006, 2013); (iii) Regional Statistics (CBS, 2016, 2013); (iv) the Statistics Netherlands Dwelling register (Statistics Netherlands, 2006, 2013), (v) the Statistics Netherlands Addresses Geographical Base register (GBR) (Statistics Netherlands, 2006, 2013); (vi) Base register Addresses and Buildings (BAG) Dutch Communities (Statistics Netherlands 2006, 2013); (vii) the Base register Topography/Top10vector (BRT/Top10vector) (Cadastre, 2007, 2013); (viii) Statistics Netherlands Land Use map (BBG) (Statistics Netherlands, 2006, 2010) and (ix) the Boundary dunes map Natura2000 (Natura2000 Ecological network PBL; Netherland Environmental Assessment Agency Nota Ruimte); and (x) the Boundary riverbed map of PBL; Netherland Environmental Assessment Agency 2011).

2.2. Development of the condition account

The condition account presents indicators for the general condition or state of an ecosystem and indicators for pressure that can affect ecosystem functioning (UN, 2017). State indicators reflect the state or condition of vegetation, soil, water and/or air. Pressure indicators reflect pressures on the environment such as from pollution, ground water management and urbanisation. Pressures can affect the condition (or state) of ecosystems and thereby affect the services provided by ecosystems. The measurement of ecosystem condition is a central aspect of ecosystem accounting since (i) monitoring ecosystem condition is relevant for a broad range of environmental policies, for instance on water quality or biodiversity; and (ii) because condition relates to the capacity of ecosystems to provide ecosystem services into the future (UN, 2017).

For the condition accounts, the most policy relevant indicators were selected based on a number of consultations with the advisory board. The ecosystem condition account for the Netherlands was mainly based on existing datasets (such as the data on water quality reported to the EU on the Water Framework Directive). For some pressure indicators (such as eutrophication and acidification) existing datasets were combined with reference values from the literature to depict the current status. Datasets were used from among others RIVM, PBL and WENR. These datasets were sometimes combined with the extent map to obtain

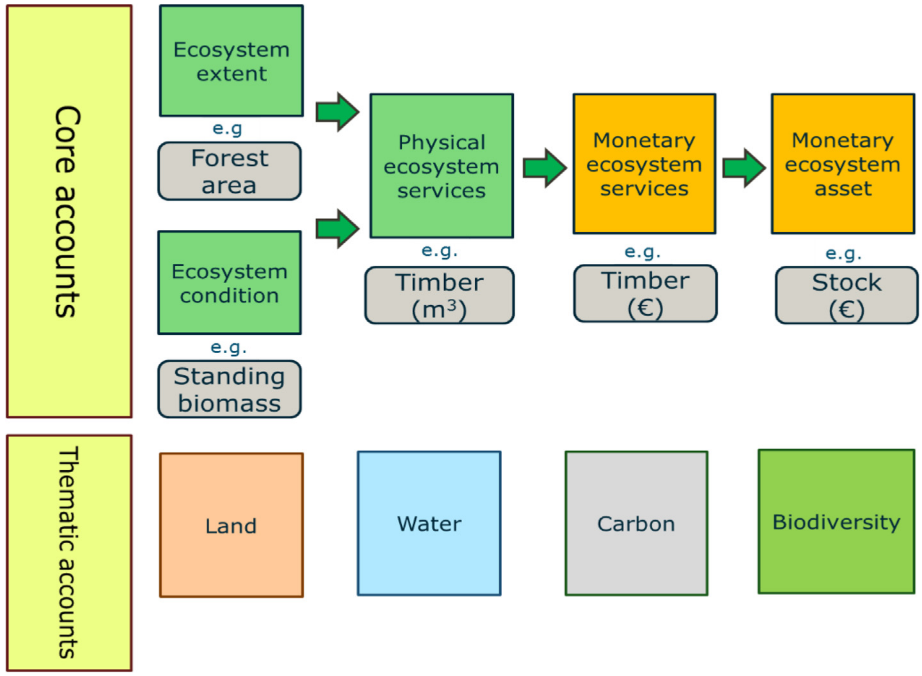

Fig. 1. The accounts of the SEEA EEA. Source: adapted from UN, 2017.

Fig. 2. Ecosystem Type map for the Netherlands for 2013.

datasets of specific relevance to the condition account (for instance to depict the spatial explicit condition of eutrophication or acidification). Where relevant, ecosystem specific limits (e.g. water quality standards) were used to indicate ecosystem condition vis-a-vis a benchmark. Based on the resulting maps, the ecosystem condition table was populated. The ecosystem condition account table was developed per ecosystem type given that condition indicators are usually relevant for a specific ecosystem, or for a cluster of ecosystems (e.g. an indicator may be relevant for all forest types but not for wetlands).

2.3. Development of the physical ecosystem services account

The biophysical ecosystem service supply and use account records the flows of ecosystem services from ecosystems to society, in physical terms. The flow is defined as the accumulation of a service in a given accounting period, usually taken as one year (but in principle accounts could also be compiled on a quarterly on monthly basis). Each service was carefully defined to represent the contribution of the ecosystem to economic activity, and was measured with different indicators, and at different resolutions.

Not all ecosystem services are straightforward to define. For example, the definition of 'crop production' is quite challenging, since a wide range of biophysical processes contribute to facilitating crop production by farmers (e.g. nutrient storage and release by soil particles, water holding capacity, and earth worm activity). In line with the SEEA EEA (UN et al., 2013) it was recognised that these individual processes cannot all be analysed and therefore, as a proxy indicator, the amount of crop yields was used as physical indicator (recognising that crop production is as much a function of ecosystem properties and processes as it reflects farmers' activities). The consequence of this approach is that the physical ecosystem services account shows higher physical output for the crop provisioning service (but generally not for other services) in intensive versus extensive agricultural systems, reflecting the use of higher quantities of fertilisers and pesticides, among others, in intensive systems. In the monetary ecosystem services account, however, the costs of fertilisers, pesticides and labour inputs are considered, thereby showing a more accurate reflection of the contribution of the ecosystem to agriculture compared to the physical account. In the SEEA EEA discussions the challenge of analysing the crop provisioning services in physical terms is acknowledged and various alternative approaches are being considered (e.g. Feyen et al., 2019; Vallecillo et al., 2019). These approaches, however, depend upon various assumptions to single out the key physical contribution of the ecosystem to crop production (e.g. soil quality, solar energy converted to crops). The limiting physical input to crop provisioning, however, differs strongly per ecosystem type, e.g., temperature in boreal areas, water in semi-arid areas, plant nutrients in many temperate agro-ecosystems), and there is as yet no generally applicable and accepted method for quantifying the ecosystem contribution to crop provisioning.

High-resolution spatial models were developed for a broad range of ecosystem services. Thirteen ecosystem services were modelled: five provisioning services, six regulating services and two cultural services. These ecosystem services were analysed and maps were produced. Based on the results from the spatial models biophysical supply tables are developed and analysed. The ecosystem services supply tables were developed for ecosystem types and for the Dutch provinces. Use tables are set up for the different economic sectors that benefit from the ecosystem services. For the use tables the International Standard Industrial Classification of All Economic Activities (ISIC) classification was used to identify user groups, supplemented by households, governments and a Global Goods category, which were essential for ecosystem services. The Gobal Goods category was added for carbon sequestration, as it is used by the global community. Users were defined as the users of the ecosystem service, not the final produced good. For example, the agricultural sector is the user of crop related ecosystem services, not the consumer that buys the processed produce. Ecosystem services were generally attributed to a single user group, unless no dominant user group could be identified. For location-bound ecosystem services the land owners were defined as users.

For mapping and modelling, two basic approaches are used: (i) downscaling of statistical information; and (ii) bottom-up modelling of ecosystem services. Provisioning services including crop production and water extraction (for drinking water) were mapped by spatially allocating information that was already present from specific statistics of other sources such as crop statistics, followed by basic modelling to assess the amount of service provided by each ecosystem type. Timber supply was modelled on the basis of the national forest inventory (Schelhaas et al., 2014; Probos, 2017), combined with the extent account for extrapolating data from the 3190 sample points of the national forest inventory. Information or regulating services are not included in the national accounts, and specific models were developed for each of the six regulating services. This involved a basic lookup table approach for mapping carbon sequestration and air filtration, to process-based modelling approaches for pollination, natural pest control and protection of floods from heavy rainfall (by permitting rapid infiltration of rainwater). For erosion control, a model based on the Revised Universal Soil Loss Equation was used from RIVM (RIVM, 2017). Pollination was the most sophisticated model developed for the accounts. The model estimate the contribution of pollination to crop yields, and allocates this contribution to landscape elements that are habitats for pollinators, specifically for wild bees and bumble bees. The model combines the following variables: (i) suitability of ecosystems such as hedgerows and forest patches as a habitat for pollinators; (ii) efficiency of pollination as a function of distance from these habitats; (iii) impacts of pollination on yields. Pest control only includes control of aphids by ladybugs. We consider pollination and pest control to be intermediate services provided by small landscape elements such as hedgerows and forest patches. They facilitate crop production in nearby fields, for those crops that require insect pollination (in the Netherlands, in particular, apples, pears, cherries, several types of vegetables, rapeseed).

Trade-offs between ecosystem services were taken into account to the extent possible with available data. For example, agricultural areas that produce annual crops for food production, could not contribute to annual carbon sequestration, as the entire crop is removed during harvest. Supplementary Annex 1 presents a brief overview of the modelling approach by ecosystem service, for more information the reader is referred to Remme (2018).

2.4. Development of the monetary ecosystem services and asset account

Valuation of ecosystem services. An important property of the SEEA EEA is that monetary valuation is conducted in a manner that is aligned with information in the standard national accounts (UN, 2017). This enables comparison of the supply and use of ecosystem services with the production and consumption of other goods and services and supports the use of ecosystem information in standard economic modelling and productivity analysis. A key concept in the SNA and the SEEA is that of 'exchange values' – i.e. the values at which goods, services, labour or assets are in fact exchanged or else could be exchanged for cash (currency or transferable deposits) (UN et al., 2009). For goods and services traded in a market, the exchange value reflects market prices. Market prices for transactions are defined in the SNA as amounts of money that willing buyers pay to acquire something from willing sellers; the exchanges are made between independent parties and on the basis of commercial considerations only. In this context, a market price should not necessarily be construed as equivalent to a free market price; that is, a market transaction should not be interpreted as occurring exclusively in a purely competitive market situation (UN et al., 2009). However, since many ecosystem services are not directly marketed, it is necessary to consider a range of approaches to the valuation of these services and to assess the consistency of those approaches with the concept of exchange value that underpins recording in the SNA (UN et al., 2013). Importantly, valuation approaches consistent with the SNA exclude consumer surplus, but include producer surplus and costs of production. The SNA includes specific value indicators such as gross and net value added and operating surplus. In the SEEA EEA Technical Recommendations, it is explained how these value indicators can be applied to and extended for the purpose of ecosystem accounting (UN, 2017). This difference in scope is a fundamental difference between valuation approaches applied in SEEA and values commonly used in environmental cost-benefit analysis (e.g. National Research Council, 2005). The implications of this valuation approach for the interpretation of the accounts are elaborated in the Discussion section.

An important consideration in SEEA EEA is how the values of ecosystem services and assets relate to those already in the national accounts. In particular, the value of ecosystem services that are used in SNA production or consumption activities may already (partly) be incorporated in the value of GDP (as measured in the SNA). For SNA production activities this is the case when (a) an actual rent payment takes place when the user is not the same as the legal owner of the underlying ecosystem asset, or (b) the user-owner has bought the ecosystem asset that provides the ecosystem service on the market. Examples include biomass provisioning services from agricultural (e.g. crop production) and forestry activity (e.g. timber production). In this case, valuation of the ecosystem services can be done on the basis of a lease price paid or with a resource rent (i.e. residual) approach (UN, 2017). In some cases the value of the ecosystem service itself is traded in the market, as in the case of standing stocks of timber that a land owner may sell to a logging company (the so-called stumpage value) – in which case this presents a more accurate value indication. Hence, in this case, the monetary ecosystem services supply and use account reflects the contribution of the ecosystem to the value of goods and services already recorded in the SNA. Ecosystem services may also directly contribute to household consumption, for example the expenditure related to nature-based tourism and recreation. This (extra) final household consumption is already included in GDP as measured in the SNA, but at the same time indicates the value attributed by households to an ecosystem service (e.g. recreation).

Other ecosystem services can be valued with exchange values that are not incorporated in GDP (as defined in the SNA). The value of all ecosystem services that are directly used for final household consumption, final government consumption, and exports are often provided 'for free' and thus not included in GDP (as defined in the SNA). Examples are air filtration and carbon sequestration. In addition, as discussed above, the value of some ecosystem services used by production activities is not included in GDP. Examples are marine fishing (when there is no direct payment for fishing licenses or quotas) or pollination for agriculture. When the value of an ecosystem service is not incorporated in GDP of the SNA, exchange values may be imputed using alternative valuation methods, such as the replacement costs and avoided damage costs methods. The challenges in valuing these services is that part of the benefits of these services reflect consumer surpluses. For instance, in the case of air filtration, people may be willing to pay for reduced disease incidence or a longer life expectancy, even though this is not reflected in any productive measure. Valuation of these services for SEEA needs to carefully filter out value elements related to the consumer surplus. In the case of air filtration, for example, this entails valuing aspects such as reduced medical costs for treatment of air pollution related diseases, or reduced work-days lost because of cleaner air.

Clearly, double counting of values – which is a particular risk in the case of services that are already partly or fully covered in the SNA, should be avoided, and the value of ecosystem services cannot be added to GDP. The SEEA EEA integrated accounts (that were not yet developed in the Netherlands) serve to connect the SEEA EEA and the SNA (UN, 2017).

A key issue in monetary valuation is what methods should be used to measure the monetary value of each ecosystem service. The choice of the applied valuation technique may significantly affect the outcomes. Our selection of methods was guided first of all by an assessment of potentially suitable valuation techniques presented in the SEEA EEA technical recommendations (UN, 2017). In addition, the distinction between values incorporated in the SNA or not as described above helped to select the most appropriate valuation technique. Finally, we have selected methods that can (as much as possible) be based on existing statistical economic data, such as national accounts statistics, production statistics, price statistics, tourism statistics, etcetera. Where possible different methods were applied and tested to arrive at the best possible results. We found that, from a conceptual and practical point of view, the best valuation techniques to apply are: (i) for provisioning services: Rent-based methods (e.g. stumpage prices, rent prices for agricultural land); (ii) for regulating services: Replacement costs or avoided damage costs methods; and (iii) for cultural services: consumer expenditure and hedonic pricing. Supplementary Annex 2 provides further details.

In the monetary *supply* table the value of ecosystems services is allocated to different ecosystem types, i.e. the units producing specific ecosystem services. Monetary values were distributed to ecosystem types based on the physical values in the biophysical maps of ecosystem services. In the monetary *use* table the value of ecosystems services is allocated to the users of these services. Users include economic units classified by industry, government sector and household sector units, following the conventions applied in the national accounts. The users of the ecosystem services correspond to the beneficiaries that were identified for each ecosystem service, see Hollings et al. (2019) for details.

Valuation of ecosystem assets. Consistent with the SEEA EEA methodology (UN, 2017), the value of ecosystem assets was derived using the Net Present Value (NPV) approach. Applying a NPV approach requires assessing the present and expected future flow of all ecosystem services, and aggregating the NPV of each service flow. Changes in future flows of service, for instance due to ecosystem degradation or depletion of resources (e.g., timber) due to overharvesting need to be considered by reducing flows of ecosystem services supply in future years. Based on past trends, it was assumed for the Netherlands accounts that all flows remain constant, i.e. that there is no degradation resulting in a decrease in ecosystem service flow in the coming decades. Even though there are no marked, national scale trends towards ecosystem degradation, this is an assumption that requires further testing when the next set of accounts is produced. Furthermore, it is assumed that there are no changes in prices for ecosystem services (which, with increasing ecosystem capital scarcity and therefore potential upward pressure on such prices, may lead to an underestimate of the value of ecosystems). Asset life is 100 years – i.e. it is assumed that the ecosystem 'produces' ecosystem services for a period of 100 years (in line with the British Statistical Office, ONS, 2016). This period is somewhat arbitrary, but values provided after 100 years do not contribute much to the Net Present Value because of the discount rate applied. A key element in assessing NPV is the discount rate. Over the years, there have been various interdepartmental working groups to determine the discount rate to be used by the Dutch government in public cost-benefit analyses. The 'Werkgroep Discontovoet' (2015) advised adjusting the discount rate for public investments to 3 percent. For nature, the advice is to take into account increases in the relative price, due to increased scarcity and limited substitution possibilities, and resulting in an effective discount rate of 2 percent. The Netherlands Environmental Assessment Agency (PBL) recommends using the normal discount rate of 3 percent for provisioning services, such as in agriculture or timber production (Koetse et al., 2017). For services that can hardly be replaced, they recommend a discount rate lower than 2 percent. In line with these recommendations, in the Dutch accounts, we apply the 3 percent discount rate for provisioning services and cultural services. For regulating services, which are scarcer and harder to substitute, we use a discount rate of 2 percent.

2.5. Development of the biodiversity account

The Biodiversity Account for the Netherlands builds upon guidance provided by the Convention on Biological Diversity (CBD) and SEEA EEA. The CBD, in its 2010 global biodiversity targets proposes a series of sets of indicators of which the ones for status and trends of the components of biological diversity are of direct relevance for the SEEA EEA biodiversity account (CBD, 2006). Additional groups of indicators for e.g. threats to biodiversity, ecosystem integrity, and accessibility are more appropriately covered by the SEEA EEA Condition account. Indicators proposed include a) trends in extent of selected ecosystems, b) trends in abundance and distribution of selected species, c) trend in status of threatened species and d) changes in genetic diversity. These indicators are comparable with indicators mentioned in the SEEA EEA technical guidance document on experimental biodiversity accounting (UNEP-WCMC, 2015), which focusses on 3 tiers, ranked by increasing information requirements: 1) ecosystem extent, 2) species richness, distributions and 3) species abundance.

The Netherlands' biodiversity account includes specific indicators related to all three tiers. Tier 1 is mainly implemented through the ecosystem extent account and the associated ecosystem type map of the Netherlands. Examples of tier 2 indices include the length of the Red List of endangered species (CBS et al., 2018a), the presence of characteristic species per ecosystem type (CBS et al., 2018b) and a novel method to spatially map species richness for selected species groups (butterflies, dragonflies), using probabilistic stacking of species distribution maps obtained through occupancy modelling (van Strien et al, 2013; Remme et al., 2016; Bogaart and de Jong, 2018). In tier 3, species level abundance and /or distribution trends are aggregated, either for the Red List of endangered species, by species group (mammals, breeding birds, reptiles, amphibians, butterflies, dragonflies and fish) or by broad habitat to form the Living Planet Index (van Strien et al., 2016; WWF, 2018).

2.6. Development of the carbon account

The carbon account provides a comprehensive overview of all relevant carbon stocks and flows in the economy and in ecosystems. This account was developed to allow for a consistent and quantitative comparison of carbon stocks and flows in the reservoirs 'biocarbon' (organic carbon in soils and biomass), 'geocarbon' (carbon in the lithosphere), atmospheric carbon and carbon in the economy. Hence, the account provides a comprehensive overview of stocks of carbon in its many different forms and the ways in which carbon flows through these different reservoirs.

The inputs to the account were modelled in a spatially explicit manner. For biocarbon, existing models and data describing biocarbon were combined with new data and with the Ecosystem Unit map for the Netherlands (EU_NL map, Statistics Netherlands, 2017). Both the stocks of carbon (in soils, peatlands and above and belowground vegetation) and flows (sequestration in living vegetation, emissions from soils and wetlands) were analysed in detail. CO2 sequestration was modelled using a quantitative look-up table (LUT) approach that linked ecosystem type from the extent account to sequestration rates (Lof et al., 2017). The biocarbon stock in soils was based on data from Wageningen Environmental Research (Lesschen et al., 2012). CO2 emissions in Dutch peatlands were modelled based on ground water levels in the peat. In turn, ground water levels were modelled based on ditch water levels, following Van den Akker et al. (2010), who calculated CO_2 emissions from subsidence of peat soils in the Netherlands. Emissions from peat and peaty soils was therefore calculated based on an in 2014 actualized soil map from the Netherlands (de Vries et al., 2014) and a map developed for PBL (2016) that depicted the ditch water levels in an area that is managed by seven water boards. For the remaining peat and peaty areas we used the ground water tables to estimate subsidence rates.

For geocarbon, data were derived from existing asset accounts for fossil fuels. These data were complemented with additional data on other types of geocarbon. Data on atmospheric carbon were derived from the national air emissions inventory and air emission accounts, whereas the information on carbon in the economy was primarily derived from the national greenhouse gas inventory report (Coenen et al., 2016), see Lof et al. (2017) for details. Carbon in the oceans was not included in this carbon account due to a lack of data.

3. Results

3.1. Ecosystem extent account

In Table 1 the aggregated ecosystem extent accounting table (for terrestrial and freshwater ecosystems) for the Netherlands for 2006 and 2013 is presented, and Fig. 1 presents the map for 2013. The account includes 31 ecosystem types, grouped into 5 main classes: agricultural land, dunes and beaches, forests and other (semi)natural environments, temporarily inundated land, built up and paved areas, and water. Table 2 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 km^2, whereas in 2013 this total extent had increased to 427 km^2 (thus showing a net increase of 33 km^2). 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 (not shown in this publication, but see CBS (2017) for detail). The most significant change in this period is the reduction in agricultural land in the Netherlands from 46% to 45%, and the increase in built-up areas. There is a minor increase in natural areas including forests and heathlands. The increase in wetlands shown in the table may be an artefact of a finer resolution applied in 2013, which means that a larger number (and area) of ditches and canals shows up in the map – actual changes in wetlands need to be analysed based on the planned update of the account to 2017.

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

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	3,846	3,815	9.3	9.2
Unknown/null	6	8	0.01	0.02
The Netherlands	41,539	41,539		

3.2. Condition account

The condition account brings together indicators on several aspects of ecosystem condition (such as vegetation cover, air quality, soil properties and biodiversity) to provide a comprehensive overview of the status of the Netherlands' ecosystems. By bringing together information sets that have, to date, been reported separately, a more informed picture can be given of where there are critical trends in ecosystems, and which parts of ecosystem condition are most relevant for policy makers to focus on. Fig. 3 shows an example of a map included in the condition account. The full account can be found in Lof et al. (2019).

The condition account shows that a very large fraction of the natural ecosystems experience eutrophication and acidification. Almost 100% of all forest, heath land, natural grassland and freshwater wetlands experience eutrophication, and almost 100% of the heathland and natural grasslands experience acidification. Due to the spatial distribution of nitrogen deposition (e.g. lower deposition near the coast and in the north of the Netherlands), dunes are relatively less affected by eutrophication. Nevertheless, still almost half of the dune area experiences eutrophication. Eutrophication can affect the competition between plant species and therefore alter species composition. For instance, increased nutrient availability in heath land favors fast growing grasses over slow growing heath vegetation, which potentially affects the ecosystem services that the ecosystem provides.

The (non-spatial) biodiversity indicator "characteristic species" shows that the ecological quality of all natural ecosystems is lower than of an intact ecosystem for all monitored ecosystem types. For forest, heath and natural grasslands only about 33% of the characteristic species are present, while for dunes and fresh water wetlands about

Table 2
Biophysical ecosystem service supply account 2013 for the Netherlands, with total biophysical supply per ecosystem unit.

Ecosystem service	Unit	Agriculture	Forest	Health	Sand/beaches/ dunes	Wetlands	Other unpaved terrain	Public green areas	Built-up and paved	Inland water	Sea	Unknown/null	The Netherlands
Area	ha	1,87,620	309,640	40,810	52,250	34,350	433,770	68,420	539,660	420,840	381,510	1,230	4,154,080
Crop production	ktons	16,258	0	0	0	0	0	0	0	0	0	0	16,258
Fodder production	ktons	15,698	0	0	0	0	340	0	0	0	0	0	16,038
Wood production	1000 m^3	0	1,035	0	50	0	0	0	0	0	0	0	1,085
Biomass production	ktons	0	0	0	0	0	359	0	0	0	0	0	359
Drinking water production	Min m^3	8,591	8,115	1,405	10,944	143	4,830	1,197	5,226	861	0	1	41,313
Carbon sequestration in biomass	ktons	203	585	8	30	8	123	18	0	0	0	0	975
Pollination													
Natural pest contrail	–	–	–	–	–	–	–	–	–	–	–	–	–
Erosion control	ktons soil	1,117	1,314	175	214	39	1,106	159	761	2	0	0	4,887
Air filtration	tons PM_{10}	6,405	14,912	145	463	114	1,553	0,252	0	0	0	0	23,844
Protection against heavy min liters in rainfall	1 hour	402,772	184,267	23,571	28,387	7,066	131,757	26,412	98,760	0	0	134	903,126
Nature recreation (hiking)	min hikers	5,863	6,235	836	2,062	453	3,950	3,251	0	1,388	15	6	24,059
Nature tourism	X1.039 tourists	5,590	1,630	264	3,120	103	1,569	256	0	372	0	0	12,916

[1]Pollination and pest control cannot be added in this table due to the set-up of the indicator.
[2]Including (semi) natural grasslands, river floodplains and salt marshes.

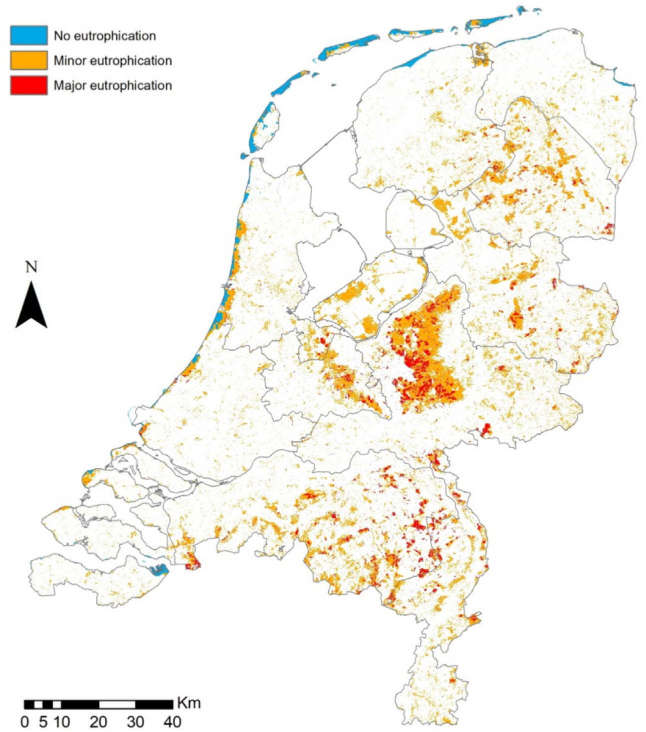

Fig. 3. Example of a map in the Condition Account: Eutrophication based on nitrogen deposition in the Netherlands and critical deposition in semi-natural and natural ecosystems (forests, dunes, heath, inland sand, freshwater wetlands, natural grasslands and salt marshes). Deposition rates are compared with critical deposition levels (that vary per ecosystem) described in Dobben et al. (2012). See Lof et al. (2019) for details.

47% of the characteristic species is present. In addition, the biodiversity indicator "Living Planet Index" shows that in several ecosystem types (e.g. heath, dunes, agricultural areas, urban areas and marine ecosystems) biodiversity has decreased since 1990. On the other hand, biodiversity in forests, coastal areas and the Wadden Sea have remained relatively stable. The biodiversity of fresh water swamps has increased since 1990.

The air quality meets the limits for the annual daily mean set by EU in more than 99.9% of the area. However, in the majority of the area, the annual daily mean does exceed the more stringent threshold set by the World Health Organisation (WHO), especially for $PM_{2.5}$. For PM_{10}, the air quality exceeds the WHO threshold in more than 60% of the urban areas. Generally, the air quality is best in the north of the Netherlands.

3.3. Physical ecosystem services account

The physical ecosystem services account includes maps for each ecosystem service and accounting tables specifying the supply by ecosystem and the use of each ecosystem service by economic sector. By definition, use equals supply (although demand for a service may be higher). An example of an ecosystem service map is provided in Fig. 3. Fig. 3 shows the map of the pollination service. This map shows the contribution of different ecosystems to crop pollination. Specifically, the service (i.e. the contribution of the ecosystem) is to provide a habitat for crop pollinators including wild bees and bumble bees that are subsequently able to pollinate a variety of crops (such as apples, pears, rapeseed, and various vegetables). The service was modelled by analysing the impact of pollination on crop production, by crop, the habitat suitability of different landscape elements for pollinators, the flying range of bees and bumblebees, and the distance of crop fields requiring pollination to landscape elements harbouring pollinators. The result,

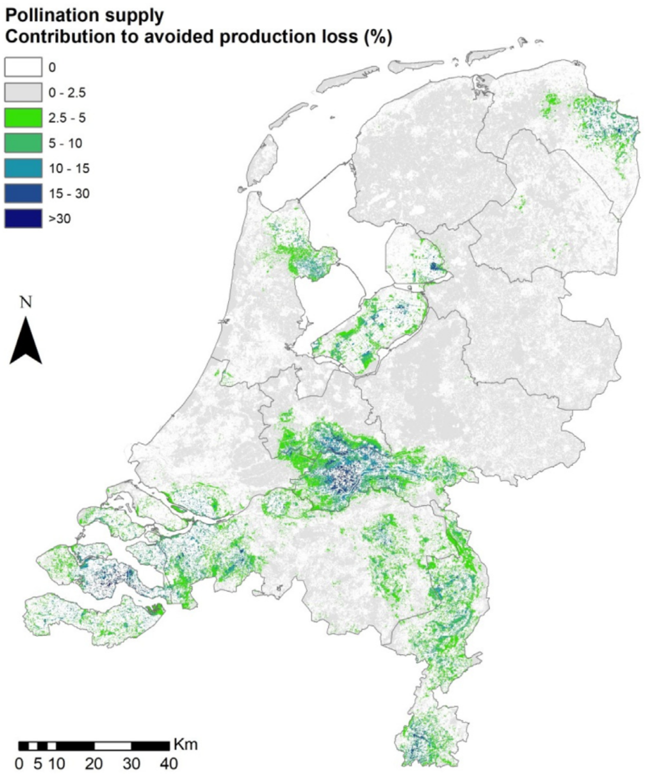

Fig. 4. Example of ecosystem supply model result map. Ecosystem contribution to avoided production loss (%) due to the presence of pollinators. The map shows the avoided production loss due to the presence of natural pollinators for all crops requiring pollination (e.g. apples, pears, rapeseed, various vegetables).

for this service, is shown in Fig. 4. The report Remme (2018) presents the results including maps for all services.

The biophysical supply tables is presented in Table 2 below. The supply table shows that forests and agricultural land supply the highest total quantities of ecosystem services, partly because these ecosystem types cover the largest extents. More natural ecosystem types (e.g. dunes, heath and broad leafed forest) supply a larger variety of ecosystem services (per ha) compared to less natural ecosystem types. However, since each service is expressed in different indicators, quantities of different services cannot be added. 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 province in the south of the country has a relatively high supply of ecosystem services per ha, supplying all ecosystem services at or above national average levels. Nationally it is known for its diverse landscape and attractive environment, and the province attracts a large share of national tourists. The biophysical use table is not included in this paper, but can be found in Remme (2018). The use account shows how ecosystem services are used by economic sectors. The ISIC sector Agriculture, forestry and fisheries uses the most ecosystem services (seven), followed by households (four). The use of ecosystem services erosion control and protection against flooding from heavy rainfall has been allocated to sectors based on land ownership (see Remme et al., 2018 for details).

3.4. Monetary ecosystem services and asset account

The monetary ecosystem services account records the monetary value of ecosystem services flows during the accounting period (e.g., one year). The monetary asset account records the net present value of ecosystem assets, based on the expected flow of ecosystem services over the lifetime of the asset. In the Netherlands, the monetary ecosystem

Table 3
Value of ecosystem service flows and associated asset values in 2015 (millions of euros).

Class	Ecosystem service	flow	asset
Provisioning	Crop production	415	13,125
	Fodder/grass production	872	27,569
	Timber production	44	1,381
Regulating	Water filtration	177	7,620
	Carbon sequestration	171	7,391
	Pollination	359	15,470
	Air filtration	86	3,700
Cultural	*Nature recreation*	*2,012*	*63,586*
	Nature tourism	*1,146*	*36,218*
	Amenity services	1,037	32,402
TOTAL		**6,320**	**208,461**

services account and the monetary asset account have been combined in one report (Horlings et al., 2019). In principle, the monetary asset accounts records closing and opening stocks of ecosystem assets, measured at the beginning of the accounting period (e.g., 1 January) and the end of the accounting period (e.g., 31 December). However, given the difficulties encountered in the Netherlands in pinpointing the precise value of the opening and closing stocks on a specific day, the asset value has been assessed in terms of an annual average (see Horlings et al., 2019 for details).

Table 3 presents the results on an aggregate level. Values for nature related tourism and recreation, which were calculated with the expenditure method, provided the highest values. These expenditures include travel costs to natural areas and admissions fees to national parks (for only few national parks entry fees have to be paid, and over 95% of value is from travel costs). Note that this limited scope for valuing tourism and recreation underestimates the value of this service: expenditure for accommodation, food and drinks and other related expenditure (mainly consumer durables, e.g. fishing gear) are excluded. The study Horlings et al. (2019) includes estimates for the value of this service if these other costs are considered as well. Table 3 also shows the asset value generated through these services.

The total value of ecosystem service flows is 6.3 billion euros and the associated value of ecosystem assets is estimated at 208 billion euros. Further research is needed and discussions with national stakeholders as well as other countries working on the SEEA, are required to come to a better understanding of how nature related tourism and recreation can be best valued. Also, the accounts are not yet complete, several services such as those related to marine fishing and coastal protection are still missing.

The monetary asset account for the Netherlands is presented in Horlings et al. (2019). Almost three quarters of the value of ecosystem assets was related to three ecosystem types, namely agricultural land (38%), dunes and beaches (18%), and forest (16%). The highest values per hectare are found in the ecosystem types dunes with permanent vegetation, active coastal dunes, beach, and public green space. The lowest values per hectare – with asset values mostly under 10 thousand euros per hectare – are found in the various ecosystem types in built-up terrain and water. The report Horlings et al. (2019) provides a more detailed description of the results, including a description how these results can be integrated in the SNA.

3.5. Biodiversity account

A summary of the biodiversity account for the Netherlands is provided in Table 4, covering ecosystem extent and ecosystem quality in terms of the relative abundance of characteristic species, as quantified by the Living Planet Index (LPI, see Section 2.5). Changes in LPI are interpreted by taking uncertainties and

interannual variation into account. During the accounting period 2006–2013 the overall LPI for the Netherlands remained relatively

Table 4
Biodiversity account for the Netherlands, 2006–2013.

Ecosystem (sub)type	Extent (ha)			Living Planet Index		
	2006	2013	Change	2006	2013	Change
Terrestrial				85	87	+2%
- Forest	326,903	329,540	+1%	93	98	+5%
- Heathland	38,343	41,493	+8%	42	37	−12%
- Coastal dunes	24,010	22,049	−9%	57	54	−5%
- Semi-natural grassland	49,841	57,790	+14%			
Freshwater				144	144	0%
- Open water	408,344	421,246	+3%			
- Wetlands	37,006	47,669	+22%			
Agricultural	1,867,094	1,822,362	−2%	63	56	−11%
Urban	519,289	546,967	+5%	63	56	−11%

stable. Besides this aggregated LPI, LPIs for smaller aggregates and individual ecosystem types were analysed. Of these, forest was the only ecosystem type for which the LPI was significantly increasing, while the LPI for heathland was strongly decreasing, despite an increase in extent. LPI for most other natural ecosystems remained stable. This in contrast to the LPIs for anthropogenic ecosystem types (Agriculture and Urban), which were decreasing significantly. See Bogaart et al. (2019) for more details. Currently, a spatial biodiversity account is being developed, building upon Remme et al. (2016), showing changes in species richness over time for quadrants of 5 by 5 km covering the whole country, for selected species groups (butterflies, potentially in the near future also vascular plants, birds and dragon flies).

3.6. Carbon account

The carbon account provides a comprehensive overview of currently available and newly developed data on carbon cycles in the Netherlands, integrating carbon in the economy and in ecosystems. The account has four different 'storage' types including: geocarbon (in oil and natural gas reserves), biocarbon (carbon contained in ecosystems including carbon in above ground and below ground biomass and in soils), carbon in the economy and carbon in the atmosphere. Currently, data were only provided for one year, 2013, but part of the value of the approach (as with the other accounts) is to assess also changes over time. Table 5 provides an overview of the overall carbon account for the Netherlands.

The carbon accounts clearly illustrate the heavy dependency on fossil fuels in the Netherlands, and the difficulties of replacing fossil fuels with renewable energy sources from national biomass sources. Emissions to the atmosphere by far exceed carbon sequestration rates, resulting in a net positive balance for carbon in the atmosphere. The Dutch ecosystems at present are a source rather than a sink for carbon due to ongoing oxidation of organic matter in peat soil, which are mostly drained and used for dairy farming. Although carbon sequestration is important in forests, meadows and natural grasslands, the total annual sequestration of carbon in above and below ground plant biomass is currently exceeded (by around a factor two) by the emissions from peat and peaty soils. Similarly, the carbon in the economy account shows that although some materials have recycling rates exceeding 90%, recycling rates of e.g. wood waste still need substantial improvements.

The carbon account as proposed in this article may serve as a format to improve current reporting on carbon. It is consistent with obligatory reporting of SEEA CF related accounts to Eurostat (Material flow accounts, Air emissions account). Moreover, because the structure, concepts and classifications of the carbon accounts are consistent with the system of National accounts (SNA) the data can be directly compared with all kinds of macroeconomic indicators. Compared to the current LULUCF reporting the accounts are spatially explicit which provides important additional information for policy applications, for instance land use planning.

4. Discussion

4.1. Uncertainties and methodological challenges in the compilation of the ecosystem accounts

Ecosystem accounts are still relatively novel at all scales, but specifically at national scale, with only very few extensive examples. One of the most notable examples are the UK Natural Capital accounts (Bright et al., 2019). Fully worked examples that follow the SEEA EEA guidelines were lacking during the development of the Dutch accounts, providing freedom to explore, but also minimal guidance for several accounts. While there are documented physical ecosystem service accounts (e.g. La Notte et al., 2017), including pilots from within the Netherlands (Remme et al., 2014; de Jong et al., 2016), there were no fully developed national condition accounts, biodiversity accounts or asset accounts when the project was initiated. Therefore, the latter accounts represent a more experimental interpretation of the SEEA EEA guidelines than the physical and monetary ecosystem accounts, which have been more extensively documented in the UNSD's process.

Previous ecosystem accounting studies have outlined a broad set of limitations and challenges when developing ecosystem accounts (e.g. Hein et al., 2015; Remme et al., 2014; Sumarga et al., 2015; Obst, 2015; Lai et al., 2018). General limitations span a large range of issues, such as the large diversity in quality and quantity of relevant data, the experimental phase of accounting guidelines that are frequently updated, and discussion on the applicability of valuation methods. Consequently, the accuracy of the models varies considerably between the different ecosystem services, as does the type of uncertainty involved. For carbon sequestration. Our lookup table approach is relatively crude: irrespective of successional stage all ecosystems of a certain type accumulate the same amount of carbon, on an annual basis. In the future, we may be able to estimate carbon sequestration based on remote sensing derived estimates of changes in aboveground standing biomass, plus a correction factor to account for accumulation or losses of soil carbon. For crop provisioning and tourism, our aggregate estimate corresponds with the numbers in the national accounts and we applied a spatial allocation – hence the uncertainty is related to the spatial distribution of our values and less so to the overall aggregate (obviously there is also a degree of uncertainty in the numbers presented in the national accounts). The pollination model that we developed for the account is relatively sophisticated from a computational perspective, however clearly it is based upon a range of assumptions (average flying distance honey bees and bumble bees, pollination dependency of crops, habitat suitability for pollinators). Pending further local data on actual pollination rates and pollinator densities in the various ecosystem types the accuracy of the model cannot be tested. It can be expected that the accuracy of the numbers in the ecosystem accounts can be improved over time, and that lessons learned could be relevant for other countries developing accounts (Ruijs et al., 2018).

A specific challenge to accounting, which is of course not restricted to the Netherlands, is that the default for accounting is to use datasets published by the government and the various research agencies reporting to the government. In some cases, it is apparent that there are limitations to using these datasets for national ecosystem accounting, which may show up for example when such datasets are compared with related indicators. In the case of the Netherlands, for example, there are reasons to question the accuracy of the air quality data, in particular the maps depicting PM concentration. These are based on extrapolations of data from limited sampling stations (around 40 air quality sample stations for the whole Netherlands), and there appear to be underestimates of some type of emissions (e.g. PM from residential wood combustion) (Hein, 2018). Nevertheless, the Dutch accounts have used these sets as input data. Clearly, this may affect the physical supply and

Table 5
Carbon account for the Netherlands (2013) in Mton C. Grey cells are null by definition.

Mton C	Geocarbon: Oil	Geocarbon: Gas and shalegas	Geocarbon: Coal	Geocarbon: Limestone and marl	Geocarbon: Total geocarbon	Biocarbon: Forests	Biocarbon: Cropland / meadows	Biocarbon: Other ecosystems	Biocarbon: Total biocarbon	Carbon in the economy: Inventories	Carbon in the economy: Fixed assets, consumer durables	Carbon in the economy: Waste	Carbon in the economy: Total carbon in the economy	Carbon in the atmosphere: Total carbon in the atmosphere	Total
Opening stock	54	627	12717		13398	48	206	123	377	24			24	3193	16993
Additions to stock	0	0	0	0	0	0.6	0.2	0.2	1.0	251	2	10	263	64.2	329
Natural expansion						0.6	0.2	0.2	1.0					1.8	3
Managed expansion										50			50	62.4	113
Discoveries	0	0	0		0										0
Upwards reappraisals	0	0	0		0										0
Reclassifications										15	2	6	23		23
Imports										186		4	190		190
Reductions in stock	1	41	0	0	42	0.6	1.3	0.6	2.4	246	0	10	256	9.4	310
Natural contraction						0.1	1.3	0.5	1.9					1.0	3
Managed contraction	1	40	0	0	41	0.5	0.0	0.0	0.5	60		3	62	8.5	113
Downwards reappraisals	0	1	0		1										1
Reclassifications										19	0	5	23		23
Exports										168		3	170		170
Net carbon balance	-1	-41	0	0	-42	0.0	-1.1	-0.4	-1.4	5	2	0	7	54.8	19
Closing stock	53	587	12717		13356	48	205	122	376	30			32	3248	17012

value of ecosystem services, in the Netherlands case the service 'air filtration'. The resulting inaccuracy could not be quantified.

Specific challenges apply to the monetary accounts, in particular because there are still some pending methodological questions related to the most appropriate valuation method for individual ecosystem services. A first issue is that the resource rent method – which is recommended in the SEEA EEA Technical Recommendations (UN, 2017), produces estimates with high margins of uncertainty and, consequently, high annual volatility, for instance when the resource rent of crop provisioning services is assessed. The uncertainty is in part caused by the various assumptions required for estimating components of the resource rent formula such as the wages for self-employed entrepreneurs. The second problem is that in many industries, market conditions eliminate rents. A key assumption of the resource rent method is that the economic value of an ecosystem service is fully captured in the price of output. However, this is contingent upon the behaviour of resource owners (entrepreneurs) who the price they are willing to accept based on market conditions and the money value of expenses. As the number of competitors for rent increases, the proportion of rent each competitor can claim declines (Torvik, 2002). Under perfect competition rents tend to zero. For example, agriculture and tourism are markets with near-perfect competition, while the drinking water industry is highly regulated. In all three cases, estimates of the resource rent are very low, sometimes even negative. In response, wherever possible, alternative valuation methods were applied. Crop provisioning from agricultural land was valued based on the market fees (rent) farmers pay to use cropland of different quality (soil versus clay). Water provisioning for drinking water production from groundwater, and water filtration in dunes were valued using a replacement cost method (i.e. the costs of physical and chemical treatment of river water to produce drinking water). Therefore, in our accounts, we have used actual rents to value the crop provisioning service and replacement costs to value the drinking water provisioning service. A third, more general, challenge pertains to the assumptions required for analysing the NPV: which discount rate is appropriate? (e.g. compared to current market interest rates a 3% discount rate for provisioning services seems high). Furthermore, it is doubtful that indeed the future flow of income for each ecosystem services can be assumed to be constant and equal to the flow observed most recently, as it is unlikely that physical flows and exchange values of services will be constant.

A specific issue is the delineation of nature-related tourism and recreation, and the valuation of this service. In particular because this service has the highest monetary value it is of high priority to clarify if and how they can be measured in such a way that overlap is avoided. For instance, in the UK Ecosystem accounts there is no distinction between tourism and recreation (e.g. ONS, 2016). It also requires further work to establish if and if so to what degree expenditure of tourists in hotels and restaurants, etc. can be attributed to ecosystems.

4.2. Inherent limitations in the ecosystem accounting approach

There are important limitations in the SEEA EEA accounts now developed for the Netherlands, and most of these are inherent to the SEEA EEA accounting approach. It is crucial that these limitations are considered in the interpretation of the information in the accounts.

First, most aspects of the SEEA EEA accounts are included for the Netherlands, but the accounts do not cover all ecosystem services, all relevant aspects of ecosystem condition, and all relevant indicators of biodiversity. Second, the valuation approach of the accounts is consistent with the SNA and therefore limited in scope. In particular, as mentioned above, the consumer surplus is excluded from the valuation approach. Therefore monetary information in the accounts should never be used as proxy for the 'total' value of ecosystems. Consequently, the accounts inform on the contribution of ecosystem to consumption and other economic activities, which is policy relevant, but they do not inform on the welfare ecosystems generate for people. There is a parallel here with GDP as an indicator for economic production. GDP not only omits the environment (the SEEA was designed to deal with this shortcoming), but it also excludes consumer surplus, fails to assess social and organisational changes in human capital, and often masks economic and social inequities (Giannetti et al., 2015).

Third, ecosystem accounts are not well suited to deal with uncertainties and complex ecosystem dynamics including ecological thresholds and stochastic events (e.g. Scheffer et al., 2001). In theory, these dynamics can be considered, but it is often not precisely know how and when a threshold in ecosystem state will be surpassed in the future and what the impacts of this change on ecosystem services supply will be. In this case, the resulting change in ecosystem services supply can be considered in the asset account that presents a net present value of the expected flow of ecosystem services. However, in practice, there is often too much uncertainty regarding both the occurrence and the impacts of such changes to include them in the accounts. These various limitations mean that care needs to be taken in presenting the SEEA ecosystem accounts to users and policy makers. The accounts provide a potentially suitable tool to inform policy and planning, but they cannot be used as the only basis for decision making. Inherent and data-driven limitations and uncertainties need to be communicated when accounts are published.

4.3. Lessons for policy applications

In spite of the challenges and limitations listed above, multiple policy uses have been identified for ecosystem accounting, on a broad variety of themes ranging from energy, biodiversity, green economic growth to climate change (see also Ruijs et al., 2018). Ruijs et al. (2018) roll out strategies to ensure that ecosystem accounting (or natural capital accounting as they state) is fit for policy. To a large extent these strategies revolve around developing a good fit between the supply of information (i.e. the accounts) and the users, and ensuring that all stakeholders understand and agree with the provided information. Bordt (2018) found that broad representation of different stakeholder groups is needed in designing and using ecosystem accounts. The Dutch accounts have tried to ensure stakeholder participation in all phases, through discussions with an advisory board, consisting of policy makers and researchers from several Dutch Ministries, government bodies and research institutes. Development of the Dutch accounts is currently (2019) in its third phase, in which the focus is on connecting the accounts to policy makers and other users. Some first lessons have emerged from the various interactions with potential users in the past years.

First, the accounts are integrate a broad range of ecological and economic information and it takes time for the users to appreciate the wealth of material that is contained in the accounts. Many users are familiar only with some of the elements covered in the accounts (e.g. water pollution) and it takes time for them to see how other information may be relevant to them (e.g. ecosystem services provided by water bodies, and changes and spatial variations therein, and the link between pollution and services supply).

Second, the value of the accounts lies in part in its regular update and production. Our discussions show that policy makers have a high interest in understanding trends in ecosystems and natural capital (at national, provincial scale, and by ecosystem type). In many cases, the exact policy use is difficult to pinpoint for different stakeholders, but all see the added value of integrated ecosystem accounts with a strong connection to economic activity. There is a key interest in following changes over time, and using such information to plan future policy. There may be a parallel with the national accounts, where GDP is seen as a core indicator, even though few people are familiar with the key underlying assumptions of GDP. In principle, the regular production of ecosystem accounts allows measuring the sustainability of ecosystem use, since the accounts show trends in extent, condition and service supply by ecosystem, provide information on specific key aspects such as biodiversity, and also comprise aggregated indicators such as changes in the monetary value of the total stock of ecosystems in a country. It is currently being examined how the SEEA ecosystem accounts can also support the measurement of progress towards reaching the Sustainable Development Goals. SEEA ecosystem accounts can be used to measure progress to SDGs related to the environment (SDGs 6, 13, 14 and 15) and potentially for SDG indicators related to agriculture, energy, employment and sustainable production and consumption (SDGs 2, 7, 8, 9, 11, and 12) (Ruijs et al., 2018).

Third, the ecosystem accounts support a wide variety of applications related to environmental and spatial planning. For instance, in the province of South Holland, some 230,000 houses need to be built in the coming decade to cope with growing population in this province (Provincie Zuid-Holland, 2017). This poses significant challenges, ranging from ensuring that impacts on natural capital are limited to ensuring that there are sufficient possibilities to increase drinking water production and offering opportunities for recreation to the new residents. These planning processes benefit from the spatial detail of the accounts. There are also efforts to connect the accounts to users in the private sector, but this appears, in many cases, more challenging given that many important Dutch companies are multinationals that generate a significant part of their environmental footprint in other countries, and given that they are often one among several companies using a specific natural resource. However, first discussions are being held on starting pilots with companies and industry associations that have large land holdings in the Netherlands.

Fourth, the accounts provide detailed information on material flows from ecosystems to the economy. 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.

However, the accounts need to find a position against other environmental monitoring systems that are already in place, such as national and EU air and water quality monitoring systems, the LULUCF reporting, etc. Given that these thematic systems are more focussed they often contain more indicators relevant to the specific theme (e.g. more water pollutants). At the same time, it became clear that combining data sources can provide important new insights. For example, the extent account could be used to model and map forest stands using data from the 2016 National Forest Inventory (Coenen et al., 2016) so that more spatially detailed estimates of stocks, harvest and regrowth are reported compared to the forest inventory output by itself. Compared to the LULUCF reporting, the integration of the extent account with the data on emissions and sequestration by ecosystem has allowed the production of a high resolution map of carbon stocks and flows not available from the LULUCF reports. A particular challenge arises when the reporting methodology differs between the SEEA and the existing, thematic reporting system. In the case of LULUCF, a difference is that LULUCF reports include emissions occurring as a consequence of land cover change (e.g. conversion of forests to croplands) within a given year. Although this reporting approach is also favoured in the SEEA CF, the SEEA EEA carbon accounts for the Netherlands have followed a somewhat simpler approach where changes in land cover within a year are not analysed, and instead emissions due to changes in land cover are reported in the form of changes between years. Hence, the SEEA EEA carbon accounts have traded temporal accuracy for higher spatial accuracy. In the future, it may be necessary to align these processes.

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 a relatively fine resolution (10 meters for many services) so that they may also be 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. 2019–2020) 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. The lessons learned in the Netherlands accounts will also be shared and evaluated in the Horizon2020 MAIA (Mapping and Assessment for Integrated ecosystem Accounting) project, which involves a collaboration between 19 partners and aims to develop and implement ecosystem accounts in 10 European countries.

5. Conclusions

Even in a data-rich and relatively small country such as the Netherlands the compilation of the ecosystem accounts was a major undertaking, requiring significant resources and time. In part, the amount of required effort was related to the experimental nature of the accounts at the time the compilation started, which meant that multiple technical discussions and stakeholder consultations were held to address the various methodological challenges. Nevertheless, a set of ecosystem accounts has now been prepared and published. Furthermore, now that the methods have been developed, it is anticipated that updating (and continued improvement of) accounts in the future will require a much smaller effort and budget.

The accounts can support a broad range of policy processes. For example, they can provide information for spatial planning, monitoring the sustainability of ecosystem use, assessing trends in particular sectors or ecosystems, identifying priorities for interventions in the conservation or management of ecosystem, and they provide a basis for detailed scenario analysis of policy options. Importantly, many of the policy uses were ‘unexpected’, i.e. the accounts were able to respond to policy questions that were not articulated at the time the compilation of the accounts started. An example is that the accounts provided inputs into the development of policies for better peat management by providing a detailed spatial baseline on where these emissions take place and how they are influenced by human management (in particular drainage). Even though there were prior datasets, the integration of detailed land use data from the extent account, water level data from the condition account, and available hydrological models provided a more accurate quantification of carbon emissions compared to what was available. Publication of these figures through the statistical office provided additional credibility and the various numbers of the Netherlands carbon account were frequently used in the Dutch political debate as well as reported in various newspaper articles.

Nevertheless, convincing a broad range of users of the relevance of ecosystem accounts at multiple scales requires further work. A barrier is the comprehensiveness and level of detail in the accounts which makes the information overwhelming to some of the users, including potential users at provincial and municipal level and in companies for which the accounts could be highly useful. First consultations of potential users indicated that they need both a much simplified way of getting access to the information, and that they would benefit from specific tools for policy analysis (e.g. a tool that shows the impacts of interventions in the landscape). In response, a web-based information platform is being developed that allows easy access to the tools, and several agencies are developing policy scenario tools using the information in the accounts. Clearly, investments in updating and continuing the accounts will only be made by the Netherlands government if there are clear societal benefits and the key priority – in addition to updating the accounts to 2018 – is to make the accounts available and understandable for as many users as possible in the coming year.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

ABS (Australian Bureau of Statistics), 2017. Experimental Environmental-Economic Accounts for the Great Barrier Reef, 2017. ABS, Canberra.
Bogaart, P.W., de Jong, R., 2018. Extending the condition account for the Netherlands, Final report for Eurostat grant project 05122.2017.003-2017.649, Statistics Netherlands, 28pp.
Bordt, Michael, 2018. Discourses in ecosystem accounting: a survey of the expert community. Ecol. Econ. 144, 82–99. https://doi.org/10.1016/j.ecolecon.2017.06.032.
Bright, Geoff, Connors, Emily, Grice, Joe, 2019. Measuring natural capital: towards accounts for the UK and a basis for improved decision-making. Oxford Review of Economic Policy 35 (1), 88–108.
Campos, P., Caparrós, A., Oviedo, J.L., et al., 2019. Bridging the gap between national and ecosystem accounting application in Andalusian forests, Spain. Ecol. Econ. 157, 218–236.
CBS, 2017. Ecosystem Unit map, product description. Statistics Netherlands. Den Haag/Heerlen, The Netherlands. Retrieved from https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map.
CBS, PBL, RIVM, WUR, 2018a. Number of threatened species in The Netherlands, by 2018 (indicator 1052, version 15, 15 May 2018). www.environmentaldata.nl. Statistics Netherlands (CBS), The Hague; PBL Netherlands Environmental Assessment Agency, The Hague; RIVM National Institute for Public Health and the Environment, Bilthoven; and Wageningen University and Research, Wageningen.
CBS, PBL, RIVM, WUR, 2018b. Trends in ecological quality, 1994-2017 (indicator 2052, version 07, 6 December 2018). www.environmentaldata.nl. Statistics Netherlands (CBS), The Hague; PBL Netherlands Environmental Assessment Agency, The Hague; RIVM National Institute for Public Health and the Environment, Bilthoven; and Wageningen University and Research, Wageningen.
Coenen, P.W.H.G., van der Maas, C.W.M., Zijlema, P.J., Arets, E.J.M.M., Baas, K., van den Berghe, A.C.W.M., Nijkamp, E.P., van Huis, E.P., Geilenkirchen, G., Versluijs, C.W., te Molder, R., Dröge, r., Montfoort, J.A., Peek, C.J., Vonk, J., Oude Voshaar, S., 2016. Greenhouse Gas Emission in the Netherlands 1990-2014, National Inventory report 2016. RIVM Report 2016-0047, RIVM, Bilthoven, The Netherlands.
De Jong, R., Edens, B., van Leeuwen, N., Schenau, S., Remme, R.P., Hein, L., 2016. Ecosystem Accounting Limburg Province, the Netherlands - Part 1: Physical supply and condition accounts. Statistics Netherlands and Wageningen University, the Hague, the Netherlands.
De Vries, F., Brus, D.J., Kempen, B., Brouwer F., Heidema A.H., 2014. Actualisatie bodemkaart veengebieden; Deelgebied 1 en 2 in Noord Nederland. Alterra-rapport 2556, Alterra Wageningen UR, Wageningen, The Netherlands.
Edens, Bram, Graveland, Cor, 2014. Experimental valuation of Dutch water resources according to SNA and SEEA. Water Resour. Econ. 7, 66–81. https://doi.org/10.1016/j.wre.2014.10.003.
Feyen, L., Kakoulaki, G., Rega, C., Robert, N., Maes, J., Kamberaj, J., Dottori, F., La Notte, A., Vallecillo, S., 2019. Ecosystem services accounting. Part II, Pilot accounts for crop and timber provision, global climate regulation and flood control The Knowledge Innovation Project on an Integrated system of Natural Capital and ecosystem services Accounting (KIP INCA) aims to develop a set of experimental accounts at the EU level, following the United Nations System of Environmental-Economic Accounting – Experimental Ecosystem Accounts.Joint Research Centre (European Commission), 2019.
Giannetti, B.F., Agostinho, F., Almeida, C.M.V.B., Huisingh, D., 2015. A review of limitations of gdp and alternative indices to monitor human wellbeing and to manage eco-system functionality. J. Cleaner Prod. 87 (1), 11–25.
Guerry, A.D., Polasky, S., Lubchenco, J., et al., 2015. Natural capital and ecosystem services informing decisions : from promise to practice. PNAS 112(24).
Hein, L., Obst, C., Edens, B., Remme, R.P., 2015. Progress and challenges in the development of ecosystem accounting as a tool to analyse ecosystem capital. Curr. Opin. Environ. Sustainability 14.
Horlings, E., Hein, L., Schenau, S., de Jongh, L., Lof, M., 2019. Monetary ecosystem services and asset account for the Netherlands. Report CBS and WUR, 2019.
Johnson, C.N., Balmford, A., Brook, B.W., et al., 2017. Biodiversity losses and conservation responses in the Anthropocene. Science 21 Apr 2017.
Lai, Tin Yu et al., 2018. Bridging the gap between ecosystem service indicators and ecosystem accounting in Finland. Ecol. Modelling 377(April 2018), 51–65.
La Notte, Alessandra et al., 2017. Physical and monetary ecosystem service accounts for Europe : a case study for in-stream nitrogen retention. Ecosystem Services, 23(November 2016): 18–29. doi: 10.1016/j.ecoser.2016.11.002.
Lesschen, J.P., Heesmans, H., Mol-Dijkstra, J., van Doorn, A., Verkaik E., van den Wyngaert, I., Kuikman, P., 2012. Mogelijkheden voor koolstofvastlegging in de Nederlandse landbouw en natuur. Alterrarapport 2396, Alterra, Wageningen, the Netherlands.
Lof, M.E., Schenau, S., de Jong, R., Remme, R.P., Graveland, C., Hein, L., 2017. The SEEA

EEA carbon account for the Netherlands. Statistics Netherlands (CBS), The Hague; and Wageningen University and Research, Wageningen. https://www.cbs.nl/nl-nl/achtergrond/2017/45/the-seea-eea-carbon-account-for-the-netherlands.
Lof, Bogaart, M.P., Hein, L., de Jong, R., Schenau, S., 2019, The SEEA-EEA ecosystem condition account for the Netherlands, Statistics Netherlands and Wageningen University, The Hague; Wageningen, the Netherlands. 88pp.
National Research Council, 2005. Valuing Ecosystem Services: Toward Better Environmental Decision-Making. The National Academies Press, Washington, DC doi: 10.17226/11139.
Obst, Carl Gordon, 2015. "Reflections on Natural Capital Accounting at the National Level" ed. Dr Andrea B Coulson ,Professor Carol A. Sustainability Accounting, Manage. Policy J. 6(3): 315–39. http://www.emeraldinsight.com/doi/10.1108/SAMPJ-04-2014-0020.
ONS, 2016. UK Natural Capital: interim review and revised 2020 roadmap. https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/methodologies/uknaturalcapitalinterimreviewandrevised2020roadmap. Accessed 12 jan 2019.
PBL, 2016. Map Drooglegging in studiegebied veengronden, Figure 4.3 in: Dalende bodems, stijgende kosten. Mogelijke maatregelen tegen veenbodemdaling in het landelijk en stedelijk gebied. PBL publication number: 1064, Planbureau voor de Leefomgeving, The Hague.
Probos, 2017. Zesde Nederlandse Bosinventarisatie MS Access database. Available online at: www.probos.nl/publicaties/overige/1094-mfv-2006-nbi-2012.
Provincie Zuid-Holland, 2017. Discussienota Verstedelijking Provincie Zuid-Holland, Koers en inzet. December 2017. Den Haag, the Netherlands.
Remme, R.P., Schröter, M., Hein, L., 2014. Developing spatial biophysical accounting for multiple ecosystem services. Ecosystem Services 10, 6–18.
Remme, R.P., Edens, B., Schröter, M., Hein, L., 2015. Monetary accounting of ecosystem services: a test case for Limburg Province, the Netherlands. Ecol. Econ. 112, 116–128.
Remme, R.P., Hein, L., 2016. Ecosystem Accounting Limburg Province, the Netherlands – Part 2: Monetary supply and use accounts. Wageningen University, Wageningen, the Netherlands.
Remme, R.P., Hein, L., van Swaay, C.A., 2016. Exploring spatial indicators for biodiversity accounting. Ecol. Indicators 70, 232–248.
Remme, R., Lof, M., de Jongh, L., Hein, L., Schenau, S., de Jong, R., Bogaart, P., 2018. The SEEA EEA biophysical ecosystem service supply-use account for the Netherlands. CBS and WUR, 2018.
RIVM, 2017. Netherlands Natural Capital model – Technical documentation erosion control. Developed for Atlas of Natural Capital. RIVM, Bilthoven, the Netherlands.
Ruijs, Arjan, Vardon, Michael, Bass, Steve, Ahlroth, Sofia, 2018a. Natural capital accounting for better policy. Ambio. https://doi.org/10.1007/s13280-018-1107-y.
Ruijs, A., Heide, M., van den Berg, J., 2018. Natural Capital Accounting for the Sustainable Development Goals. Current and potential uses and steps forward. PBL Netherlands Environmental Assessment Agency, The Hague.
Scheffer, M., Carpenter, S., Foley, J.A., Folke, C., Walker, B., 2001. Catastrophic shifts in ecosystems. Nature 413, 591–596.
Schelhaas, M., Clerkx, A.P.P.M., Daamen, W.P., Oldenburger, J.F., Velema, G., Schnitger, P., Schoonderwoerd, P., Kramer, H. (2014). Zesde Nederlandse bosinventarisatie: methoden en basisresultaten (Alterra-rapport 2545). Wageningen, Alterra.
Sunderland, T., Waters, R., Marsh, D., Hudson, C., Lusardi, J., 2018. Accounting for national nature reserves: a natural capital account of the national nature reserves managed by Natural England. Natural England Research Report NERR078, United Kingdom.
TEEB, 2010. The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, London and Washington (2010).
UN et al., 2014a. The System of Environmental-Economic Accounting; Central framework. UN, New York, 2014.
UN et al., 2014b. The System of Environmental-Economic Accounting; Experimental Ecosystem Accounting. UN, New York, 2014.
UN, 2017. SEEA Experimental Ecosystem Accounting: Technical Recommendations. UN New York, 2017.
UNCEEA (United Nations Committee of Experts on Environmental-Economic Accounting), 2019. International Coordination Survey 2019. Statistical Commission Background document to the March 2019 meeting. UN New York, 2019.
Vallecillo, S., La Notte, A., Kakoulaki, G., Kamberaj, J., Robert, N., Dottori, F., Feyen, L., Rega, C., Maes, J., 2019. Ecosystem services accounting Part II Pilot accounts for crop and timber provision, global climate regulation and flood control, JRC technical reports, European Union 2019.
van den Akker, J.J.H., Kuikman, P.J., de Vries, F., Hoving, I., Pleijter, M., Hendriks, R.F. A., Wolleswinkel, R.J., Simões, R.T.L., Kwakernaak, C., 2010. Emission of CO2 from agricultural peat soils in the Netherlands and ways to limit this emission. In: Farrell, C and J. Feehan (eds.), 2008. Proceedings of the 13th International Peat Congress After Wise Use – The Future of Peatlands, Vol. 1 Oral Presentations, Tullamore, Ireland, 8 – 13 june 2008. International Peat Society, Jyväskylä, Finland. ISBN 0951489046. pp. 645–648.
van den Bergh, J.C.J.M., 2009. The GDP paradox. J. Econ. Psychol. 30 (2), 117–135.
van Strien, A.J., van Swaay, C.A., Termaat, T., 2013. Opportunistic citizen science data of animal species produce reliable estimates of distribution trends if analysed with occupancy models. J. Appl. Ecol. 50 (6), 1450–1458.
Van Strien, A.J., Gmelig Meyling, A.W., Herder, J.E., Hollander, H., Kalkman, V.J., Poot, M.J.M., Turnhout, S., van der Hoorn, B., van Strien-van Liempt, W.T.F.H., van Swaay, C.A.M., van Turnhout, C.A.M., Verweij, R.J.T., Oerlemans, N.J., 2016. Modest recovery of biodiversity in a western European country: The Living Planet Index for the Netherlands. Biol. Conserv. 200, 44–50.
Werkgroep Discontovoet, 2015; Rapport werkgroep discontovoet 2015, Publisher: Ministry of Finance, The Hague, the Netherlands. 95 pp.
WWF. 2018. Living Planet Report – 2018: Aiming Higher. Grooten, M. and Almond, R.E. A. (Eds). WWF, Gland, Switzerland.