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Ecosystem accounting to support the Common Agricultural Policy

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ABSTRACT

The System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA EA) provides an integrated statistical framework which organizes spatially explicit data on environmental quality, natural capital and ecosystem services and links this information to economic activities such as agriculture. In this paper we assess how the SEEA EA can support the monitoring and evaluation of environmental objectives of the Common Agricultural Policy (CAP). We focus on the Netherlands, for which an elaborate set of SEEA EA accounts has been published, and the themes of nitrogen pollution and farmland biodiversity. We studied the completeness of indicators included in the accounts, their quality and analysed how the accounts could support agri-environmental reporting, agri-environmental measures effectiveness assessments, and results-based payments to farmers. As a reference we used the Driving forces – Pressures – State – Impacts - Responses (DPSIR) framework. The Dutch SEEA EA accounts only include half of the indicators which we considered essential to assess the effects of farming on natural capital and ecosystem services for the two studied environmental themes. However, most gaps in the accounts could be filled with other publicly available environmental monitoring data. Regarding N pollution, the availability and reliability of indicators at landscape and farm scales are not sufficient to support the assessment of agri-environmental measures effectiveness and results-based payments to decrease N pollution. The accounts have a higher potential to support the assessment of measures to conserve farmland biodiversity, in particular due to high resolution maps of ecosystem extent and ecosystem services flows. The potential of the SEEA EA accounts may be more limited in other countries where ecosystem accounting has only recently started. However, the SEEA EA is also implemented at the European Union scale, so that SEEA EA indicators will gradually become available for all European countries. To enhance the relevance of the SEEA EA in the agri-environmental policy area, we recommend to integrate information on farming emissions (externalities) recorded in the SEEA Central Framework with SEEA EA accounts and evaluate the applicability of SEEA EA accounts for case studies at landscape and farm scales. Our research shows that the Dutch SEEA EA accounts, complemented with other data sources, have potential to strongly enhance the CAP monitoring and evaluation framework but further steps need to be taken to fill data gaps.

1. Introduction

Since the 1950′s, farming intensification has driven an unprecedented increase in food output of agricultural systems in many parts of the world including Europe. At the same time, intensification has put pressure on the natural capital (NC) of agro-ecosystems and their surrounding environment. NC underpins the ability of ecosystems to provide society with a broad range of ecosystem services (ESs), including fertile soils, regulating geo-chemical cycles, and providing opportunities for recreation (Cardinale et al., 2012; Foley et al., 2005). Farming intensification has been increasingly affecting these ESs, depleting the NC base of farming landscapes (Donald et al., 2001; Matson et al., 1997). ESs contribute significantly to agricultural production (Dainese et al., 2019) and are also important for society at large, but their value is not adequately considered by many farmers and policy makers (Bommarco et al., 2013).

The Common Agricultural Policy (CAP) is a major part of the EU regulatory framework, as illustrated by the CAP implementation comprising 38% of the 2014–2020 EU budget. Since the 1990′s concerns for NC and ESs degradation have been gradually integrated to the CAP (Bouwma et al., 2018). The CAP currently includes three main environmental objectives: (1) climate change mitigation and adaptation; (2) the sustainable management of natural resources (soil, air and water); and (3) the enhancement of biodiversity and ESs (EC, 2018a). To pursue these environmental goals, income support payments to farmers have

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been made conditional to compliance with minimum environmental standards established by the main EU environmental directives and the implementation of greening measures. Moreover, Agri-Environment Measures (AEMs) provide farmers with incentives to implement measures that go beyond the minimum environmental standards and greening obligations. However, CAP instruments remain unbalanced, with priority given to farm income support over the protection of NC and enhancement of ESs (Bateman and Balmford, 2018; Dupraz and Guyomard, 2019; Pe'er et al., 2019). Furthermore, the environmental effectiveness of greening measures and AEMs has been questioned. Indeed, farmers often opted for greening measures that can be applied with minimal changes to the existing farming practices but these measures have limited benefits for farmland biodiversity (Pe'er et al., 2017). Synthesis of studies on AEMs show an overall moderate positive effect on farmland biodiversity (Batáry et al., 2015), but environmental effectiveness varies significantly across AEMs schemes (Kleijn et al., 2011; Uthes and Matzdorf, 2013).

The achievement of CAP environmental objectives is assessed through the CAP Common Monitoring & Evaluation Framework (CMEF). The CAP CMEF includes a set of Agri-Environmental Indicators (AEIs), which have to be used by Member States when assessing the achievement of CAP environmental objectives (EC, 2017). However, the impact indicators of the CMEF indicate changes in individual components of NC (e.g. soil carbon content, nitrates concentration in groundwater or farmland biodiversity) but do not address how such changes affect ecosystems and the services they provide (e.g. soil contribution to biomass production, crop pollination) (Pe'er et al., 2019). Member States may complement indicators of the CMEF with national indicators (EC, 2018b), but this option is not often implemented due to insufficient data. Data sources are often lacking or not measured consistently over time and space, thereby constraining the evaluation of environmental measures in the CAP (Uthes and Matzdorf, 2013). As a result, most evaluations use indicators of land use and farming practices as proxies of environmental effects (Dupraz and Guyomard, 2019; Primdahl et al., 2003). Proxy indicators are assumed to bear a cause-effect relationship with the environmental objectives of AEMs, but Primdahl et al. (2010) found that such assumptions are often not supported by scientific evidence.

The System of Environmental-Economic Accounting (SEEA) is the United Nations standard for NC accounting, which consists of two frameworks, the SEEA Central Framework (SEEA CF) and the SEEA Ecosystem Accounting (SEEA EA) framework. The SEEA CF provides methods to account for stocks and uses of environmental assets, such as water, timber or minerals, environmental expenditures, and emissions and discharges of pollutants. The SEEA EA complements the SEEA CF by focusing on ecosystems. The SEEA EA provides an integrated statistical framework which organizes spatially explicit biophysical data on ecosystem assets and flows of ESs and links this information to economic activities such as agriculture (UNSD, 2021).

The System of Environmental-Economic Accounting Ecosystem Accounting (SEEA EA) has the potential to support the monitoring and evaluation of agri-environmental policies but its application to the CAP has not yet been examined. SEEA EA accounts have been published in 24 countries and the SEEA EA is also applied at European scale, in coordinated efforts by the Joint Research Center, the European Environment Agency and Eurostat (La Notte et al., 2017; Vallecillo et al., 2019; Vallecillo et al., 2018). The SEEA EA may address gaps in the CMEF, by providing spatially explicit indicators on the links between agriculture, environmental quality, NC and ESs. Monitoring systems that provide relevant indicators on the effects of the CAP on environmental quality already exist in European countries (EIONET, 2021), in connection with the EU environmental legislation (e.g. Nitrates Directive, Habitats Directive). However, these environmental monitoring systems focus on single themes, such as water or biodiversity. The SEEA EA allows to combine environmental thematic data into an integrated assessment of ecosystems and flows of ESs to the economy and human well-being. Furthermore, the SEEA EA, once fully implemented, may provide consistent data sources for the monitoring and evaluation of AEMs by providing a public database hosted by statistical offices. The SEEA EA has already been used to address specific agri-environmental issues, such as soil carbon emissions in the Netherlands (Hein et al., 2020). However, no study has yet considered how the SEEA EA concepts and indicators can support the monitoring and evaluation of the CAP environmental objectives.

In this paper we explore how the SEEA EA can support the monitoring and evaluation of the CAP environmental objectives. We address three research questions (1) Which indicators are required to evaluate the effects of farming practices on NC and ESs?; (2) Do the SEEA EA accounts contain the required indicators to evaluate the effects of farming practices on NC and ESs, and if not, are there complementary environmental monitoring systems that can enhance the SEEA EA?; (3) Are the available indicators in the SEEA EA accounts and complementary monitoring systems sufficient to support the monitoring and evaluation of the CAP environmental objectives? To address the third question, we examine three potential policy applications: (i) reporting on the achievement of specified agri-environmental objectives in a region or country; (ii) assessment of AEMs effectiveness; and (iii) supporting results-based AEMs.

As a case study, we consider the Netherlands, where an elaborate set of SEEA EA accounts has been published (Bogaart et al., 2020; Horlings et al., 2020; Lof et al., 2019; Lof et al., 2017; Remme et al., 2018; Statistics Netherlands and WUR, 2021; van Leeuwen et al., 2017). We focus on two of the main environmental objectives of the CAP (EC, 2018a): (i) the reduction of water and air pollution by nitrogen (N), and (ii) the protection and enhancement of farmlands habitats and biodiversity. Both are critically important for Dutch environmental management (Bouma et al., 2020). In addition to the SEEA EA we investigate publicly available data from national environmental monitoring programs relevant for N pollution and farmland biodiversity. These data sources could easily be incorporated in the SEEA EA accounts, should policy makers decide to use the SEEA EA to monitor CAP environmental objectives. In the discussion section of the paper we reflect upon the implications for the SEEA EA implementation in the Netherlands and the EU.

2. Methods

2.1. Application of the SEEA EA concepts to agri-environmental policy issues

The SEEA EA is designed to be consistent with the System of National Accounts, the accounting framework used to produce standard economic indicators such as Gross Domestic Product. The central concept of the SEEA EA is the treatment of ecosystems as assets (stocks) providing ESs (flows) to economic units. The SEEA EA framework allows monitoring how stocks of ecosystem assets (EAs) and flows of ESs change over time, both in bio-physical and monetary terms, through a set of core accounts complemented by satellite accounts. EAs are spatial areas defined by ecosystem characteristics and classified according to homogenous ecosystem types (ETs), such as permanent grasslands. Ecosystem extent accounts record changes in EAs' areas, i.e. the quantity of assets. Ecosystem condition accounts record changes within EAs, i.e. the quality of assets. Physical changes in the stocks of EAs are measured by assessing changes in the extent (area) and condition of EAs. Ecosystem monetary asset accounts record stocks of EAs in monetary terms.

Each EA supplies a set of final ESs which contribute to individual and societal well-being. Every flow of a final ES is an exchange between an EA, i.e. the provider of the service, and an economic unit, i.e. the user of the service. Final ESs are often underpinned by biophysical processes

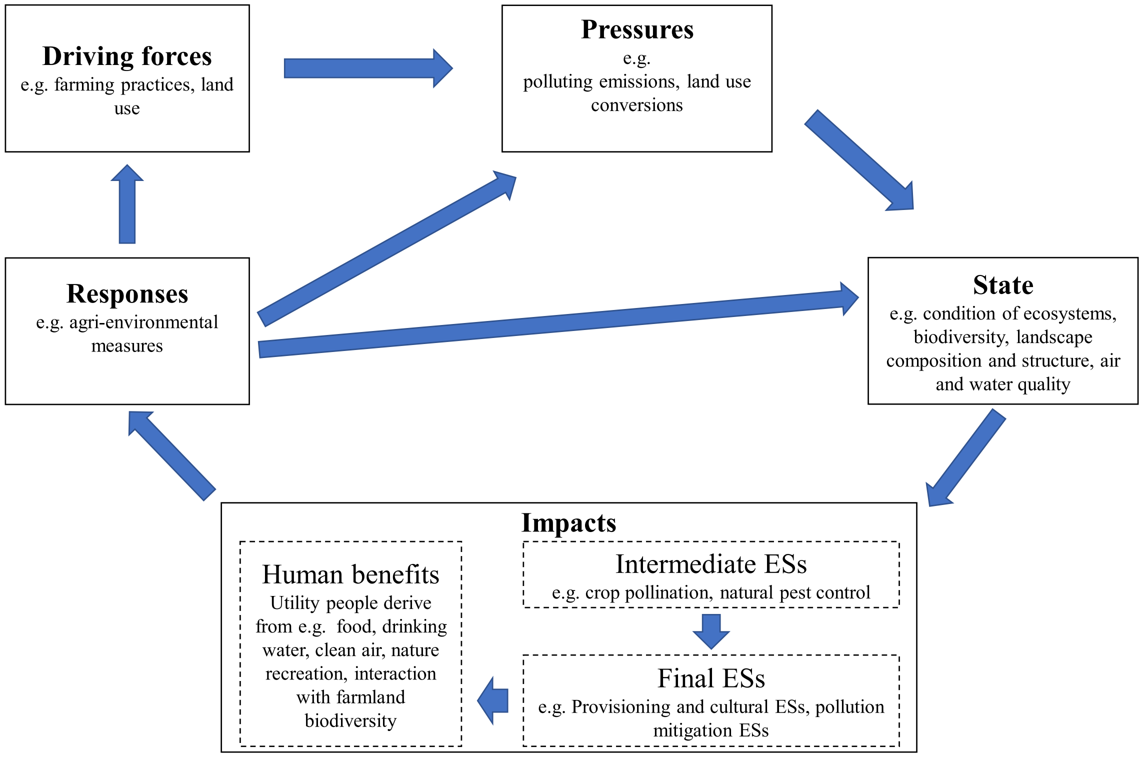

Fig. 1. Integrating ESs in the DPSIR framework.

between ecosystems. Such flows between EAs are defined as intermediate ESs, in distinction to final ESs. For instance, crop pollination is an intermediate ES flow from EAs providing habitats for pollinators (e.g. hedgerows) to EAs dedicated to pollination dependent crops (e.g. apple trees), which provide a final ES used by farmers for agricultural production. Such distinction between intermediate and final ESs aims to avoid double counting when valuing flows of ESs to the economy. Flows of ESs are recorded in ESs biophysical supply and use accounts. ESs monetary supply and use account record flows of ESs in monetary terms. In addition to these core accounts, thematic accounts compile spatially explicit data for specific environmental issues, such as biodiversity or climate change.

In the SEEA EA, biodiversity is primarily considered an ecosystem characteristic that underpins the provision of ESs. Consequently, functional biodiversity (i.e. those components of biodiversity that are critical to ecosystem functioning) is recorded in ecosystem condition accounts, and the human appreciation of biodiversity is considered a cultural ES in the SEEA EA. Finally, a SEEA EA species account may be compiled to provide further information on non-use aspects of biodiversity, such as the presence of and trends in endemic and threatened species.

In this paper, we analyse how SEEA EA accounts could be used to elucidate and quantify the effects of AEMs on NC and ESs. These effects can be approached from three perspectives. First, AEMs aim to increase ESs provided by ecosystems within or outside the farmland managed by farmers. These ESs contribute to agricultural production on the farm (e.g. nutrients cycling, crop pollination) and mitigate pollutant flows that result from production (e.g. nutrients retention). Second, AEMs aim to increase regulating ESs (e.g. carbon sequestration) and cultural ESs (e.g. farmland biodiversity) provided by farmland ecosystems to society at large. Third, AEMs aim to decrease negative externalities that result from agricultural pollution. Farming related pollutants accumulate in the environment and cause damages that can take two forms: (1) degraded NC (air, water), which results in increased operational costs (water treatment) or health costs (air pollution), (2) loss of ESs due to the degradation of the condition of ecosystems (e.g. freshwater eutrophication resulting in a loss of nature recreation and tourism ES).

2.2. Selection of indicators required to assess the effects of AEMs on NC and ESs

AEMs effects depend upon the extent to which AEMs have driven the anticipated changes in farming and land use practices (policy performance), and whether such changes result in the expected environmental outcomes (policy outcome) (Primdahl et al., 2003). Policy performance in itself may not deliver the expected environmental outcomes (Primdahl et al., 2010). On the other hand, policy outcome may result from other factors than changes in land use and farming practices (EC, 2017). Thus, to assess the effects of AEMs, evaluators analyse cause-effect relationships between indicators of AEMs implementation, farming and land use practices, and environmental outcomes. Indicators are often structured in a causal-chain indicator framework, such as the Driving forces – Pressures – State – Impacts - Responses (DPSIR) framework (Smeets and Weterings, 1999), which is widely used in environmental policy assessments (Niemeijer and de Groot, 2008). For instance, the European Environment Agency used the DPSIR to develop indicators for environmental issues in the CAP (European Environment Agency, 2005).

We used the DPSIR framework to select indicators required to assess the effects of AEMs for the two themes: (i) water and air pollution by N; and (ii) farmlands habitats and biodiversity. Furthermore, we conducted a literature analysis to reveal the specific cause-effect relationships binding the components of the DPSIR framework for these two themes in the Netherlands. We applied the DPSIR to a typically Dutch farming landscape which consist of three main ETs, (1) agricultural fields, (2) natural and semi-natural landscape elements such as hedgerows, and (3) surface water bodies. We considered Driving forces to reflect farm and land use management, Pressures to reflect harmful flows resulting from farm and land use management, such as N pollution and habitat conversion, State to indicate the condition of the agricultural fields and surrounding ecosystems affected by farm and land use management. Impacts correspond to losses or gains in ESs and exposure of people and businesses to degraded natural resources resulting from a change in state (Fig. 1). Responses indicate implemented AEMs. Indicators were selected at two levels, the level of ecosystems and the level of landscapes.

Table 1
Selected indicators for the theme N pollution.

Indicator category	#	Indicator
Pressures	P1	Ammonia emissions to the atmosphere (kg NH_3/ha/year)
	P2	Net Soil N surplus: N inputs minus N gaseous losses and N outputs in agro-ecosystems (kg N/ha/year)
	P3	N load to surface water: N transported by surface and sub-surface flows from agro-ecosystems to aquatic ecosystems (kg N/ha/year)
	P4	Nitrates transported by sub-surface flows from agro-ecosystems to phreatic aquifers (kg N/ha/year) in a groundwater catchment
State	S1	Nitrates concentration in shallow groundwater in agro-ecosystems (mg NO_3^-/l)
	S2	Nitrates concentration in drinking water extraction wells (mg NO_3^-/l)
	S3	N concentration in (semi-)natural aquatic ecosystems (mg total N/l)
	S4	Water transparency (Secchi depth in m.)
	S5	Phytoplankton growth (Chlorophyll-a concentration in µg/l)
	S6	NH_3 concentration in the atmosphere (µg NH_3/m^3)
	S7	Particulate Matter (PM) concentration in the atmosphere (µg $PM_{2.5}/m^3$, µg PM_{10}/m^3)
	S8	Wetlands and (semi-)natural riparian vegetation area (ha)
Final ESs	FES1	N retention by aquatic ecosystems and terrestrial ecosystems at the land water interface (kg N/ha/year).
	FES2	Recreation and tourism activities (angling, water sporting) in aquatic ecosystems (number of activities/ha/year)

Landscape structure often plays an important role in AEMs effectiveness (Batáry et al., 2011), and certain indicators should be assessed at the landscape scale (e.g. connectivity of ecosystems providing habitat to farmland species). We considered externalities as pressures which expose people to a damage, such as nitrates leaching to groundwater increasing water treatment costs. In other cases, damages that arise from externalities result in a loss of ESs, such as when N loads to surface water bodies lead to eutrophication and a resulting loss of nature recreation ES.

Comprehensive information systems are already in place in EU member states to monitor indicators of Driving forces and Responses, through agricultural census and the administrative monitoring of CAP payments. Although a few Driving forces (e.g. areas per crop types) and Responses (e.g. AEMs such as area of buffer strips) indicators may be reflected in SEEA EA ecosystem extent accounts, Driving forces and Responses indicators are out of the scope of SEEA EA accounts (Section 2.1). Therefore, this paper focused on indicators of the categories Pressures, State and Impacts. We only considered Pressures which arise from farm and land use management and limited our selection to ESs provided and used by farmland ecosystems. We also considered final ESs provided by other ecosystems, when the provision of such ESs is affected by farm and land use management. We did not include indicators that are important to consider in the analysis of environmental effects of AEMs but cannot be influenced by AEMs, such as soil type or rainfall surplus.

2.3. Analysis of information contained in the Dutch SEEA EA accounts and other national environmental monitoring systems

The Dutch SEEA EA accounts reviewed in this study included accounts compiled for the years 2006–2013 (ecosystem extent account, ecosystem condition account, ESs supply and use account, ESs and assets monetary account, biodiversity account, and carbon account) and updated accounts compiled for the years 2013–2018 (ecosystem extent account, ecosystem condition account, ESs supply and use account, ESs and assets monetary account) (see Table A1, Appendix A).

We also investigated environmental monitoring networks which provide data to monitor the implementation of the main environmental EC directives and legislation in the Netherlands. These systems provide publicly available data on a continuous basis over the whole country and could therefore potentially be integrated in future compilations of the Dutch SEEA EA accounts. We briefly describe these data sources. Details and references are presented in Table A2, Appendix A.

In the Netherlands, farm related N flows and stocks are monitored through six complementary networks: (1) the Farm Accountancy Data Network (FADN), which collects farm management data; (2) the national monitoring network on the effects of the manure policy (LMM), which estimates N content of the upper groundwater of farms; (3) the national monitoring network of groundwater quality (LMG); (4) the nutrients monitoring network in agriculture specific surface waters (MNLSO), which consists of water quality measurements in locations where agriculture is the dominant source of nutrients loads; (5) the water quality monitoring data reported to the Water Framework Directive (WFD); and (6) the nature areas ammonia monitoring network (MAN). Data of these monitoring networks are only available for sampling units, but complementary process-based models allow quantifying N flows and stocks in maps covering the whole territory. The model INITIATOR provides maps of ammonia emissions and N inputs to agricultural soils. These data are used as inputs by respectively the Operational Priority Substances model (OPS) and the National Water Quality Model (LWKM) to quantify N flows in the atmosphere and water. Outputs of these models are used to report polluting emissions to air, water and soil in the Netherlands Pollutant Release and Transfer Register (Government of the Netherlands, 2021). Moreover, the OPS model is part of the AERIUS calculation tool, which computes N deposition on hexagonal tiles of one hectare and thereby supports the national policy to limit N deposition on Natura 2000 areas (Marra et al., 2019).

Biodiversity data in the Netherlands is collected in the framework of the national ecological monitoring network (NEM), which consists of monitoring programs for twelve species groups. We focused our review on birds, which make most of the farmland species targeted by AEMs, and insects, because of their importance for ESs supporting agricultural production and as a source of food for farmland birds. Several networks provide farmland bird species yearly counts data on sample plots spread across the Netherlands (Boele et al., 2020; Roodbergen et al., 2011). A particularly intensive effort is carried out every about fifteen years to generate the Netherlands bird atlas, which contains species distribution maps (Altenburg et al., 2017). Details about farmland bird monitoring networks reviewed in the study are presented in Table A2, Appendix A.

For each indicator, we assessed the quality of the data available in the Dutch SEEA EA accounts and other environmental monitoring systems described above. Specifically, we assessed the scale at which those data sources provide reliable indicators, given the spatial resolution of maps, or sampling intensities and frequencies. Regarding N pollution, we considered the scales of farms, catchments and regions. Regarding farmland biodiversity, we considered the scales of fields, landscapes and regions. Our assessment was based on a review of past studies which have assessed uncertainties related to these data sources.

2.4. Potential applicability in support of CAP implementation

We considered three potential policy applications to test the applicability of the Dutch SEEA EA accounts completed with other environmental monitoring systems to support monitoring and evaluation of the CAP environmental objectives in the Netherlands. First, we assessed if the SEEA EA accounts could support reporting on the status and trends of agri-environmental objectives in a region or country, the current reporting scale for the CAP CMEF. Progress towards CAP environmental objectives is currently tracked through the CAP CMEF with environmental impact indicators (EC, 2017) (See Table A3, Appendix A). To assess the potential added value of SEEA EA accounts to enhance the CAP CMEF, we compared impact indicators of the CAP CMEF to the indicators available in the Dutch SEEA EA accounts and complementary monitoring systems, and we showed how gaps in the CAP CMEF impact

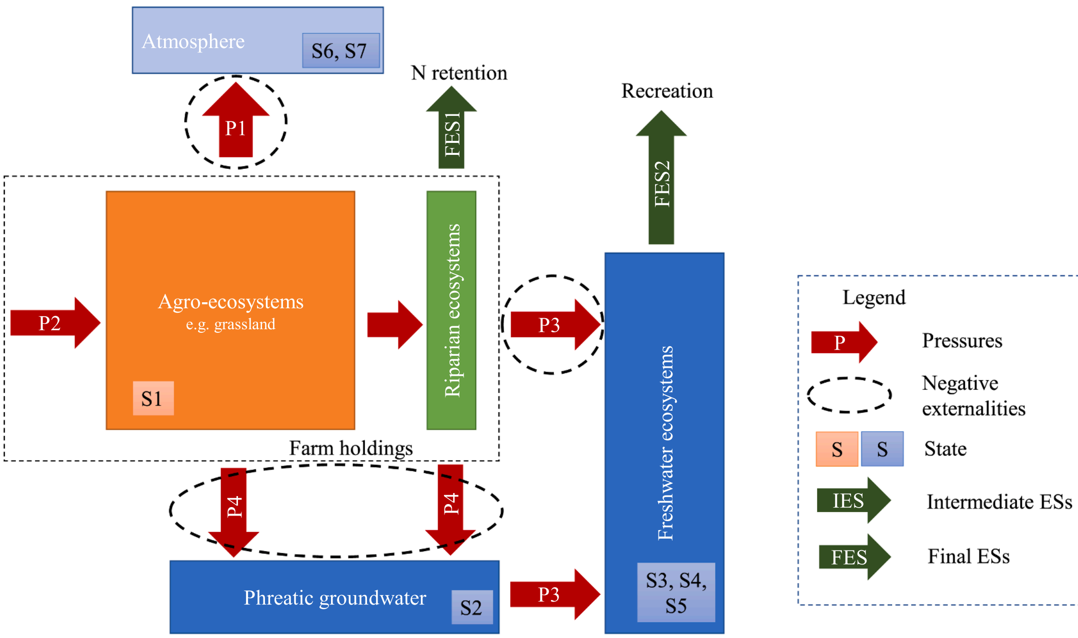

Fig. 2. Causal chain of selected P, S and I indicators for the theme N pollution, for the meaning of the numbers see Table 1.

indicators could be filled with the SEEA EA accounts, should they be compiled to support agri-environmental policies.

Second, we tested if the SEEA EA accounts could support the assessment of AEMs effectiveness by comparing spatial units with and without AEMs implementation. Specifically, we assessed whether the Dutch SEEA EA accounts and complementary monitoring systems provide reliable indicators at the scale of spatial units used for the assessment, which may be fields, farms or spatial areas with homogenous bio-physical conditions (landscape, catchment) and farming systems. Such assessments can be used, for example, to finetune AEM implementation in the EU.

Third, we assessed if the SEEA EA accounts could support results-based AEMs, where payments to farmers are based on the achievement of specified environmental objectives measured by the indicators. Specifically, we investigated if the Dutch SEEA EA accounts and complementary monitoring systems could provide reliable farm scale indicators of negative externalities and ESs supply.

3. Results

3.1. Required indicators to assess effects of AEMs on NC and ESs

3.1.1. Reduction of water and air pollution by N

Table 1 below describes the indicators that we consider to be crucial to analyse the effects of AEMs on reducing eutrophication loads from farming ecosystems, drawing from the literature on N flows in agro-ecosystems and rural landscapes (Durand et al., 2011; Jarvis et al., 2011) and the effects of N on aquatic ecosystems (Cellier et al., 2011; Grizzetti et al., 2011). Fig. 2 shows the causal-chain between the selected Pressures, State and Impacts indicators.

The various cause-effects relationships expressed in Fig. 2 above are conceptually well known for the Netherlands. However, quantitative dose–response functions between indicators are difficult to establish, in particular due to the high spatial and temporal variability of underlying bio-physical conditions, and the existence of multiple factors that confound the relations between indicators. In applying SEEA EA in support of CAP implementation, it is crucial that these uncertainties are understood and that it is considered to what degree SEEA EA is able to provide robust data in spite of their occurrence. We review the most important sources of uncertainties and knowledge gaps below.

N flows at farm scale have been extensively studied and dose–response functions have been derived to support the establishment of regulations (Fraters et al., 2012) and sustainable farm N management (Aarts et al., 2015; Schröder et al., 2019). However, uncertainties remain due to unknown farm management or biophysical characteristics that influence cause-effect relationships between indicators. For example, statistically significant relationships between net N surplus and nitrate concentration in shallow groundwater have been established for farms on sandy and peat soils but not for farms on clay soils (Fraters et al., 2012; Fraters et al., 2015). (Noij et al., 2012) found that unfertilized grass buffer strips substantially mitigated N loading only under specific hydrological conditions, which are met in a small proportion of the farmed area in the Netherlands.

Linking N losses at farm scale to changes in NC and ESs in surface water catchments is also complex. First, a range of factors complicate the establishment of causal links between changes in net N surplus and N loads at catchments scale: (1) the large spatial and temporal variability of N loads and concentrations (Rozemeijer et al., 2010a; Rozemeijer et al., 2010b); (2) the existence of other potential sources of N losses than agriculture; and (3) the frequent diversion of river water into polder areas (Rozemeijer et al., 2012). Second, water bodies types vary in their responses to N loads, due to differences in soil types, hydro-morphology, as well as species abundance and composition (Portielje and van der Molen, 1999). Moreover, N pollution interacts with other Pressures, in particular phosphorous loads (van der Molen et al., 1998). Third, the effects of eutrophication on the recreation potential of surface water bodies have been qualitatively described (Boere, 1987), but we did not find empirical studies that show how nature recreation and tourism ESs flows quantitatively respond to changes in surface water eutrophication in the Netherlands (Hein, 2006).

The link between farm management and NC at catchment scale on which we have the most insights is the effect on water extraction for drinking water. High nitrates concentration in shallow groundwater generally result in excess nitrates in phreatic aquifers, though spatial patterns of denitrification in soils may strongly influence this relationship, as observed in regions with sandy soils in the Netherlands (Fraters et al., 2020). Excess nitrates in extracted groundwater lead to increased costs for drinking water companies, due to water monitoring and processing operations which are required to keep the nitrates concentration below the drinking water standard of 50 mg/l (van Loon and Fraters, 2016).

Table 2
Selected indicators for the theme farmland habitats and biodiversity.

Indicator category	#	Indicator name
Pressures	P1	N inputs: N applied in chemical and organic fertilizers, N atmospheric deposition (kg N/ha/year)
	P2	Grasslands management intensity (averaged vegetation greenness index in spring)
	P3	Drainage of grasslands during winter (in cm below ground level)
	P4	Land use changes: area of semi-natural habitats conversions, area of cropping pattern changes (ha)
State	S1	Grasslands plant species richness (number of species per ha)
	S2	Insects abundance and richness (insects biomass, number of species per ha)
	S3	Area covered by agricultural land uses providing habitats to farmland bird species (e.g. seed crops, summer grains, luzerne, extensive grasslands, fallows, field margins, crop stubbles) (ha)
	S4	Area covered by semi-natural landscape elements (ha)
	S5	Crop diversity (number of crops per farm)
	S6	Landscape openness (average length of sightline, in meters)
	S7	Average field size (ha)
	S8	Connectivity (e.g. average nearest distance between breeding and foraging habitat patches, in meters)
	S9	Abundance and spatial distribution of farmland species targeted by AEMs (number of birds/km^2)
	S10	Abundance and species richness of functional species groups (e.g. pollinators, pest enemies) (biomass, number of species/km^2)
Intermediate ESs	IES1	Crop pollination: avoided production loss due to the presence of pollinators (ton/ha/year)
	IES2	Natural pest control (e.g. % of field visitation by lady bugs)
Final ESs	FES1	Contribution to biomass production (ton/ha/year)
	FES2	Farmland species observations (species records/ha/year)

3.1.2. Protection and enhancement of farmland habitats and biodiversity

AEMs in the Netherlands target 68 farmland species for which the country has international obligations of conservation (via the Habitats and Birds Directives). Our analysis was focused on bird species, which make most of the species targeted by AEMs, and functional species groups, such as pollinators and pest enemies, which are expected to also benefit from the implemented measures. We selected eighteen indicators (see Table 2) on the basis of existing studies about farmland biodiversity in the Netherlands. Fig. 3 shows the causal chain between selected Pressures, State and Impact indicators. Farming Pressures affect the condition, quantity and spatial cohesion of habitat patches, and the resulting farmland species' abundance and richness (Benton et al., 2003). In applying our framework for the selection of indicators, indicators of both farmland habitats and farmland biodiversity are considered as State indicators. While some State indicators may be quantified for each ecosystem unit (S1, S2), we consider most of these indicators as best quantified at landscape scale, since species may rely on multiple ETs for their survival, and causal links between farming Pressures, farmland species habitats and populations are largely influenced by the landscape structure (Batáry et al., 2011). We characterized the landscape structure through indicators of landscape composition (S3, S4, S5) and configuration (S6, S7, S8).

Species habitat requirements determine how populations respond to changes in farming Pressures and the State of ecosystems and landscapes. In the Netherlands, meadow birds have been the target of most farmland species conservation efforts, as the country hosts a significant proportion of the global populations of several meadow bird species. Consequently, meadow birds is the species group for which we have the best knowledge on the causal links between farming Pressures, State indicators and birds populations (Kleijn et al., 2010; Schekkerman and Beintema, 2007; Verhulst et al., 2006). For instance, meadow birds require an open landscape (Teunissen et al., 2012) and respond unfavorably to woody landscape elements, which increase the risk of predation, in particular by foxes. This is also valid for cropland bird species adapted to open habitats (Geiger et al., 2014). Conversely, numerous studies found significant positive associations between the area of woody landscape elements and other species groups, such as pest enemies and pollinators (Holland et al., 2017). Therefore, for an appropriate monitoring and evaluation of AEMs, indicators of farming Pressures, landscape composition and configuration should be determined per species or groups of species with similar habitats requirements.

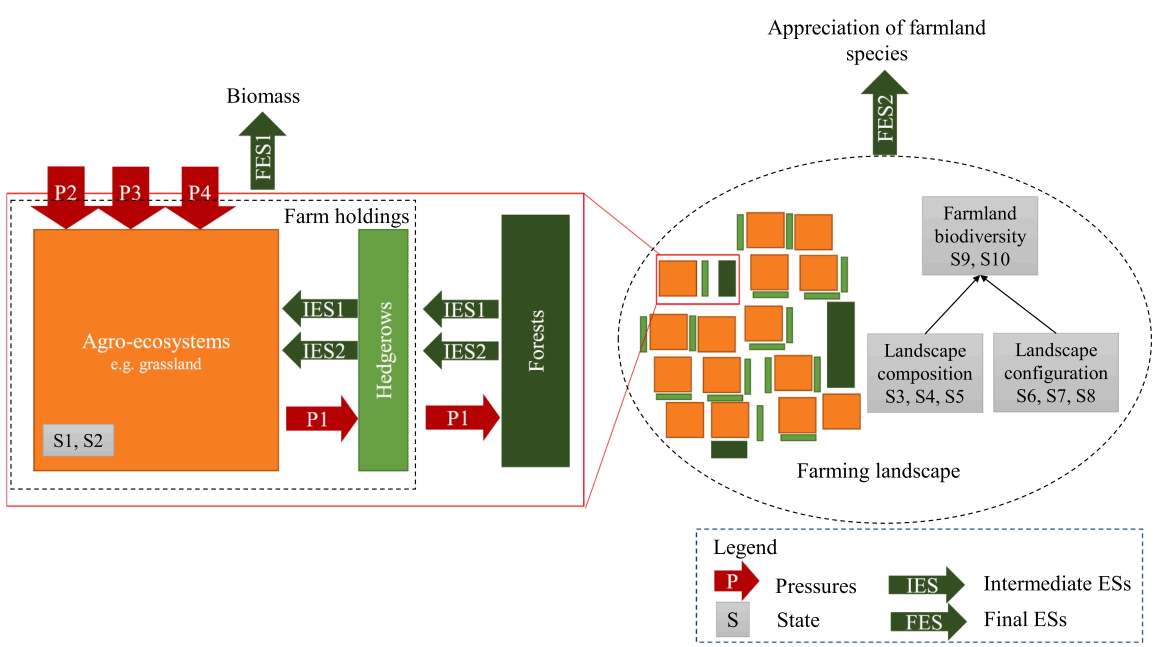

Fig. 3. Causal chain of selected P, S and I indicators for the theme farmland habitats and biodiversity, for the meaning of the numbers see Table 2.

3.2. Assessment of information available in the SEEA EA accounts and other national environmental monitoring systems

For each environmental theme, we assess indicator gaps in the Dutch SEEA EA accounts as developed to date, and we show how the accounts could be completed with other national environmental monitoring systems to include all selected indicators. Then, we assess the ability of the existing data sources to quantify the selected indicators at multiple scales. Tables 3 and 4 present our main findings for respectively N pollution and farmland biodiversity. Details on the data sources and justifications of our assessment are presented in Appendix B; Table B1 (N pollution) and Table B2 (farmland biodiversity).

3.2.1. Reduction of water and air pollution by N

The current Dutch SEEA EA accounts include five of the fourteen required indicators for the theme of water and air pollution by N: none of the four Pressure indicators, four of the eight State indicators and one of the two Impact indicators (Table 3). Regarding State indicators, the accounts include N concentration of surface water bodies reported under the WFD, but WFD data hardly includes ditches (van Puijenbroek et al., 2014), and most monitoring locations used for WFD reporting are located in downstream catchments influenced by other N sources than farming (Fraters et al., 2020). N concentrations in ditches, which are close to agricultural fields where N losses occur, better reflect N losses from farming than N concentrations in larger downstream water bodies. Most of the absent indicators could be obtained from other existing environmental monitoring systems. For instance, MNLSO data could complement the WFD indicators. MNLSO data is more directly linked to N losses from farming than WFD data, and it has been used to assess the effects of policy measures on water quality (Rozemeijer et al., 2014).

In terms of ES, the Dutch SEEA EA ESs supply and use accounts include indicators of nature recreation and tourism activities, but do not include N retention in riparian ecosystems. The accounts do include an ES of phreatic groundwater purification provided by terrestrial ecosystems, which is valued by comparing water treatment costs between phreatic groundwater and surface water based extraction (using a replacement cost approach). All terrestrial ecosystems located in the groundwater extraction and protection areas are assumed to equally contribute to the service, so that agro-ecosystems in these zones provide a water purification service to drinking water companies. From an agro-environmental policy perspective, considering agro-ecosystems as providers of a water purification service is questionable, given the intensity of inputs use in the majority of agriculture areas in the Netherlands. This approach contradicts the perspective taken in our study, in which the farming activities generate negative externalities for the drinking water sector. Therefore, the water purification ES estimated by the current accounts is not suited to assess the links between farming practices and N pollution of drinking water. However, estimation of the N retention ES could be obtained from existing models used to quantify N flows in water (Bolt et al., 2020; de Knegt et al., 2020).

To support agro-environmental policy, the Dutch SEEA EA accounts should be completed with other data sources. In particular, the condition accounts should include pressure indicators related to N flows in ecosystems, by integrating outputs from existing national models. Furthermore, the condition accounts should be extended with indicators specific to the condition of agro-ecosystem, such as nitrates concentration in shallow groundwater or ammonia concentration in the atmosphere.

In most cases, existing data sources only provide reliable estimates of indicators at a regional scale, for main soil and farm types (Table 3). Farm statistics (FADN) provide reliable farm scale estimates of ammonia emissions and Net N surplus. However, estimates of N concentration in shallow groundwater (LMM) and surface water eutrophication indicators (MNLSO) are only reliable at a regional scale, for main soil and farm types (Buijs et al., 2020; Fraters et al., 2020), due to insufficient sampling intensity and frequency (Rozemeijer et al., 2010b). Existing models provide maps of Pressures and nitrates concentration in shallow groundwater at a high spatial resolution, but these estimates have a high uncertainty at the level of map grid cells (Bolt et al., 2020; Kros et al., 2019; RIVM, 2017). Therefore, aggregation of model outputs for main regions or large catchments is required to obtain reliable results. Regarding ESs, nature recreation and tourism ESs indicators are based on statistics at provincial level downscaled to ETs on the basis of the location of hiking paths and tourism facilities. Therefore, the same value

Table 3
Indicators included in the Dutch SEEA EA accounts and other data sources for the theme N pollution, spatial coverage and scale of reliable estimations allowed by these existing data sources (detailed information is presented in Table B.1, Appendix B).

#	Indicator name	Data sources		Spatial coverage	Scale
		Dutch SEEA EA accounts	**Other**		
P1	NH_3 emissions to the atmosphere		FADN INITIATOR	Sample Map	Farm Regional
P2	Net N surplus		FADN INITIATOR	Sample Map	Farm Regional
P3	N load to surface water		LWKM	Map	Regional
P4	N load to deep groundwater	Not available			
S1	N concentration in shallow groundwater in agro-ecosystems		LMM RIVM Nitrates map, LWKM	Sample Map	Regional Regional
S2	N concentration in drinking water wells		LMG, drinking water companies	Sample	Catchment
S3	N concentration in (semi-) natural aquatic ecosystems	Dutch SEEA EA condition account (WFD monitoring data)	WFD monitoring, MNLSO	Sample	Regional
S4	Water transparency	Dutch SEEA EA condition account (WFD monitoring data)	WFD monitoring	Sample	Regional
S5	Phytoplankton growth		WFD monitoring, MNLSO	Sample	Regional
S6	NH_3 concentration in the atmosphere		OPS/GCN	Map	Catchment
S7	PM concentration in the atmosphere	Dutch SEEA EA condition account	OPS/GCN	Map	Catchment
S8	Wetlands and (semi-)natural riparian vegetation	Dutch SEEA EA extent account		Map	Field
FES1	N retention		LWKM	Map	Regional
FES2	Recreation and tourism	Dutch SEEA EA biophysical ES account, Dutch SEEA EA ESs and assets monetary accounts		Map	Regional

of ES provision is assigned to all water bodies in the catchments of a given province.

In order to provide reliable assessments at farm or catchment scale, monitoring networks with higher sampling intensities and frequencies or models with high spatial resolution input data would be required. For instance, reliable farm scale estimates of N concentrations in shallow groundwater require a high sampling intensity (e.g. (Boumans et al., 2001) use three samples per ha). The estimation of reliable N concentrations and N loads at catchment scale requires a near continuous sampling of water quality (Rozemeijer et al., 2010b). Regarding the nature recreation and tourism ES, the spatial resolution of the nature recreation and tourism ES model could be increased by using big data from mobile networks and social media (Havinga et al., 2020).

3.2.2. Protection and enhancement of farmland habitats and biodiversity

The current Dutch SEEA EA accounts include eleven of the eighteen required indicators to monitor and evaluate AEMs for their effects on farmland habitats and biodiversity: two of the four Pressure indicators, six of the ten State indicators and three of the four Impact indicators (Table 4). Most of the missing indicators could be added from other environmental monitoring systems. Land cover and land use data from the Dutch SEEA EA extent account can provide indicators of land use change (P4), and the resulting availability and spatial configuration of potential farmland habitats (S3, S4, S5, S7, S8). Some specific habitat indicators for birds (P2, P3, S1, S2, S6) are absent from the accounts, but part of these absent indicators (P2, P3, S6) could be obtained from other existing data sources (Melman et al., 2014). The biodiversity account reports the Living Planet Index for farmland but does not provide information on abundance and spatial distribution of farmland species targeted by AEMs schemes (S9). However, these indicators are available from existing biodiversity monitoring systems (Altenburg et al., 2017; Roodbergen et al., 2011) and could be included in the accounts. The biodiversity account also includes farmland butterfly species distribution maps, which is of interest as indicator of birds habitat quality (S2). No information on abundance and spatial distribution of functional species groups (S10), such as pollinators or pest enemies, is available in the account, nor is available in other environmental monitoring systems. This gap reflects the lack of insects monitoring data in the Netherlands (Schmidt et al., 2020). Regarding ESs indicators, the Dutch SEEA EA accounts include the provisioning (FES1) and regulating services (IES1, IES2), but no cultural ES (FES2). Pilot research using citizen science data to quantify people interactions with biodiversity presents a promising way to fill this gap (Havinga et al., 2020).

The Dutch SEEA EA extent account provide high spatial resolution land cover and land use maps that can support estimations of several indicators (P4, S3, S4, S7, S8) with field scale data. However, the Top10NL map, which is the basis for the land cover data included in the extent account, does not include all small landscape elements. Doorn et al. (2016) estimated that around 18% of the total area of small landscape elements is not included in the Top10NL map, because around 80% of isolated trees and small groups of trees, and around 30% of line woody elements are not captured. Nevertheless, tree crown mapping using very high resolution digital elevation models (Meijer et al., 2015) could be used to increase the coverage of woody landscape elements in the accounts.

Bird census data that is collected every year in the country (Altenburg et al., 2017; Boele et al., 2020) enables to assess species population trends at provincial scale (Kleyheeg et al., 2020), without information on changes in spatial distribution. Intensive counts carried out between 2013 and 2016 for the bird atlas (Altenburg et al., 2017) have produced species distribution maps at one to five km grid cells resolution. However such resource intensive effort is not frequently repeated: the previous

Table 4
Indicators included in the Dutch SEEA EA accounts and other data sources for the theme farmland habitats and biodiversity, coverage and scale of reliable estimations allowed by these existing data sources (detailed information is presented in Table B2, Appendix B).

#	Indicator name	Data sources		Coverage	Scale
		Dutch SEEA EA accounts	**Other**		
P1	N inputs		FADN	Sample	Farm
			INITIATOR	Map	Regional
P2	Grasslands mowing intensity		Groenmonitor	Map	Field
P3	Drainage of grasslands	Dutch SEEA EA ecosystem condition accounts		Map	Landscape
P4	Land use changes	Dutch SEEA EA ecosystem extent accounts		Map	Field
S1	Grasslands plant species richness	Not available			
S2	Insects abundance and richness	Dutch SEEA EA biodiversity accounts		Map	Landscape
S3	Area of agricultural habitats	Dutch SEEA EA ecosystem extent accounts		Map	Field
S4	Area of semi-natural landscape elements	Dutch SEEA EA ecosystem extent accounts		Map	Field
S5	Crop diversity	Dutch SEEA EA ecosystem extent accounts		Map	Field
S6	Landscape openness		Environmental Data Compendium	Map	Field
S7	Field size	Dutch SEEA EA ecosystem extent accounts		Map	Field
S8	Connectivity	Dutch SEEA EA ecosystem extent accounts		Map	Field
S9	Abundance and spatial distribution of targeted farmland species		Farmland birds monitoring networks (BMP, MAS, PTT),	Sample	Regional
			Bird Atlas of the Netherlands	Map	Landscape
S10	Abundance and species richness of functional species groups (pollinators, pest enemies)	Not available			
IES1	Crop pollination	Dutch SEEA EA ESs biophysical accounts		Map	Unknown
IES2	Natural pest control	Dutch SEEA EA ESs biophysical accounts		Map	Unknown
FES1	Contribution to biomass production	Dutch SEEA EA ESs biophysical accounts		Map	Regional
FES2	Cultural interactions with farmland biodiversity	Not available			

bird atlas survey had taken place fifteen years before. Opportunistic observations from citizen science platforms offer an opportunity to generate more frequent bird atlas, using site occupancy models (Strien et al., 2010). Such models have been used to provide the butterflies species spatial distribution maps in the Dutch SEEA EA biodiversity accounts. Extending the biodiversity accounts with farmland bird species spatial distribution maps would be a valuable enhancement of the SEEA EA accounts.

With regards to ESs, even though ESs are modeled at a high spatial resolution, we do not know if the ESs accounts actually provide data that is reliable at field or farm scale because the models have not been validated for this scale. Several potential sources of uncertainty could limit the accuracy of the crop pollination model. For example, the crop pollination ES model does not integrate pollinators species abundance and richness in ETs providing the crop pollination ES, which likely impacts the reliability of the crop pollination ES model at field, farm or landscape scales.

3.3. Potential applicability in support of CAP implementation

3.3.1. Reduction of water and air pollution by N

3.3.1.1. Agri-environmental reporting. The Dutch SEEA EA accounts completed with other data sources could usefully complement the CAP CMEF, so that changes in water quality and air quality and ESs linked to the CAP implementation are better captured. With regards to surface water quality, the CAP CMEF uses the percentage of rivers which exceed the limit of 50 mg NO_3^-/l as indicator. However, the 50 mg NO_3^-/l is adequate with regards to the provision of drinking water, but not sufficient to guarantee the ecological quality of surface water bodies (STOWA, 2018). Using complementary eutrophication indicators (transparency, phytoplankton) would provide a more complete picture of surface water quality, but these indicators are currently absent in the CAP CMEF. With regards to air quality, the CAP CMEF is limited to ammonia emissions and does not provide any indicator of the resulting ammonia or PM concentration in the atmosphere. Hence, here also the SEEA EA can make a useful contribution, i.e. by showing how air quality varies in agricultural areas. Indeed, air quality indicators in the Dutch SEEA EA accounts show that areas with intensive livestock production, such as the 'Gelderse Valley' in the centre of the Netherlands, have relatively high $PM_{2.5}$ concentrations throughout the year (Government of the Netherlands, 2021).

However, in most cases, water and air quality are influenced not only by agriculture but also by emissions from other sources. Therefore, water and air quality indicators should be completed with indicators about the share of the farming sector in total N emissions. In the Netherlands, according to the national emissions registry, the farming sector contributed to around half of total N loads to surface water in 2018, through direct losses from fields and its contribution to atmospheric N deposition (Government of the Netherlands, 2021). Regarding air quality, the farming sector contributed to about half of N emission to air in 2019 (Government of the Netherlands, 2021). (Weijers et al., 2011) estimated that ammonia aerosols contribute to about 50% of $PM_{2.5}$ in the Netherlands, and most ammonia emissions are coming from the farming sector (85% in 2019). However, locally, these proportions may be different. With the AERIUS model, the local contributions of the farm sector can be retrieved, but these data are not yet included in the Dutch SEEA EA accounts.

With regards to ESs, the water purification ES quantified in the current Dutch SEEA EA accounts is not adequate for agri-environmental reporting. However, accounts could be complemented by other data sources to provide indicators on the importance of semi-natural ecosystems in farming landscapes for water purification. Moreover, the ESs accounts could be further developed to estimate nature recreation and tourism activities depending on the quality of surface water bodies.

3.3.1.2. Assessment of AEMs effectiveness. In principle, accounts and complementary monitoring systems could be used to assess the effects of water related AEMs on N pollution at catchment scale. Detecting such effects requires to assess how aggregates of farm scale Pressures, NC and ESs respond to AEMs implementation, by comparing catchment with AEMs implementation (treatment catchments) to catchments without AEMs implementation (control catchments). For this application, accounts should include reliable estimates of indicators at catchment scale. This would require increasing sampling intensities of water quality monitoring data and the reliability of models at high spatial resolution, as shown by the Section 3.2. In the Netherlands, a landscape scale application of the INITIATOR model using high resolution input data on animal numbers, land use and farm management allowed to test the effects of agricultural measures on water quality (Kros et al., 2011). Therefore, enhancing accounts with landscape applications of INITIATOR combined with improved water quality monitoring data would be useful to assess AEMs effectiveness on water quality at catchment scale. Once effects of AEMs on water quality changes have been established, accounts could link such changes in water quality to the provision of ESs, such as nature recreation and tourism, and to externalities, such as drinking water treatment costs. However, quantifying such cause-effect relationships requires further research.

3.3.1.3. Results-based AEMs. Results based AEMs require measuring negative externalities and ESs supply delivered by farmers at the scale of the farm. At present the accuracy of the national scale Dutch SEEA EA accounts and complementary environmental monitoring systems is insufficient for farm scale applications. Therefore, to support results-based AEMs, the Dutch SEEA EA accounts should be enhanced with accurate estimates of N indicators at high resolution. The National Institute for Public Health and the Environment is testing new technologies, such as connected water sensors (Pellerin et al., 2016) to improve the spatial and temporal resolution of nutrient monitoring at farm scale (Hooijboer et al., 2020), but major efforts would be required to scale this up to the whole country.

3.3.2. Protection and enhancement of farmland habitats and biodiversity

3.3.2.1. Agri-environmental reporting. Regarding farmland habitats and biodiversity, the SEEA EA accounts could enhance the CAP CMEF in two ways. First, the Dutch SEEA EA biodiversity accounts could provide frequently updated farmland species distribution maps, and thereby support the assessment of the extent of High Nature Value (HNV) farmland in the Netherlands. The extent of HNV farmland in the Netherlands has been estimated for the year 2012, through a combination of land cover and land use, farm practices and bird and butterflies species distribution maps from respectively 1998–2000 and 2006 (Doorn et al., 2013). However, the HNV farmland map has not been updated since 2012. The Dutch SEEA EA could support the updating of the HNV farmland area assessment with the farmland butterfly species distribution maps (period 2006–2013) available in the biodiversity accounts. Extending the biodiversity accounts to farmland plant and bird species would further enhance the accounts usability. Second, SEEA EA ESs accounts could provide farmland biodiversity related ESs indicators, such as crop pollination and natural pest control, which are completely absent in the current CAP CMEF impact indicators. ESs contributing to agricultural production are especially relevant, in line with the objective to stimulate farming practices that rely more on biodiversity related ESs and less on chemical inputs. The Dutch SEEA EA accounts already include indicators of crop pollination ESs and natural pest control ESs. The latter is at the moment limited to the control of aphids by lady bugs, but extension of the natural pest control ES model is being implemented (M. Lof, personal communication 2021).

3.3.2.2. Assessment of AEMs effectiveness. To assess AEMs effects on targeted species, species counts data is required so that changes in species abundance can be related to AEMs implementation. In the Netherlands, some farmers collectives implementing AEMs have set up monitoring schemes and bird census data is regularly collected by the national bird monitoring programs. The Dutch accounts do not include these data sources, which are not public. However, the Dutch SEEA EA accounts have the potential to support AEMs evaluation studies by providing indicators on field and landscape scale factors which are likely to influence AEMs effects. For instance, the ecosystem condition accounts include the level of drainage of peatland meadows, and ecosystem extent accounts provide high resolution land cover and land use data that can support several relevant indicators of landscape composition and configuration, as shown in Section 3.2.

Another potential application of the Dutch SEEA EA accounts is to assess the effects of AEMs on the supply of multiple ESs, in order to analyse trade-offs and synergies. For instance, the accounts could be used to assess whether AEMs deliver benefits to farmers in terms of crop pollination, in addition to the main target of farmland species conservation. To confirm this potential, it would be useful to validate the crop pollination ES model and assess accuracy of its outputs at landscape and farm scales.

3.3.2.3. Results-based AEMs. Regarding results-based AEMs for farmland biodiversity, relevant indicators may be the abundance of targeted species on farms implementing AEMs or indicators of the quality of habitats provided by farms, such as grassland plant species richness and insects species richness indicating habitat quality for farmland birds (Visser et al., 2020). The current Dutch accounts do not include these indicators required to support results-based payments. There are only distribution maps for butterfly farmland species in the accounts, and these maps have a too coarse resolution to be linked to farm scale. There are no indicators on other insects groups, nor on plant species in the accounts. Nevertheless, habitat quality indicators should be increasingly available in the future. For instance, ongoing research seek to detect species-rich grasslands with the combined use of remote sensing technologies and crowd sourced photographs (BoerenNatuur, 2021). Furthermore, it should be noted that AEMs outcomes are not only driven by the quality of provided habitat at farm scale but also by landscape characteristics, such as landscape openness (van der Vliet et al., 2008). Therefore, for results-based AEMs to succeed, they should target farms located in those landscapes which offer the best potential for targeted birds populations (Melman et al., 2008). For this targeting, the Dutch accounts can already make a useful contribution, through indicators in the ecosystem extent and condition accounts, as shown in Section 3.2.

4. Discussion

The existing Dutch SEEA EA accounts include half of selected indicators for the two environmental themes: two of the eight Pressure indicators, ten of the eighteen State indicators, and four of the six ESs indicators. Gaps in Pressure indicators reflect that the SEEA EA framework is focused on the assessment of EAs and ESs flows. The Dutch SEEA EA accounts include those Pressure indicators that are closely related to the condition of ecosystems (N deposition, drainage), but leave out N emissions from farming activities. Farming emissions are already within the scope of the SEEA CF accounts, which record physical flows of pollutants from the economy to the environment (FAO and UN, 2020). However the SEEA CF is not spatially explicit, so that it does not allow to link farming emissions to changes in the condition of ecosystems and ESs flows. Our study shows that integrating information of N emissions from the SEEA CF accounts (and potentially other externalities) in the SEEA EA accounts would be relevant and enhance the usability of SEEA EA accounts to support agri-environmental policies. SEEA EA accounts that integrate information on N flows would enhance the assessment of negative farming externalities related to N, by supporting spatially explicit assessment of the social costs of N emissions, in terms of ESs loss and exposure to a degraded NC.

Our results show that the sampling and resolution of the Dutch SEEA EA accounts and complementary national environmental monitoring datasets limits their applicability. Regarding the theme of N pollution, the availability and reliability of indicators at landscape and farm scale are not sufficient to support the assessment of AEMs effectiveness and results-based AEMs. Regarding the theme of farmland biodiversity, the accounts have a higher potential thanks in particular to high resolution maps of ecosystem extent and ESs flows. Nevertheless, we noticed ample possibilities in the future to increase the accuracy of indicators at local scale with innovative technologies, such as connected sensors, remote sensing and big data.

Moreover, accounts could also be compiled at farm scale and used as a tool to monitor NC, ESs and negative externalities in farm holdings. Farmers increasingly record farm nutrients flows using digital tools, such as the Annual farm Nutrient Cycle Assessment (ANCA) model (van Leeuwen et al., 2019), which delivers farm scale estimates of ammonia emissions, soil N surplus and N leaching (Aarts et al., 2015). There are also initiatives to monitor key performance indicators for biodiversity in dairy and arable farms (Doorn and Jongeneel, 2020). Using the SEEA EA framework would help in ensuring consistency and linkage of NC accounts compiled at farm scale with the national scale SEEA EA accounts. For instance, the Dutch SEEA EA carbon accounts already include indicators of CO_2 emissions from drained organic soils, and CO_2 sequestration from semi-natural vegetation on farmland that could be integrated in farm scale accounts. Furthermore, the Dutch SEEA EA accounts would enable to link indicators recorded at farm scale (e.g. ammonia emissions, area of species-rich grasslands) to impacts on NC and ESs that are measurable at a larger scale (e.g. atmospheric N deposition, farmland bird species abundance).

Most indicator gaps in the existing Dutch SEEA EA accounts could be filled with other publicly available environmental monitoring data covering the whole Netherlands. The accounts complemented with these other data sources could enhance the CAP CMEF, by providing relevant indicators of NC, farmland biodiversity and ESs at national and provincial scales. However, the Netherland is among the most advanced EU member states for the compilation of accounts (Hein et al., 2020) and a country with abundant environmental monitoring data. Therefore, the potential application of the SEEA EA accounts may be more limited in other countries where ecosystem accounting has only recently started and less environmental monitoring data is available. Thus, certain indicators may not be available for all EU countries, which would limit the applicability of the SEEA EA to enhance the CAP CMEF. Nevertheless, SEEA EA accounts are also compiled at EU scale, and relevant indicators for agri-environmental policy, such as an assessment of the crop pollination ES (Vallecillo et al., 2018), have already been generated for all EU countries. Findings of this study can support further the design of EU scale SEEA EA accounts to support CAP monitoring, for example in the selection of relevant indicators. To achieve this goal, our approach should be extended to other environmental objectives of the CAP, such as climate change mitigation and the sustainable use of water and soil resources, and to countries with different agro-ecological conditions than the Netherlands.

Besides efforts at EU scale, EU member states are now engaged in the compilation of national SEEA EA accounts (García-Bruzón et al., 2020), which requires significant resources. It will therefore be crucial to demonstrate the policy relevance of accounts to increase and sustain such efforts in the long term. Applying SEEA EA accounts to support CAP monitoring would be a major policy application, given the importance of the CAP in the EU budget. Such application could also support monitoring the Green Deal achievements, with respect to the protection of farmland biodiversity and reduction of greenhouse gas emissions and other polluting emissions from agriculture. Our findings can help countries in the selection of relevant indicators for their national SEEA

EA accounts to support CAP monitoring. However, aligning supply and demand of information is not the only challenge in making accounts fit for policy. Other aspects, such as stakeholders engagement, embedding accounts in governmental institutions and clear communication of outputs, also play an important role (see (Ruijs et al., 2019) and (Hein et al., 2020) for lessons drawn from the Dutch experience in developing SEEA EA accounts).

An important issue for policy applications is the position and complementarity of the SEEA EA with respect to other existing environmental monitoring systems. Our study shows that many required data to support CAP monitoring are already available in existing monitoring networks for water and air quality or farmland biodiversity in the Netherlands. However, the SEEA EA accounts can provide added value to these existing systems through the integration of multiple data sources in one consistent spatially explicit framework. For instance, the integration of information on ecosystem extent from the SEEA EA and information on farmland biodiversity from existing biodiversity monitoring networks could provide insights into the effects of agricultural land use on farmland species. Another example is forest carbon stocks and flows reporting. In this case, the combination of spatial land cover data in ecosystem extent accounts with forest inventory data provided detailed spatial data on carbon stocks and flows in the Netherlands (Hein et al., 2020). Thus, spatially explicit data in the SEEA EA could complement the existing carbon reporting for Land Use, Land Use Change and Forestry (LULUCF) in the EU. Finally, the SEEA EA provides information on the supply and use of ESs, in a spatially explicit manner, with a national coverage and regular updates, which is not covered by other existing environmental monitoring systems in the Netherlands.

5. Conclusion

Since the SEEA EA was published in 2014, the approach has been tested in multiple countries around the world and chapters one to seven of the SEEA EA have been adopted as a statistical standard by the UN Statistical Commission in 2021. In the EU, the SEEA EA is applied at European scale and by an increasing number of member states. Thus, much progress has been done in the testing and implementation of the SEEA EA. Meanwhile, there is a need to link the SEEA EA to policy and other users, among others by demonstrating potential applications of the published SEEA EA accounts. This study assesses the fitness of accounts to provide relevant indicators to evaluate agri-environmental policies, by focusing on N pollution and farmland biodiversity in the Netherlands. To further assess the potential use of SEEA EA accounts in agri-environmental policy, our approach should be extended to other countries and other environmental objectives of the CAP.

To support agri-environmental policies, the SEEA EA accounts should include indicators of pressures that link farming activities to changes in NC and ESs flows. In the Netherlands, a major omission in the accounts is that N emissions are not included as a pressure indicator. Nevertheless, a detailed system to record such flows (AERIUS) exists, but the developers of the first generation of ecosystem accounts did not yet connect AERIUS to the SEEA EA. Our paper shows that doing this would greatly enhance the applicability of the SEEA EA to support the monitoring and evaluation of CAP environmental objectives.

The current accounts have a higher potential for farmland biodiversity, thanks in particular to high resolution maps of ecosystem extent and ESs flows. A natural progression of our study would be to test this potential for concrete case studies at landscape scale and to assess the accuracy of ESs maps. Moreover, we recommend expanding the Dutch SEEA EA accounts with, in particular, bird species spatial distribution data to enhance the applicability of accounts to monitor AEMs effects.

In conclusion, our study supports using the Dutch SEEA EA accounts to enhance monitoring of the CAP for the two studied environmental themes in the Netherlands. The existing accounts already provide relevant NC, farmland biodiversity and ESs indicators at provincial and national scale. Gaps in the accounts can be filled with existing complementary data sources on N emissions, as well as ongoing development of the accounts on the spatial modeling of biodiversity (farmland species accounts) and ESs. Regarding the assessment of AEMs effectiveness and support to results-based payments, we recommend further research to test the refinement and application of the accounts at landscape and farm scales.

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CRediT authorship contribution statement

Nicolas Grondard: Conceptualization, Methodology, Investigation, Writing – original draft. **Lars Hein:** Conceptualization, Methodology, Writing - review & editing. **Lenny G.J. Van Bussel:** Conceptualization, Methodology, Writing - review & editing.

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.

Appendix A

Table A1
Dutch SEEA EA accounts reviewed in the study.

Account types	Years	Reference
Ecosystem extent account	2006, 2013	https://www.cbs.Dutch/en-gb/background/2017/12/ecosystem-unit-map
Ecosystem condition account	2013	https://www.cbs.Dutch/en-gb/custom/2019/15/seea-ecosystem-condition-account-for-the-netherlands
Ecosystem services supply and use account	2013	https://www.cbs.Dutch/en-gb/background/2018/23/the-ecosystem-service-supply-and-use-in-the-netherlands
Monetary valuation of ESs and assets	2015	https://www.cbs.Dutch/en-gb/background/2020/04/monetary-valuation-of-ecosystem-services-for-the-netherlands
Biodiversity account	2006–2013	https://www.cbs.nl/en-gb/background/2020/41/seea-eea-biodiversity-account-2006–2013
Carbon account	2013	https://www.cbs.Dutch/en-gb/background/2017/45/the-seea-eea-carbon-account-for-the-netherlands
Updated ecosystem extent account, condition account and ESs supply and use account, Monetary valuation of ESs and assets	2013, 2015, 2018	https://www.cbs.nl/nl-nl/publicatie/2021/22/natuurlijk-kapitaalrekeningen-nederland-2013–2018

Table A2
National environmental monitoring systems reviewed in the study.

Name	Description	References
Bedrijven-Informatienet (BIN)	The BIN is the Dutch part of the Farm Accountancy Data Network of the European Union. It collects yearly information on farm management, including nutrients inputs, outputs and changes in stocks. 1500 farms are included, representing 90% of the cultivated area in the country. The BIN data is used as inputs to estimate Net N surplus per farm and soil type. This indicator is used to report on the implementation of the EC Nitrates Directive.	(Poppe, 2004) (Fraters et al., 2020)
Landelijk Meetnet effecten Mestbeleid (LMM)	The LMM is a national monitoring system to assess the effects of the manure policy. It monitors nitrate concentrations in the upper groundwater on a sample of about 450 farms across the four main soil types in the country, for three main farm types (dairy farms, arable farms, other farms). Results are used to report on the implementation of the EC Nitrates Directive.	(Fraters et al., 2020)
Landelijk Meetnet Grondwaterkwaliteit (LMG)	The LMG is a national monitoring system to assess the quality of groundwater in 350 wells across the four main soil types in the country. Results are used to report on the implementation of the EC Nitrates Directive and Water Framework Directive.	(Fraters et al., 2020)
Meetnet Nutriënten Landbouw Specifiek Oppervlaktewater (MNLSO)	The MNLSO monitors nutrients in surface water in 168 monitoring locations for which agriculture is the dominant source of nutrients loads.	(Buijs et al., 2020)
Water Framework Directive water quality monitoring data	Water quality monitoring data collected by Rijkwaterstaat and water boards, and used for reporting on the implementation of the EC Water Framework Directive The KRW Nut Trend website presents N concentrations values, N status (N concentration vs. N reference value for a good ecological condition) and temporal trends of N concentrations for water bodies reported under the WFD.	https://www.waterkwaliteitsportaal.Dutch/wkp.webapplication https://www.krw-nutrend.Dutch/
Meetnet Ammoniak in Natuurgebieden (MAN)	Monitoring of ammonia atmospheric concentration in 84 nature areas. MAN data is used as calibration data by the OPS model to generate ammonia concentration maps.	https://man.rivm.nl/#detailpopup
Farmland birds monitoring networks	Several complementary networks monitor birds populations in the Netherlands. The main ones are the Broedvogel Monitoring Project (BMP, for breeding birds and the Punt-Transect-Tellingenproject (PTT, for wintering birds). The Meetnet Agrarisch Soorten (MAS) complements these networks by focusing on farmland areas, which are underrepresented in the BMP.	(Roodbergen et al., 2011) (Boele et al., 2020)
Landelijk Waterkwaliteitsmodel (LWKM)	The LWKM model is a national model used to simulate effects of policies and climate change on water quality. Outputs of the model are used to report emissions of pollutants to water in the Pollutant Release and Transfer Register	(Bolt et al., 2020) http://www.emissieregistratie.Dutch/erpubliek/bumper.en.aspx
Operational Priority Substances (OPS) model	OPS models the concentration and deposition of atmospheric pollutants. It is used in combination with air quality measurements to produce the Grootschalige Concentratie Kaarten (GCN), concentrations, at 1 km grid cell resolution, over the Netherlands.	(RIVM, 2020)
INITIATOR manure spatial allocation module	INITIATOR is an integrated nutrient model that estimates N processes in terrestrial and aquatic ecosystems. The manure spatial allocation module of INITIATOR calculates N inputs to agricultural soils and ammonia emissions at the parcel scale. It provides two outputs, N inputs to agricultural soils at 250 m. grid cells resolution and ammonia emissions at 100 m. grid cells resolution, which are used as input data by respectively the LWKM and OPS models.	(Kros et al., 2019)

Table A3
The CAP environmental objectives and impact indicators (EC, 2017).

CAP environmental objectives	Impact indicators CMEF
Contribute to climate change mitigation and adaptation, as well as sustainable energy	GHG Emissions from agriculture (I.07.1) Organic carbon content in arable soils (I.12)
Foster sustainable development and efficient management of natural resources such as water, soil and air	Soil erosion by water (I.13) Ammonia Emissions from agriculture (I.07.2) Gross Nitrogen Balance (I.11.1.a) and Gross Phosphorus Balance (I.11.1.b) on agricultural land Nitrates in ground water (I.11.2.a) and in surface water (I.11.2.b) Water abstraction in agriculture (I.10)
Contribute to the protection of biodiversity, enhance ecosystem services and preserve habitats and landscapes	Farmland Bird Index (I.08) High Nature Value farming (I.09)

Appendix B

Table B1
Assessment of indicators available in the Dutch SEEA EA accounts and other existing agri-environmental monitoring data for the theme N pollution (grey shaded cells: indicator not applicable at this scale). (See above-mentioned references for further information.)

#	Indicator name	Data sources	Spatial resolution/ sampling intensity	Temporal resolution/ sampling frequency	Spatial coverage	Time coverage	Potential application: Results-based payments – Single farm	Potential application: AECM efficiency assessment – Field	Potential application: AECM efficiency assessment – Farm	Potential application: Agri-environmental reporting – Catchment/ Landscape	Potential application: Agri-environmental reporting – Province/ National	
P1	NH3 emissions to the atmosphere	Initiator	100 m grid cells	Year	100%	2000-2015					X	Uncertainty of NH3 emissions at farm to landscape scale is estimated at 100-150%. It is reduced to 35-45% when aggregating at national scale (Kros et al., 2019).
P2	Net N surplus	FADN	Farm	Year	80% of the national agricultural area	1991-2019			X			Uncertainties of farm scale net N surplus estimates have been quantified at 12 % on farms with intensive monitoring programs. (Oenema et al., 2015).
		Initiator	Agricultural parcels	Year	100%	2000-2015					X	Uncertainty at farm to landscape scale is high due to uncertainties in N inputs and NH3 emissions, estimated at 100-150% (Kros et al., 2019).
P3	N load to surface water	LWKM		Year	100%	1990-2018					X	Outputs of the LWKM model are reliable at the scale of the main water catchments and water boards areas (Bolt et al., 2020)
P4	N load to deep groundwater											Quantifying of N loads to deep groundwater requires modeling N flows through phreatic aquifers. Such work has been done for case studies on specific groundwater catchments (van den Brink et al., 2008). However, we did not find a national dataset with estimates of N load to groundwater catchments across the country.
S1	N concentration in shallow groundwater in agro-ecosystems	LMM	16 samples per farm	1 sample/year	400 farms				X		X	N concentrations in shallow groundwater show high spatial and temporal variations due to the heterogeneity of farming practices, soil types, hydrology and weather conditions (Fraters et al., 1998; Rozemeijer et al., 2009; Rozemeijer et al., 2010a). Reliable farm scale estimates require a high sampling intensity (e.g. (Boumans et al., 2001) use 3 samples per ha). Reliable assessments for main farm types and soil regions can be obtained with the current sampling intensity of the LMM (Fraters et al., 2020; Fraters et al., 1998)
		RIVM Nitrates map	500 m.		100%	2008-2011 2012-2015					X	Spatial extrapolation of LMM point measurements to a 500 m resolution map, but high uncertainty at the level of 500 m grid cells. The map is reliable for aggregated results at regional scale (RIVM, 2017).
		LWKM		Year	100%	1990-2018					X	Outputs of the LWKM model are reliable at the scale of the main water catchments and water boards areas (Bolt et al., 2020)
S2	N concentration in drinking water wells	LMG, drinking water companies			Drinking water wells					X	X	Nitrates concentration in drinking water wells is continuously monitored by drinking water companies.

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Table B1 (*continued*)

S3	N concentration in (semi-)natural aquatic ecosystems	Dutch SEEA EA condition account/WFD monitoring	Average of samples per water body	3 years average from monthly samples	National and regional water bodies						X	Spatial coverage of WFD reporting is not exhaustive and hardly includes ditches (van Puijenbroek et al., 2014), which are directly influenced by diffuse farming losses. Water quality in the WFD reported water bodies is influenced by multiple sources besides farming (Fraters et al., 2020)
		MNLSO		Monthly samples	168 monitoring locations in agricultural sub-catchments	1990-2019					X	Monitoring locations are located in catchments where agriculture is the dominant land use and the influence of other N sources is minimal (Buijs et al., 2020). MNLSO data can be used to assess the effects of policy measures on N concentrations of surface water bodies for main soil types regions (Rozemeijer et al., 2014)
S4	Water transparency	Dutch SEEA EA condition account/ WFD monitoring	Average of samples per water body	3 years average from monthly samples	National and regional water bodies						X	Only large water bodies are included in the WFD reporting, which excludes many small water bodies, such as ditches, directly influenced by diffuse farming losses. Water quality in the WFD reported water bodies is influenced by multiple sources besides farming (Fraters et al., 2020)
S5	Phytoplankton growth	WFD monitoring	Average of samples per water body	3 years average from monthly samples	National and regional water bodies						X	Only large water bodies are included in the WFD reporting, which excludes many small water bodies, such as ditches, directly influenced by diffuse farming losses. Water quality in the WFD reported water bodies is influenced by multiple sources besides farming (Fraters et al., 2020)
		MNLSO		Monthly samples	168 monitoring locations in agricultural sub-catchments	1990-2019					X	Monitoring locations are located in catchments where agriculture is the dominant land use and the influence of other N sources is minimal (Buijs et al., 2020).
S6	NH_3 concentration in the atmosphere	GCN	1 km grid cells	year	100%					X	X	Uncertainty is about 24% at the 1km grid scale (Hoogerbrugge et al., 2020)
S7	PM concentration in the atmosphere	Dutch SEEA EA condition account/GCN	1 km grid cells	year	100%					X	X	Uncertainty is 15% at the 1km grid scale (Hoogerbrugge et al., 2020)
S8	Wetlands and (semi-)natural riparian vegetation	Dutch SEEA EA extent account	2.5 m raster maps	2-3 years	100%	2013-2015-2018	X	X	X	X	X	The Dutch SEEA EA ecosystem extent map integrates land cover and land use information from the national topographic map (Top10NL).
FE S1	N retention	LWKM – KRW Verkenner		Year	100%	1990-2018					X	Outputs of the LWKM model are reliable at the scale of the main water catchments and water boards areas (Bolt et al., 2020)
FE S2	Nature recreation and tourism	Dutch SEEA EA biophysical ES account	Province	year	100%	2013, 2015, 2018					X	Accounts are based on the downscaling of Provincial statistics.

Table B2
Assessment of indicators available in the Dutch SEEA EA accounts and other existing agri-environmental monitoring data for the theme farmland habitats and biodiversity (grey shaded cells: indicator not applicable at this scale). (See above-mentioned references for further information.)

#	Indicator name	Data sources	Spatial resolution/ sampling intensity	Temporal resolution/ sampling frequency	Spatial coverage	Time coverage	Potential application: Results-based payments	AECM efficiency assessment			Agri-environmental reporting	
							Single farm	Field	Farm	Catchment/ Landscape	Province/ National	
P1	N inputs	FADN	Farm	Year	80% of the national agricultural area	1991-2019	X		X			The FADN collects and analyses data on N inputs from about 1500 farms that represent around 80% of the national agricultural area (Fraters et al., 2020)
		Initiator	Agricultural parcels	Year	100%	2000-2015					X	Uncertainty at farm to landscape scale is high due to uncertainties in N inputs, estimated at 100-150% (Kros et al., 2019).
P2	Grasslands management intensity	Groenmonitor	Agricultural parcels	Every 5 to 10 days	100%	2007-2010	X	X	X	X	X	Groenmonitor (https://www.groenmonitor.Dutch/) provides vegetation index data at field scale derived from satellite images at 10 meters resolution. Temporal analysis of vegetation index can support assessment of grassland management intensity (Melman et al., 2014).
P3	Drainage of grasslands	Dutch SEEA EA ecosystem condition accounts	25 m	Year	For organic soils only	2006, 2016				X	X	Estimated based on information on ditch water levels for seven waterboard areas in 2016, completed with the 2006 groundwater table map in other areas. Waterboards determine target ditch and surface water levels per catchment.
P4	Land use changes	Dutch SEEA EA ecosystem extent accounts	2.5 m raster maps	2-3 years	100%	2013, 2015, 2018	X		X	X	X	The Dutch SEEA EA ecosystem extent map integrates land cover and land use information from the national topographic map (Top10NL). The smallest landscape elements (isolated trees, small groups of trees and hedgerows) are not mapped in the Top10NL. Nevertheless, it includes around 82% of the area of small landscape elements (Doorn et al., 2016). Specific information on agricultural land use (e.g. crop types) is derived from the national agricultural parcel registry (BRP). The BRP is based on farmers' declarations to the administration in relation to CAP subsidies.
S1	Grasslands plant species richness											The vascular plant atlas (https://www.verspreidingsatlas.Dutch/vaatplanten) records the presence of vascular plant species in 1 km blocks across the country, but blocks mix species records from all land cover types.
S2	Insects abundance and richness	Dutch SEEA EA biodiversity accounts	5 km raster map	year	100%	2006 - 2013				X	X	The Dutch SEEA EA biodiversity accounts include farmland butterfly species distribution maps derived from site occupancy models. The maps show whether a given species is present in each 5 km grid but do not provide an estimation of abundance. A species richness map is obtained by combining individual species distribution maps.
S3	Area of agricultural habitats	Dutch SEEA EA ecosystem extent accounts	2.5 m raster maps	2-3 years	100%	2013, 2015, 2018	X	X	X	X	X	Specific information on agricultural land use (e.g. crop types) is derived from the national agricultural parcel registry (BRP). The BRP is based on farmers' declarations to the administration in relation to CAP subsidies.
S4	Area of semi-natural	Dutch SEEA EA ecosystem	2.5 m raster maps	2-3 years	100%	2013, 2015, 2018	X	X	X	X	X	The Dutch SEEA EA ecosystem extent map integrates land cover and land use information from the

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Table B2 (*continued*)

	landscape elements	extent accounts										national topographic map (Top10NL). The smallest landscape elements (isolated trees, small groups of trees and hedgerows) are not mapped in the Top10NL. Nevertheless, it includes around 82% of the area of small landscape elements (Doorn et al., 2016)..
S5	Crop diversity	Dutch SEEA EA ecosystem extent accounts	2.5 m raster maps	2-3 years	100%	2013, 2015, 2018	X		X	X	X	Specific information on agricultural land use (e.g. crop types) is derived from the national agricultural parcel registry (BRP). The BRP is based on farmers' declarations to the administration in relation to CAP subsidies.
S6	Landscape openness	Environmental Data Compendium	100 m resolution		100%	2009				X	X	The indicator was calculated for the year 2009 and is used as indicator by the Netherlands Environmental Assessment Agency (PBL) :https://www.clo.Dutch/en/indicators/en1022-landscape-openness. (Meeuwsen and Jochem, 2015)
S7	Average field size	Dutch SEEA EA ecosystem extent accounts	2.5 m raster maps	2-3 years	100%	2013, 2015, 2018	X		X	X	X	Specific information on agricultural land use (e.g. crop types) is derived from the national agricultural parcel registry (BRP). The BRP is based on farmers' declarations to the administration in relation to CAP subsidies.
S8	Connectivity	Dutch SEEA EA ecosystem extent accounts	2.5 m raster maps	2-3 years	100%	2013, 2015, 2018				X	X	Indices of connectivity can be calculated using the Dutch SEEA EA ecosystem extent account maps.
S9	Abundance and spatial distribution of targeted farmland species	Farmland birds monitoring networks (BMP, MAS, PTT)	BMP: 2206 sample plots MAS: a few hundred sample plots per province in 5 provinces PTT: around 600 transects	year	100%	1990-2019					X	Counts from the monitoring networks are analysed to produce population indexes at national and provincial scales: - Breeding birds species annual population index (from 1990) - Wintering birds species annual population index (from 1983)
		Bird Atlas of the Netherlands	> 4000 1km grid cells counted each year during 3 years	15 years	100%	1973-77, 1978-83, 1998-2000, 2012-2015				X	X	The bird atlas of the Netherlands (2013-2015) provides: - Relative breeding birds species density maps at 1km resolution - Wintering birds species distribution maps at 5 km resolution
S10	Abundance and species richness of functional species groups (pollinators, pest enemies)	Dutch SEEA EA ESs biophysical accounts										There is no systematic monitoring of pollinators and pest enemies in the Netherlands. Existing monitoring networks are limited to butterflies, dragonflies and beetles, with a limited coverage of farmland. (Kleijn et al., 2018; Schmidt et al., 2020) Some studies are available on pollinators (Carvalheiro et al., 2013)
IES 1	Crop pollination	Dutch SEEA EA ESs biophysical accounts	EAs vector map	year	100%	2013, 2015, 2018				X	X	The crop pollination ES is modelled by spatially matching crop pollination supply and demand. Crop pollination supply is assumed to be driven by the suitability of ETs to provide nesting and foraging habitats to pollinators. Crop pollination demand is derived from crop types and pollination requirement per crop type. Potential limitations of the model : (1) the ecosystem extent map does not include some of the smallest

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Table B2 (*continued*)

										land cover units that provide habitats to pollinators (small hedgerows), (2) the model does not take into account the quality of habitat patches (e.g. availability of floral resources), and (3) the model does not take into account the use of pesticides. As the model uses high resolution land cover input data, it may provide reliable results at farm scale, but no validation of the model with field data (e.g. pollinators field visits) has been performed to confirm this possibility.
IES 2	Natural pest control	Dutch SEEA EA ESs biophysical accounts	EAs vector map	year	100%	2013		X	X	The accounts only model the control of aphids by ladybugs. There is ongoing work to expand the model to other pests and diseases.
FES 1	Contribution to biomass production	Dutch SEEA EA ESs biophysical accounts	Agricultural parcels	year	100%	2013, 2015, 2018			X	Total harvested biomass is assigned to ecosystems based on yield statistics at provincial scale. Fodder production is disaggregated at a higher resolution by using net primary productivity calculated from remote sensing data, but the accuracy of these high resolution estimates is not assessed in the accounts.
FES 2	Cultural interactions with farmland biodiversity									No data available, but method developed by (Havinga et al., 2020) could be applied to assess this ES.

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