National Ecosystem Assessments in Europe: A Review

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National ecosystem assessments form an essential knowledge base for safeguarding biodiversity and ecosystem services. We analyze eight European (sub-)national ecosystem assessments (Portugal, United Kingdom, Spain, Norway, Flanders, Netherlands, Finland, and Germany) and compare their objectives, political context, methods, and operationalization. We observed remarkable differences in breadth of the assessment, methods employed, variety of services considered, policy mandates, and funding mechanisms. Biodiversity and ecosystem services are mainly assessed independently, with biodiversity conceptualized as underpinning services, as a source of conflict with services, or as a service in itself. Recommendations derived from our analysis for future ecosystem assessments include the needs to improve the common evidence base, to advance the mapping of services, to consider international flows of services, and to connect more strongly to policy questions. Although the context specificity of national ecosystem assessments is acknowledged as important, a greater harmonization across assessments could help to better inform common European policies and future pan-regional assessments.

Keywords: IPBES, ecosystem service mapping, quantification, boundary object, conservation

In order to safeguard biodiversity and the services that ecosystems provide to humans, national ecosystem assessments (NEAs) form an essential knowledge base to inform decisionmaking in policy and practice. Globally, the *Strategic Plan for Biodiversity of the Convention on Biological Diversity* (CBD 2010) includes ecosystem services (ES) as a policy rationale in a broad set of goals. The Aichi target strategic goal D, for instance, declares to "enhance the benefits to all from biodiversity and ecosystem services." At the European level, the *EU Biodiversity Strategy* sets specific targets dedicated to ES and requires member states to "map and assess the state of ecosystems and their services in their national territory" and to integrate "these values into accounting and reporting systems at EU and national level by 2020" (Action 5 under Target 2 on the restoration of degraded ecosystems, European Commission 2011). NEAs are one form to comply with these targets. An assessment is the "analysis and review of information for the purpose of helping someone in a position of responsibility to evaluate possible actions or think about a problem" (Maes et al. 2013). The recently published *Guide for Assessments from the Intergovernmental Platform on Biodiversity and Ecosystem Services* (IPBES 2015) included assessments based on literature reviews, as well as on the critical review and evaluation of current knowledge (including indigenous and local knowledge) and expert judgment to identify evidence and knowledge gaps. More specifically, an ecosystem assessment serves as a policy-question-based synthesis of data on the state of biodiversity and ecosystems and of the ES they provide (Maes et al. 2013). An ecosystem assessment therefore evaluates the links between humans and their natural environment in a way that is relevant for decisionmaking (Ash et al. 2010).

Several European countries have started to assess biodiversity, ecosystems, and ES at the national scale. Although few complete assessments exist in Europe, there are several ongoing activities, such as those in France, Sweden, Denmark, Greece, Switzerland, and Italy (Braat 2014, Teller 2014). Given the absence of standards for conducting assessments and diverging national political contexts, resources, and interests, approaches to NEAs differ among countries. To learn from these assessments and to inform ongoing and future assessments, it is crucial to analyze how these NEAs have been conceptualized and operationalized in practice. Furthermore, because many European NEAs aim to comply with the common policy Target 2, Action 5 of the EU Biodiversity Strategy, an assessment of their comprehensiveness, systematic selection of assessed information, and comparability is needed. This analysis is to serve as baseline information for decisionmakers and scientists of countries who have not yet conducted an NEA to learn from initial practical experience, as well as the planned Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessments across Europe and globally.

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In this article, we provide an overview of European (sub-) national ecosystem assessments. We review and analyze eight published NEAs and compare their stated objectives, political context, concepts, methods, and aspects of the operationalization of the NEAs. We analyze the policy aims and audience addressed by the assessments. In particular, we were interested in whether NEAs tackle similar, recurring questions and current challenges concerning mapping and assessing ecosystems and ES, as well as how the relationship between biodiversity and ES has been conceptualized and assessed. On the basis of the elements the assessments contain, we create a typology of NEAs characterizing the diversity of potential approaches. We close with conclusions for the advancement of future NEAs and for the necessary steps toward cross-European consistency.

Selection of NEAs

We identified published European NEAs on the basis of current overview studies (Braat 2014), information of the EU Mapping and Assessment of Ecosystems and Their Services (MAES) working group (Teller 2014) and the *IPBES Catalogue of Assessments on Biodiversity and Ecosystem Services* (*http://catalog.ipbes.net*). We focused on assessments published after the Millennium Ecosystem Assessment (MA 2005). Our analysis was restricted to assessments that assessed specific biophysical information on ecosystems or ES and covered the whole country. Therefore, we included only The Economics of Biodiversity and Ecosystems (TEEB) studies that were going beyond case studies or a predominant focus on mainstreaming economic values of ecosystems and ES. Eight NEAs were selected, including different stages and forms of assessments—that is, both completed NEAs, such as the UK NEA (2011), and advanced scoping studies, such as the Norwegian NEA (table 1; NOU 2013). We included one elaborated regional ecosystem assessment (Flanders; INBO 2014) that in its relatively large coverage, depth, and rigor showed characteristics of an NEA (Jacobs et al. 2016). Although the Swiss assessment (Staub et al. 2011) provided important conceptual advances and links to national indicators, it was not included, because it did not yet assess biophysical information. To the best of our knowledge, our selection presents an overview of all currently published NEAs in Europe.

Review questions

To assess and compare the NEAs, 15 review questions were developed to cover the following aspects of the assessments: objectives and aims, political context (including framing, mandate, and funding), content-related and methodological aspects, and issues related to governance and implementation (table 2). Furthermore, we identified recurring questions and current challenges concerning mapping and assessing ecosystems and ES.

Search methods

All documents were read and their content analyzed and categorized against the review questions by authors fluent in the respective languages. Answers were noted and quality-checked by the first author. Answer categories were built to classify and condense information. Then, answers were double-checked by pairs of two authors. In case of ambiguities, the lead authors of the NEAs were contacted in order to verify the information. This document analysis allowed for the objective exploration of the documented aspects of NEAs. However, it did not allow for checking whether aspects that were not documented were actually not considered or simply omitted. For instance, the fact that academia was not mentioned specifically as a target audience in the objectives does not necessarily imply that this group was not considered.

ES were classified according to the group level of the Common International Classification of Ecosystem Services (CICES, version 4.3; Haines-Young and Potschin 2013), with slight renaming for reasons of clarity and comprehension. ES that fall under each of these group categories were recorded and counted.

Short characterization of the NEAs

The Portuguese NEA (Pereira et al. 2009) was one of the subglobal assessments conducted as part of the Millennium Ecosystem Assessment. It assessed nine ecosystem types and a selection of ES, and it contained five case studies. The UK NEA (2011) is one of the most comprehensive NEAs in Europe. It assessed eight ecosystem types and a large number of related ES. It contained four regional assessments on the status and trends of ecosystems and ES, as well as an exploration of different forms of the valuation of ES. The Spanish NEA (EME 2012) assessed 14 ecosystem types (including terrestrial, aquatic, transition, and urban ecosystems) and 22 ES, including five case studies. As part of the Spanish NEA, a further report on economic valuation was published in 2014 (EME 2014). The Norwegian NEA (NOU 2013) was an expert report for the Norwegian national parliament. It contained an assessment of 11 ecosystem types, as well as a biophysical and monetary valuation of a selection of ES. The assessment for the Belgian region of Flanders (INBO 2014) was a subnational ecosystem assessment that focused on spatially quantifying 16 ES and the state and trends of biodiversity, as well as its role in the provision of ES. The Dutch assessment (de Knegt 2014) specifically quantified the state and trends of the provision and the actual use of 17 ES in the Netherlands. The Finnish assessment (Jäppinen and Heliölä 2015), a TEEB report, contained a short assessment of 28 ES and case studies on mapping the value of ES. The German assessment (Albert et al. 2015) recommended national ES indicators and provided maps on the current state of these indicators.

Objectives and aims (review questions 1–2)

The NEAs stated diverse objectives and aims (table 3a). The objective most often mentioned was to assess the current state of knowledge on ecosystems and ES, followed by the objective to provide the knowledge base for policy-relevant questions concerning the sustainable management of ecosystems.

Table 1. NEAs included in the review.

Country (Year)	Name of assessment (original name)	Language	Approximate number of pages	Number of authors	Reference
Portugal (PT) (2009)	Ecosystems and Human Well-Being. Portuguese Assessment of the Millennium Ecosystem Assessment *(Ecossistemas e Bem-Estar Humano. Avaliação para Portugal do Millennium Ecosystem Assessment)*	Portuguese[a]	770	>60	Pereira et al. (2009)
United Kingdom (UK) (2011)	UK National Ecosystem Assessment	English[a]	1470	>300	UK NEA (2011)
Spain (SP) (2012 and 2014)	Ecosystems and Biodiversity for Human Well-Being. Spanish National Ecosystem Assessment *(Ecosistemas y biodiversidad para el bienestar humano. Evaluación de los Ecosistemas del Milenio de España: Valoración Económica de los Servicios de los Ecosistemas Suministrados por los Ecosistemas de España)*	Spanish[a]	2000; 170	approximately 60	EME (2012) EME (2014)
Norway (NO) (2013)	Nature's Benefits: On the Values of Ecosystem Services *(Naturens Goder: Om verdier av Økosystemtjenester)*	Norwegian[a]	430	12[b]	NOU (2013)
Flanders (region of Belgium) (VL) (2014)	Nature Report: State and Trend of Ecosystems and Ecosystem Services in Flanders *(Natuurrapport: Toestand en Trend van Ecosystemen en Ecosysteemdiensten in Vlaanderen (NARA-T))*	Dutch[a]	1530	approximately 50	INBO (2014)
Netherlands (NL) (2014)	Indicators for nature's services *(Graadmeter diensten natuur)*	Dutch[a]	230	approximately 30	de Knegt (2014)
Finland (FI) (2015)	Towards A Sustainable and Genuinely Green Economy: The Value and Social Significance of Ecosystem Services in Finland (TEEB for Finland)	English	150	approximately 30	Jäppinen and Heliölä (2015)
Germany (DE) (2015)	Recommendation for the development of a national set of indicators for ecosystem services *(Empfehlungen zur Entwicklung eines ersten nationalen Indikatorsets zur Erfassung von Ökosystemleistungen)*	German and English	50	18	Albert et al. (2015)

[a] Includes English synthesis.
[b] Several experts have delivered text, but only the expert committee is officially listed as authors.

Both objectives are in line with the definition of an ecosystem assessment (Ash et al. 2010, Maes et al. 2013). Four assessments (NO, NL, FI, DE) mentioned the exploration of concepts, methods, and indicators and therefore presented work in progress toward the classic purposes of an assessment. The German assessment had a focus on indicator development, whereas the Norwegian report critically evaluates the concept's applicability to a Norwegian context.

Several target audiences were referred to in the NEAs (table 3b), from informing different sectors to adding to the international MA initiative (PT, SP) or complying with laws and strategies. The UK NEA explicitly mentioned the capacity-building aspect of the assessment process. This assessment actively fostered interdisciplinary collaboration and transdisciplinary approaches by involving stakeholders alongside scientists in the assessment process. The involvement of stakeholders was also a prominent objective in the Spanish assessment, whereas the Flemish assessment pointed to improved cross-sector communication through the report.

Political context (review questions 3–5)

The framing, policy mandate, and funding sources of each NEA are summarized in table 4a–4c. All NEAs referred to specific policy documents, conventions, and initiatives to frame the assessment. The most commonly mentioned framing was the MA, followed by TEEB and national accounting initiatives such as the World Bank–led Wealth Accounting and the Valuation of Ecosystem Services (WAVES) project and UN System of Environmental–Economic Accounting (SEEA) framework. The majority of reports also linked to international conventions, such as the Convention on Biological Diversity (CBD), Ramsar, UNCCD, and UNFCCC. Four assessments (UK, SP, NO, VL) referred to IPBES. The NEAs of EU member states that were published after the EU Biodiversity strategy (2011) all referred to this strategy and its particular requirement to map and assess ecosystems and ES.

The framing reflected the policy mandates set for individual assessments. The Portuguese assessment is an interesting example, because it resulted from a competitive

Table 2. Review questions.

Topics	Questions
Objectives and aims	1. What were the stated objectives and aims of the assessment? 2. Who was the intended audience?
Political context	3. Which policy documents and initiatives were used to frame the assessment? 4. Was there a policy mandate and who provided it? 5. Who funded the assessment?
Content-related and methodological aspects	6. Which elements and topics did the assessment cover? 7. How were these elements assessed? 8. Which ES were assessed? 9. Which contextual aspects of ES have been empirically assessed? 10. How was the link between biodiversity and ES conceptualized and how was it empirically assessed? 11. Have interregional flows of ES from other countries been assessed?
Operationalization	12. Who was identified as stakeholders for this assessment? 13. How were these stakeholders involved? 14. How many authors were involved in the assessment? 15. Has the assessment been externally peer reviewed?

Table 3a. Objectives and aims.

Objectives and aims (question 1)	PT	UK	SP	NO	VL	NL	FI	DE
Current state of knowledge on ecosystems and/or ES	X	X	X	X	X	X	X	X
Scientific evidence base for management and decisionmaking for sustainable ES provision	X	X	X	X	X	X	X	
Provision of information for accomplishment of a law or strategy			X		X	X	X	X
Provision of information to the Millennium Ecosystem Assessment	X		X					
Social and/or economic valuation of ES		X	X		X		X	
Enabling stakeholder participation, collaboration, cross-sector communication and awareness raising		X	X	X	X		X	
Strengthening interdisciplinary collaboration		X	X					
Exploring and generating adapted concepts, methods and indicators to assess and value ES				X		X	X	X

Note: X represents a positive identification. Country abbreviations in table 1.

Table 3b. Intended audience.

Intended audience (question 2)	PT	UK	SP	NO	VL	NL	FI	DE
Decisionmakers, administration, and environmental managers	X	X	X	X	X	X	X	X
Beneficiaries and stakeholders (NGOs, business, civil society)	X	X	X		X			
Academia	X		X					X

Note: X represents a positive identification. Country abbreviations in table 1.

process launched by the UN-led MA initiative. During the process, it received support letters from several governmental actors. In contrast, governments—and in particular the respective ministry of the environment or environment agencies—clearly provided the mandate in five cases (UK, SP, NO, FI, DE). In the case of the Dutch and the Flemish assessment, government research institutes performed the assessment together with partners in the context of their official tasks. The UK NEA had the highest variety of mandataries, including the Department for Environment, Food, and Rural Affairs (Defra); the Welsh Assembly Government; the Scottish Government; the Northern Ireland Environment Agency; and national research councils. The policy mandate also stipulated the funding of the assessment. In the case of the UK NEA, all the above-mentioned mandataries were also funders, allowing for a potentially more holistic approach that integrates various and sometimes competing interests (e.g., between nature conservation and agriculture).

Six NEAs received funding from a single source—either the government, environmental ministries, or related environmental and nature-conservation agencies. The Portuguese and the UK assessments have drawn from a variety of funding sources. In-kind contributions of universities and research institutes were mentioned explicitly in the Portuguese assessment, whereas these contributions through authors and associated resources are expected to be considerable in most cases.

Table 4a. Political context, framing and funding of the NEAs.

Framing policy documents and initiatives (question 3)	PT	UK	SP	NO	VL	NL	FI	DE
CBD and other international treaties		X	X	X	X		X	X
Millennium Ecosystem Assessment	X	X	X	X	X	X	X	X
IPBES		X	X	X	X			
EU biodiversity strategy 2020			X	X	X	X	X	X
EU directives and common policies	X	X	X		X		X	
National and regional strategies, plans, and programs	X		X		X	X	X	
Parliamentary committee report		X						
TEEB and national accounting initiatives		X	X	X	X	X	X	X

Table 4b. Framing of the NEAs.

Policy mandate (question 4)	PT	UK	SP	NO	VL	NL	FI	DE
Millennium Ecosystem Assessment (subglobal assessment)	X		X					
Government, ministry of environment or environment agency		X	X	X			X	X
Government research institute					X	X		
Regional administration		X						
Research council		X						

Table 4c. Funding of the NEAs.

Financial support (question 5)	PT	UK	SP	NO	VL	NL	FI	DE
Millennium Ecosystem Assessment	X							
Government, ministry of environment or environment agency		X	X	X	X	X	X	X
Regional administration		X						
(National) science funding agency	X	X						
Research center or university	X							
Public sector bank	X							

Content and methods of the NEAs (review questions 6–11)

Elements of the NEAs. We observed similarities and remarkable differences in the type of elements present in each NEA, as well as in the methods used to assess ecosystems and ES (table 5). All eight NEAs addressed the state of ES. This was followed by an assessment of trends of ES (seven NEAs). In six NEAs, direct and indirect drivers of change were discussed, and societal responses and decisionmaking options were suggested. The state and trends of ecosystems and biodiversity were documented in five assessments, in particular those that were more elaborated. The social or economic valuation of ES was part of five assessments. Interactions between ES were assessed in three NEAs (UK, SP, VL), mainly using literature review and expert judgment. Interestingly, the relationship between biodiversity and ES was often implicit and was specifically and systematically addressed in only four assessments (UK, SP, VL, NL) based on literature review, expert judgment, and conceptual thinking (see also section 3.5). Evaluations on how a country relies on ES provided by ecosystems outside its borders were found in four assessments (UK, NO, VL, NL). Three NEAs (UK, SP, VL) also developed their own conceptual frameworks for their assessments. These frameworks were adaptations of the MA framework (MA 2005), with a more prominent position of ecosystems (or *natural capital*) forming the basis of ES provision. These frameworks also reflected the conceptual development of ES science over the years, with the UK NEA distinguishing *ecosystem goods* (i.e., the outcomes of ecosystems combined with other capital input) or the Flemish assessment distinguishing more precisely different contextual aspects in the generation of an ES (*supply*, *demand*, *use*). A vertical comparison of all elements in table 5 also clearly identifies three more comprehensive assessments that addressed a larger number of the 12 elements we classified. The UK and the Spanish NEA each addressed 11 elements, and the Flemish assessment addressed 10 elements. The vertical comparison also clearly identifies the German scoping study, which focused on indicator development for the state of ES.

The methods of the NEAs. We furthermore observed a variety of methods employed for the NEAs. Most frequently used

Table 5. Elements of the NEAs that were systematically assessed and methods used (questions 6 and 7).

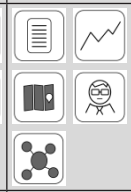
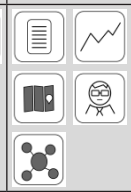
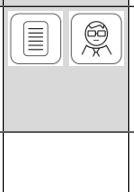
Elements	PT	UK	SP	NO	VL	NL	FI	DE
State and trends of ecosystems and biodiversity								
State of ES								
Trends of ES								
Direct and indirect drivers of change								
Future scenarios								
Social and economic values and/or relation ES and well-being								
Interactions between ES								
Relation ES and biodiversity								
Use of ES from other countries								
Own conceptual framework								
Response options for decisionmaking								

Table 5. Continued.

Elements	PT	UK	SP	NO	VL	NL	FI	DE
Case studies[a]								

[a] By *case studies*, we mean geographically restricted areas for which different aspects of an ecosystem assessment are performed in depth.

Legend

	Literature review	An assessment of evidence available from published sources.
	Statistics	Aggregated descriptive representation of data.
	Maps	The geographically explicit, area-wide representation of information.
	Expert judgement	An appraisal of a trend or an importance of a phenomenon given by a person with specialist knowledge in the field.
	Modeling	Simulating a system in order to quantify the parts of the system that are of specific interest for the assessment.
	Workshop and interviews	Systematic interactions with stakeholders in order to create knowledge relevant for the assessment.
	Different forms of valuation	The assessment of the importance of a service that goes beyond biophysical measurement, includes economic valuation, health values, etc.
	Conceptual thinking	The development of a framework that depict elements of a system and the interactions between them.

were literature reviews and national statistics. These were followed by expert judgement, in particular for assessing the direct and indirect drivers of change, the interactions between ES, and the relationship between biodiversity and ES. Mapping and spatial modeling were used for different elements, such as the state and trends of ecosystems and biodiversity, the state of ES, the valuation of ES, and case studies. Although the EU Biodiversity 2020 strategy (published in 2011) requested the mapping and assessing of ES by member states, few assessments have to date mapped ES systematically. The Flemish assessment provided maps on all assessed ES, which, depending on the ES, show the ecosystem condition, capacity, flow, use, and/or demand of the respective ES (see below for definitions of terms). The Spanish NEA presented maps showing qualitative trends of ES per ecosystem type and quantitative maps that depicted ES flow or capacity depending on the service. The German report contained preliminary maps on selected indicators, which depict the capacity or flow of the respective ES as well as indicators for ES demand. The UK NEA (performed before the launch of the EU biodiversity strategy) contained few maps for single selected services (e.g., soil-carbon storage) and few maps for subregions. The UK NEA and the Finnish assessment contained maps on the economic value of ES for parts of the country.

Ecosystem service categories (question 8). NEAs assessed between 6 and 28 ES according to a classification on the group level of CICES (figure 1, supplemental appendix S1 for details). The ES included in all NEAs were the provision of food, drinking water, fiber and materials, carbon sequestration, and recreation. Seven NEAs assessed pollination (lifecycle and habitat) and the regulation of soil fertility. Pest control was assessed six times, whereas air-quality regulation (in the group waste mediation) and biomass for energetic use were assessed five times. Noteworthy ES that were assessed in only a few studies include cork production (PT), ornamental resources (UK, NO), and the existence value of indigenous aspects of biodiversity (NL). These examples show how despite calls for harmonization, ecosystem assessments are context specific and retain typical region-specific characteristics. Across all eight NEAs, provisioning services were assessed 53 times, regulating services 71 times, and cultural services 34 times.

Assessments of contextual aspects of ecosystem services (question 9). NEAs considered to a different degree the contextual aspects of ES that play a role in the ES delivery process (table 6). These aspects relate to the fact that ES come into existence at the interplay between the biophysical and socioeconomic characteristics of ecosystem use (Villamagna et al. 2013). Although these aspects have been termed differently in the literatusre (e.g., Villamagna et al. 2013, Schröter et al. 2014a, Yahdjian et al. 2015), we briefly describe here their generic meanings. *Ecosystem condition* is the sum of biophysical properties that underpin services. *Capacity* is the potential of an ecosystem to provide a particular service. *Flow* describes the actual provision of that service to humans.

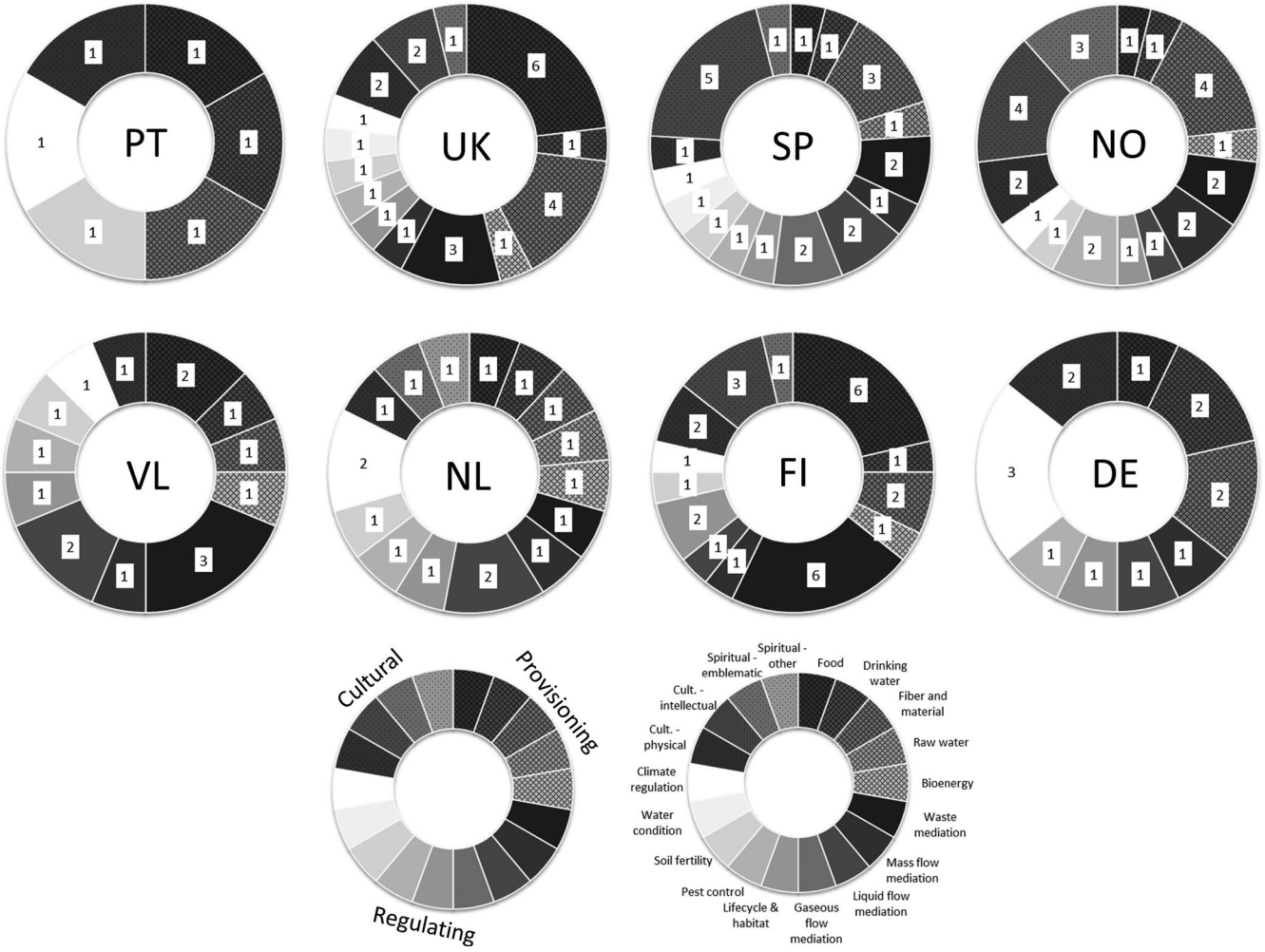


Figure 1. Ecosystem services assessed in the NEAs. Color grading refers to service types within categories of services (provisioning: hatched; regulating: plain; cultural: dotted). The numbers indicate the quantity of services assessed within each group. Abbreviations: DE, Germany; FI, Finland; NL, Netherlands; NO, Norway; PT, Portugal; SP, Spain; UK, United Kingdom; VL, Flanders.

In case no distinction is made between the capacity and flow of services, an ES assessment can potentially refer to either of these aspects. *Use* and *demand* are considered together here for reasons of simplicity and refer either to the use and consumption of a service irrespective of where the ES originates or to factors that influence the needs of people for that service (Wolff et al. 2015). *Values of ES* are measures of importance based on the principles, preferences, and virtues that explain which ES matter to people (Chan et al. 2012).

Ecosystem condition was assessed in five cases. However, the particular aspects of biodiversity that are crucial for the provision of specific services were seldom identified and assessed (see section 3.5); neither was the fact that the ecosystem condition for the high provision of some ES (e.g., provisioning) may be at odds with the condition underlying the provision of other ES (e.g., cultural). Several NEAs did not systematically distinguish different aspects of ES but instead generally assessed services, which can relate to the potential or actual provision—that is, the capacity or flow (PT, UK, SP, NO, FI). Two NEAs systematically assessed the capacity of ecosystems to provide a service (VL, DE). The Flemish assessment contrasted this capacity to the flow and the demand for this service in the area. The German assessment compared capacity with demand as well. Notably, the Dutch assessment aimed to contrast flow with the total use in the Netherlands. ES values were assessed in four cases—that is, the two TEEB-like assessments (NO, FI) and two of the more elaborated NEAs (UK, VL).

The conceptual and empirical links between biodiversity and ecosystem services (question 10). Biodiversity and ES were conceptually linked in three ways in NEAs (figure 2): (1) biodiversity as supporting and underpinning ES, (2) biodiversity conflicts and trade-offs with ES, and (3) biodiversity as (part of) an ES. These different relationships between biodiversity and ES have been distinguished earlier (Mace et al. 2012,

Table 6. Contextual aspects of ecosystem services systematically assessed in the NEAs (question 9).

Contextual aspects	PT	UK	SP	NO	VL	NL	FI	DE
Ecosystem condition	X	X	X	X	X			
Capacity			X[a]		X			X
Flow					X	X		X
Services[b]	X	X	X	X			X[c]	
Use or demand			X[a]		X	X		X
Social and/or economic values		X	X[a]	X	X		X[d]	

[a] Present for some services in the second report.
[b] No systematic distinction between capacity and flow.
[c] Distinction capacity and flow conceptually recognized, but not systematically implemented yet.
[d] For single, selected services.

Reyers et al. 2012). Conceptual differences in how biodiversity links to ES may result from different understandings of the meaning of *biodiversity*, relating to either the diversity of life or to different surrogates, such as species and habitats, as part of particular conservation objectives.

The first and classic conceptualization is biodiversity as supporting and underpinning ES (Mace et al. 2012), acting as a regulator and maintaining stability of ecosystems. Conceptually, this view is shared across all NEAs. Few, however, have specifically assessed the relationship between this aspect of biodiversity and ES. The UK NEA assessed the amount of evidence and the importance of the number of taxonomic groups for the provision of final ES. The Flemish assessment provided a considerable amount of conceptual work and expert assessments on the role of different components of biodiversity for ES provision. For instance, stocks (biomass, numbers, area, and surface) were conceptually linked to provisioning services; structures and patterns predominantly to cultural services; and functions and processes to regulating services. The *composition of biodiversity*, referring here to the identity and possibly the abundance of ES providing species, is linked to conservation activities. Furthermore, the Flemish NEA provided expert assessments of the role of taxonomic groups and ecosystem types for ES.

The second perspective addresses conflicts and trade-offs occurring between biodiversity and ES. Conceptually, this refers to cases in which the management for ES does not focus on biodiversity *per se* and leads to a decrease in biodiversity. Certain components of biodiversity are seen as damaging or contrary to service provision and vice versa. For instance, the German assessment stated that the management for ES should not be misconceived as equal to biodiversity conservation, referring particularly to the potentially detrimental effects of management for provisioning services through, for example, forestry and agriculture (Albert et al. 2015). The Dutch NEA assessed the impact of specific populations to service provision. Conflicts and harm through species are assessed with the help of expert judgments for food provision, timber and biomass production, coastal protection, and natural heritage (de Knegt 2014). For instance, species potentially causing a nuisance to society are mentioned in this context, such as pests and parasites including rabbits, ticks, rats, or mosquitoes. This link has furthermore been empirically assessed in the Flemish assessment through spatially explicit correlation analyses, contributing as a first step toward identifying causal relationships. Although for the majority of services, a positive spatial correlation with the presence of specific taxonomic groups has been observed, trade-offs have been uncovered among all assessed taxonomic groups and some services (INBO 2014).

The third perspective considers biodiversity as (part of) a service itself (cf. Mace et al. 2012). The Spanish NEA has explicitly stated that it does not consider this option and the Norwegian NEA only discusses it. Other countries have included, for instance, habitats and wild species as part of the natural heritage (UK, NL); as emblematic species representative for biodiversity in the country (UK, NL); or as existence values (FI). Furthermore, strong overlaps between indicators for components of biodiversity and ES can be observed, such as the naturalness and diversity of ecosystems as indicators for cultural services or the proportion of natural and seminatural small structures in agricultural landscapes as an indicator for pollination and pest control in the case of the German assessment.

Operationalization of the NEAs (questions 12–15). The most commonly involved stakeholder groups in the assessments were ministries and (environmental) administration and academic institutions, followed by NGOs and private sector institutions (table 7a). These stakeholders could contribute to the assessments (table 7b) by defining user needs and expressing their views in five cases. Stakeholders were also part of the assessment process by means of, for instance, workshops, interviews, and questionnaires in four cases. Scenario development was done in three cases (PT, UK, SP).

Author numbers differed largely among assessments and ranged from 12 for Norway to more than 300 for the UK NEA (table 1). External peer review was conducted in five cases (PT, UK, SP, VL, NL).

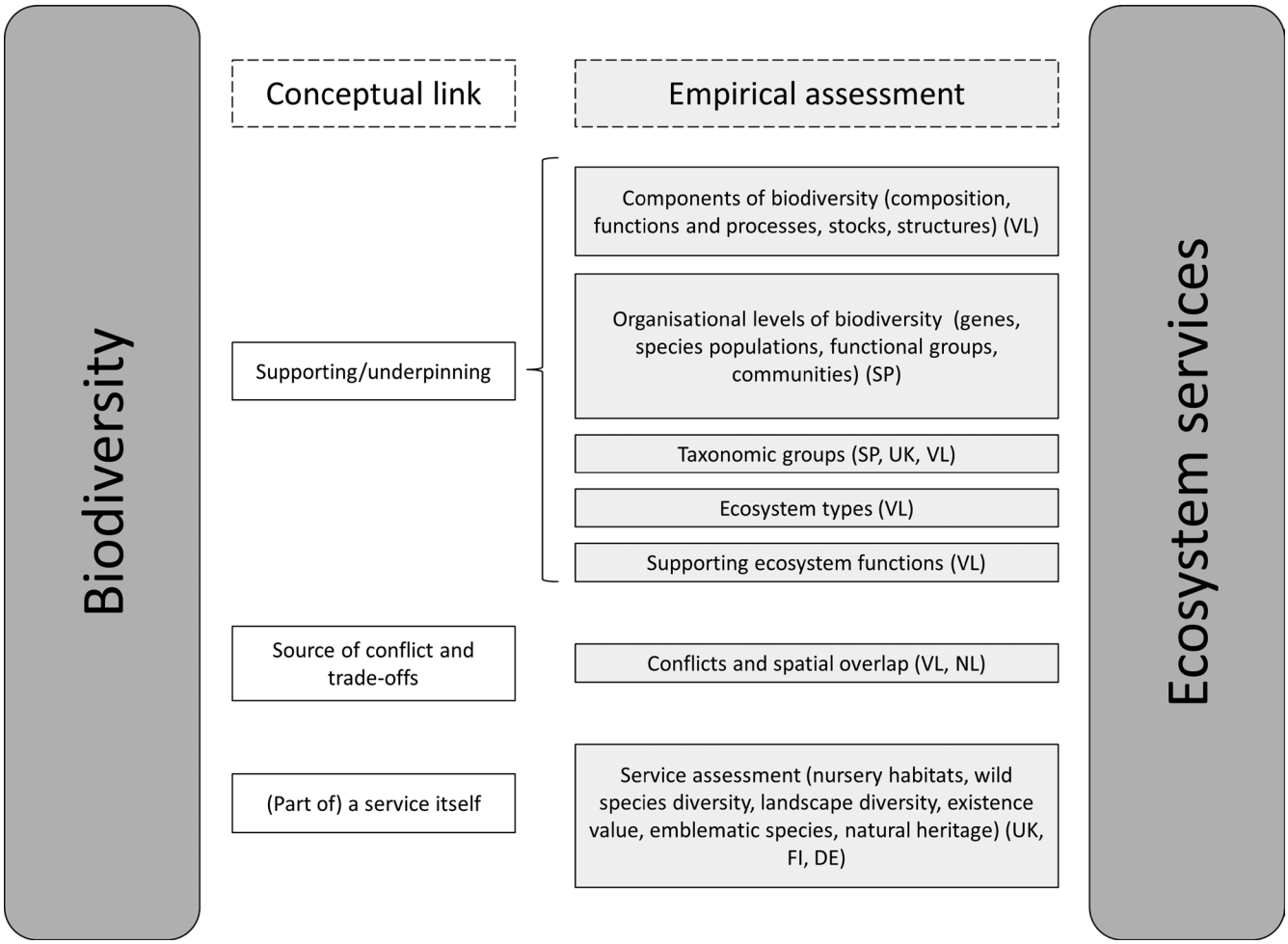


Figure 2. Conceptual and empirically assessed links between biodiversity and ecosystem services observed in the NEAs. The country codes inside the boxes specify in which NEAs this relationship has been assessed. Abbreviations: DE, Germany; FI, Finland; NL, Netherlands; SP, Spain; UK, United Kingdom; VL, Flanders.

Definition of types of NEAs

We heuristically identified four broad types of NEAs. The first type closely follows the approach of the MA (PT, UK, SP). Typical for these "MA-like assessments" were a large number of assessed elements, including the state and trends of ecosystems and biodiversity, the state and trends of ES, the drivers of change, future scenarios, and response options. These reports were published from 2009 to 2012. The second type is "advanced scoping studies" (NO, FI, DE), which were published from 2013 to 2015. Typical for these NEAs were the few elements they contained and their particular focus on indicators (DE) or monetary-valuation case studies in accordance with the TEEB approach (NO, FI). A third type is an assessment with a particular research aim (NL). The Dutch report contained several elements of an NEA but lacked completeness and breadth of the analysis because it focused on a specific research question. A fourth type is represented by the Flemish assessment. This NEA can be characterized as an MAES-like assessment that strongly linked to the requirements of the EU Biodiversity Strategy on Mapping and Assessment of Ecosystems and their Services (Maes et al. 2013), because it contained systematic, spatially explicit assessments. Furthermore, having been published in 2014, it already contained elements that reflected the advancement of the ES research field, such as assessing different contextual aspects of ES or assessing the link with biodiversity and ES footprints.

Discussion

In the following sections, we discuss the role of the ES concept as a boundary object in NEAs, the evolution and typology of NEAs, and the relationship between biodiversity and ES. We furthermore provide five recommendations for future NEAs.

The ecosystem-service concept as a boundary object. An ecosystem assessment is a social process (Wilson et al. 2014) and can provide a bridge to connect different sectors (Bonn et al. 2009). Within such a process, the ES concept can act as a *boundary object* that connects different societal actors and

Table 7a. Identification and consideration of stakeholders in the NEAs.

Identification and consideration of stakeholders (question 12)	PT	UK	SP	NO	VL	NL	FI	DE
Ministries and (environmental) administration	X	X	X	X	X	X	X	X
NGOs	X	X	X	X	X	X	X	
Private sector institutions	X	X	X	X	X	X	X	
Academic institutions	X	X	X	X	X	X	X	X
Media			X					

Table 7b. Involvement of stakeholders in the NEAs.

Involvement of stakeholders (question 13)	PT	UK	SP	NO	VL	NL	FI	DE
Definition of user needs and expressing initial views	X	X		X	X	X		
Assessment (workshops, interviews, and questionnaires)	X	X	X				X	
Scenario development	X	X	X					

different scientific disciplines (Abson et al. 2014, Schröter et al. 2014b, Opdam et al. 2015). It does so by being vague enough to allow for different perspectives to come together while at the same time being robust enough to help develop a common vision. This role of the ES concept is expressed in the process of many NEAs. Stakeholder engagement had a prominent place in the aims of some assessments and was realized to different degrees in most NEAs. The UK NEA prominently expressed the advancement of interdisciplinary work among participating scientists as an aim of the assessment. By their nature, NEAs connect policymakers and their policy questions to scientific questions. Although the ES concept supports collaboration and exchange during an NEA, the capacity of the concept to actually align different interests of actors is limited. For instance, all involved parties may support the general objective to sustain the ES humanity depends on, but views may differ on, for example, which services to prioritize in assessments or which methods to use for ES valuation.

The evolution and typology of NEAs. We have distinguished four types of NEAs that have developed in their temporal and country-specific context, including MA-like assessments, MAES-like assessments, scoping studies, and studies with a particular research aim. An MA-like assessment could be characterized as a holistic analysis of the conditions, trends, and scenarios of biodiversity and ES. An MAES-like assessment represents a further development of NEAs and includes in addition a spatially explicit biophysical quantification and valuation of ES for the whole area, as was requested by the EU Biodiversity Strategy in 2011. The UK NEA lacked such a prominent spatial component. Our analysis demonstrated that scoping studies go beyond pure feasibility studies and already provide an assessment of information on ES. The difference is often the number of elements such assessments contain. Furthermore, such studies discuss how the ES concept could be applied to a national context (NO), as was also done as the first step of the French NEA (MEDDE 2015). Under scoping studies, we included also the TEEB reports of Norway and Finland. Both contained preliminary biophysical assessments of ecosystems (NO) and ES (NO, FI) but in general placed more emphasis than other reports on valuation and contained case-study-based illustrations of the economic significance of ES. TEEB studies do not aim to be spatially comprehensive at a (sub-)national level and are more focused on addressing policy-specific questions. A report such as the Dutch assessment could be seen as a first step toward an NEA because it synthesized information on ES in a policy-relevant way. This report, however, in comparison with the others, lacked, for instance, an institutional grounding in the form of a long-term assessment process, a clear policy mandate, and stakeholder involvement.

Future NEAs are likely to evolve further in regard to process and approaches, both because of advanced scientific understanding and the work of IPBES. Among the capacity-building priorities identified in IPBES is the support of future NEAs (IPBES 2015). IPBES is preparing several thematic and regional assessments, as well as a global assessment, guided by the IPBES conceptual framework (Díaz et al. 2015). The latter aims to be a tool to connect several scales of analysis and knowledge systems. The next generation of NEAs is likely to use the IPBES Conceptual Framework and other guidance set out in the Guide for Assessments from the IPBES (IPBES 2015).

Biodiversity and ecosystem services are mainly assessed separately. The links between biodiversity and ES have been assessed in three conceptually distinct ways. The first link depicts ES as functionally dependent on biodiversity. This was the dominant conceptualization in the literature (Cardinale et al. 2012, Hooper et al. 2012, Harrison et al. 2014). Although several publications reported multiple positive correlations between biodiversity metrics and ES (e.g., Harrison et al. 2014), it remains a challenge to use this knowledge in assessments, let alone in policy- and decision-making processes. In NEAs, the functional link between biodiversity and ES is most often not empirically assessed. In particular, country-specific knowledge on small-scale

biodiversity–ES relationships is missing, and methods and tools to assess this information are currently being developed. This might partly be due to the fact that both biodiversity and ES are complex concepts that cannot be measured with one single metric. Both encompass multiple attributes at different temporal and spatial scales, which challenges the relevance of biodiversity indicators for assessing ES. A second reason for the mainly conceptual link between biodiversity and ES may be that biodiversity-monitoring schemes often focus on threatened habitats and species for conservation objectives. However, the contributions of these species to energy and material flows within the food web are often marginal, because these tend to instead relate to the functional composition of biotic communities (Cardinale et al. 2012, Lavorel 2013). The missing information on the functional link is often based on lack of data on biodiversity groups important for the provision of provisioning and regulating services. This lack has been discussed in three NEAs (UK, SP, VL). However, biodiversity groups that are well studied, such as vertebrates or iconic plants, often contribute to cultural services. The UK NEA has pointed to this "cultural divide" between biodiversity backing provisioning and regulating services on one hand and cultural ES on the other (Norris et al. 2011).

The second link emphasizes the conflict between biodiversity and some ES. This link is little developed in the literature, although certain aspects of biodiversity are already described as "disservices" (Dunn 2010, Gómez-Baggethun and Barton 2013). Trade-offs between biodiversity and ES result from direct interactions between both but are regularly conceptualized and measured as negative impacts of service use on biodiversity and not vice versa (e.g., Power 2010).

The third link depicts biodiversity as either a service or as part of a service. According to this understanding, some components of biodiversity (e.g., a diverse landscape or iconic plant and animal species) can be considered as a service being directly enjoyed by people (Mace et al. 2012, von Haaren et al. 2014). Including aspects of biodiversity prominently as a service itself might allow for better engagement of the biodiversity community within an assessment, because biodiversity experts and conservationists might have a fundamentally different value system (Reyers et al. 2012, Tallis and Lubchenco 2014), preferring the intrinsic values of biodiversity over anthropocentric approaches. Nevertheless, a precise distinction between indicators for biodiversity and ES is needed next to an advancement of appropriate assessment methods.

Recommendations for advancing future NEAs. ***Improving the common evidence base.*** National or regional statistical data were used in the NEAs, enhancing the empirical evidence base of assessments. Unsurprisingly, statistical data on indicators are often readily available, especially for assessing the state and trends of provisioning services, such as food, timber, or water, which most often form marketable goods and are therefore included in national statistics. For regulating and cultural services, less data are available (European Commission 2014), and ways need to be found to account for them. In particular, new monitoring concepts for the functional dependence of ES on biodiversity are necessary.

Under its Action 5, the EU Biodiversity Strategy urges the EU member states to map and assess ecosystems and their services (MAES). The MAES initiative includes also the recognition of economic values and calls for the development of a consistent reporting or accounting system. The importance of achieving the objectives of Action 5 on countrywide mapping and assessment and the development of a common knowledge base for ecosystems is underlined by ESMERALDA, a Horizon 2020 funded project (the European Commission's framework program for research and innovation). It gives direct support to the member states with their implementation of Action 5.

If common policies should be developed on the basis of the results of NEAs, then a framework for a common European baseline for national assessments is needed. The ES that were most commonly assessed across all NEAs could indeed provide a common starting point for such large-scale harmonization of ecosystem related data. However, as evident from our analysis, NEAs are highly context specific with regard to national policies and stakeholder interests, as well as environmental settings and socioeconomic characteristics; therefore, this framework design needs to leave space for country-specific adaptations. Nevertheless, for synthesis and comparison across the European Union, a core set of common elements with common methods is necessary. Therefore, there is a need to harmonize data across the EU. For biodiversity, work is underway to identify essential variables (Pereira et al. 2013). For ES, there is also a need for the standardization of indicators and methods to quantify and assess ES for different policy purposes (Crossman et al. 2013, Polasky et al. 2015, Schröter et al. 2015). The European Commission has recently started an initiative on the development of natural-capital accounts, in line with the United Nation's System of Environmental–Economic Accounts.

Advancing mapping of ecosystem services. It is apparent that to date, mapping and spatial modeling have rarely been used systematically in NEAs, even if dedicated policy exists at the EU level on mapping and assessment (European Commission 2011, 2014). It is important to note that some NEAs have been realized before the launch of the EU Biodiversity strategy that formulates this request.

ES are provided and demanded in specific areas, and policy advice concerning ecosystem protection, enhancement, and restoration therefore requires spatial information. If NEAs shall provide such information for decisionmaking, better use of spatially explicit analyses is needed. An important issue is to identify spatially separate areas in which ES are being provided, used, and demanded (Schröter et al. 2014a, Albert et al. 2016). Such information can increase clarity on where and how much of a potential to provide a service is actually used and therefore indicate the sustainability of

ecosystem use. Such spatial distinction can also help to identify to what degree service-providing areas match with areas in which beneficiaries make use of a service and thereby inform planning and regulatory processes and possibly also financial and fiscal instruments (Bonn et al. 2014, Reed et al. 2014). Within the field of mapping ES, there is furthermore a strong research need for more accurately incorporating ecological relationships and therefore functionally inferring ES from different aspects of biodiversity (Lavorel et al. 2014), as well as further exploring the potential of remote sensing for ES assessments (de Araujo Barbosa et al. 2015).

Distinguishing the contextual aspects of ecosystem services. Different contextual aspects of ES, such as the capacity, flow, and demand for ES, have been identified as a crucial elements for assessing ES (Burkhard et al. 2014, Schröter et al. 2014a, Albert et al. 2016). We have observed important conceptual developments in distinguishing these contextual aspects of ES in several assessments (VL, DE, NL) in order to provide information on sustainability of ecosystem use. Further work is needed to operationalize this distinction and in particular to cope with lack of data, in particular on the capacity of ecosystems to provide services but also on the manifold aspects that influence the demand for services (Wolff et al. 2015).

Including interregional flows of ES in NEAs. NEAs usually assess only the ES provided in the respective country but ignore a country's demand for ES beyond its borders and the associated footprint on biodiversity and ecosystems. Benefits from ecosystems cross national borders (López-Hoffman et al. 2010, Liu et al. 2016), such as via the transportation of goods or the movement of people appreciating landscapes elsewhere.

Four NEAs (UK, VL, NO, NL) explicitly addressed international flows of ES and could provide helpful guidance for tackling this challenge in other assessments. The UK NEA (2011) has made a first attempt to assess the footprint for biomass. The Flemish assessment (INBO 2014) emphasized that the state and trends of ecosystems and ES in Flanders are closely linked to the state and trends of ES in foreign ecosystems. The Norwegian assessment (NOU 2013) distinguished three types of impact on other countries' ecosystems—namely the indirect environmental impacts of Norwegian foreign investments, import of goods and services, and development aid. The Dutch assessment found that for none of the 17 ES is demand met by the actual provision of services by Dutch ecosystems, but demand either remains unmet or is being fulfilled by technological alternatives or import from abroad (de Knegt 2014).

Increasing the policy relevance of NEAs. A major issue for future NEAs is to better connect and integrate the results of the assessment with policy-relevant questions and policy impact assessments. Often, NEAs start with the identification of a set of policy-relevant questions that are then addressed on the basis of different data and knowledge sources. Most NEAs framed their goals with respect to policy targets. Understandably, because the stated aims of NEAs are relatively broad, the results cannot always easily be broken down to serve practical management processes.

So far, mechanisms have been weak to translate the NEA results into ongoing planning processes, such as environmental impact assessments, or priority setting for decisionmaking. Pathways to further operationalize the NEA evidence base through different policy support tools are needed, and several country-specific studies have made advances to link ES to existing national indicators (Staub et al. 2011, Mace et al. 2015, Albert et al. 2016). Overarching policy-relevant questions that could be addressed in assessments could be guided by the Aichi targets 2 and 3, calling for the mainstreaming of biodiversity and ES, such as in the planning or the development of economic policy instruments.

The ongoing development of natural-capital accounts at the global, EU, and national scales can be considered an important step to operationalize the results of NEAs. At the global level, Aichi target 2 calls for the incorporation of biodiversity values into national accounting. At the EU level, Action 5 of the EU Biodiversity Strategy sets the ground for the establishment of national natural-capital accounts. Such accounts consist of regularly updated information about biodiversity, ecosystems, and ES, which NEAs typically collect. Such information is an essential basis to implement current biodiversity policy as well as to design new biodiversity policy. Furthermore, accounting can make the contribution of natural capital to economic development explicit alongside produced or manufactured capital, as well as human capital. In this way, natural-capital accounting provides important input to decisionmaking at regional, national, or EU level.

NEAs might also be helpful in informing conservation priority setting for the goal of the EU Biodiversity Strategy on restoring 15% of degraded ecosystems or the development of green infrastructure (European Commission 2011). In particular, the outcomes of NEAs are needed as a baseline against which further progress in achieving biodiversity targets can be evaluated. These connections of NEA assessment data with actual policy implications need to be further developed to inform and support policies that have an impact on natural resources, including policies on water, climate, agriculture, and forest, as well as for spatial planning.

Collaboration with national statistical offices will be key to mainstreaming the standardized data of ecosystems and biodiversity into policy domains. For this purpose, the continuation of key data collection and repeated and updated assessments are needed.

Conclusions

The diversity of approaches and methods applied in NEAs to assess ecosystems, biodiversity, and ES highlights the context dependency of national assessments, which makes comparisons across NEAs challenging. This diversity is also

explained by the temporal context in which the NEAs have been developed and by the progress made in the field during the last years. Although European NEAs naturally have a focus on national policy needs, those NEAs published after the EU Biodiversity Strategy often also aim to comply with it. A greater harmonization of data and methods could foster better implementation of policies at the European level on the basis of national results. To support the IPBES synthesis process, NEAs should be integrated at the European level. Standardization or at least harmonization of data collection, indicators, and methods to assess biodiversity and ES is needed, such as is currently underway with the MAES process. There are, however, limits to harmonization, as the development of context-dependent scenarios and the selection of country-specific ES have shown.

An ideal role model of an NEA does not exist. Rather, we have observed a continuum ranging from advanced scoping studies to elaborate assessments that cover many aspects that are currently under development in the research field of ES. Differences exist in terms of the number of involved scientists and therefore the costs for the assessment. The depth of an assessment is influenced by national investments and in-kind contributions of the scientific community. If an ideal NEA would be sketched, it could contain the following aspects: The building blocks or elements of the more comprehensive NEAs (PT, UK, SP, VL) could be seen as a benchmark for future NEAs. An NEA should contain an area-wide assessment of ecosystems and the ES they provide and should therefore not be primarily based on case studies. This assessment should distinguish both the capacity to provide services and their actual use. An NEA should aim for standardization and harmonization across countries for reasons of consistency on a European level. On the basis of that, several work packages could in a modular approach explore more country-specific problems, such as the assessment of international flows of ES or the relation to nationally policy-relevant questions. An ideal assessment could contain several stages, including the initial identification of goals for policy, practice, and science with stakeholders; scoping and feasibility studies; a collation and review of available data and evidence; inter- and transdisciplinary assessment and analysis processes; and peer review in iterative cycles. Furthermore, the conceptual and institutional set-up would allow for monitoring as iteration through planned time steps and follow-ups. To build on existing experience, we call for more exchange among NEA practitioners. Much knowledge has accumulated on the national level, and better networks for exchanging and jointly advancing knowledge should be developed. The current global IPBES and European MAES processes could be valuable catalysts for this endeavor.

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Supplemental material

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