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National mapping and assessment of ecosystem services projects in Europe – Participants' experiences, state of the art and lessons learned

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ABSTRACT

Backed by the Biodiversity Strategy to 2020 and 2030, numerous 'Mapping and Assessment of Ecosystem Services' (MAES) projects have been completed in recent years in the member states of the European Union, with substantial results and insights accumulated. The experience from the different approaches is a valuable source of information for developing assessment processes further, especially with regard to their uptake into policy and more recently, into ecosystem accounting. Systematic approaches towards best practices and lessons learned from national MAES projects are yet lacking. This study presents the results of a survey conducted with participants of national MAES projects overviewing 13 European MAES processes. Focus hereby is put on the types of methods used, the assessed ecosystem services, and the perceived challenges and advancements. All MAES projects assessed ecosystem services at several levels of the ecosystem service cascade (69% at least three levels), using a diverse set of data sources and methods (with 4.7 types of methods on average). More accessible data was used more frequently (e.g., statistical and literature data being the most popular). Challenges regarding policy uptake, synthesizing results, and data gaps or reliability were perceived as the most severe. Insufficient evaluation of uncertainty was seen as a major critical point, and emphasized as crucial for uptake and implementation.

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Moving towards accounting for ES in the frame of environmental-economic accounts, considering uncertainties of ES assessments should be even more important.

1. Introduction

The EU Biodiversity Strategy 2020 Target 2 Action 5 requested the EU member states (MS) to map and assess ecosystems and their services (ES) in their territory (EC, 2011). Responding to this mandate, national ecosystem assessment and mapping and assessment projects have emerged all over Europe, following up on work from the Millennium Ecosystem Assessment (MA, 2005) and The Economics of Ecosystems and Biodiversity (TEEB, 2010). Aligning with terminology from the EU Working Group coordinating the work across the European Union, in this paper we will call these efforts national MAES (Mapping and Assessment of Ecosystem Services).

During the years these assessments received increasing support and coordination from the European Commission in the form of networking opportunities, guidance materials, as well as funding opportunities. In particular, the scientific Coordination and Support Action ESMERALDA,[1] funded under the Horizon 2020 program contributed relevantly to the harmonisation and standardisation of approaches, methods, and terminology in the newly formed "MAES community" (Burkhard et al., 2018; Burkhard and Maes, 2017; Santos-Martín et al., 2013). Nevertheless, all national MAES assessments were designed and implemented independently from each other, reflecting the specific needs and interests of the different countries, as well as their different possibilities and attitudes. Some of the countries wished to accomplish the whole MAES obligation in a single ambitious national MAES project, while others have established longer term MAES programs, with autonomous governance and a stable funding, allowing a series of subsequent MAES projects, complementing and building on each other (see e.g. the French[2] webpage). Some of the national MAES works started earlier, while others started relatively recently, some of which are still ongoing. The slow but clear evolution in guidance, also created differences between the early starter and the late coming EU MS in terms of the structure, focus, and methods of their assessments.

Policy interest in ecosystem assessments still persists after the deadline of the EU Biodiversity Strategy 2020, with increasing emphasis on the standardisation of assessments and reporting frameworks both at the EU and global levels (EC, 2019a, 2020; UN, 2022). An important milestone in this standardisation process was achieved with the recent adoption of the System of Environmental Economic Accounting - Ecosystem Accounting (SEEA EA) as a UN statistical standard (UN, 2021), which will facilitate the integration of ecosystems, their condition and services into national accounting workflows (EC, 2019b; Edens et al., 2022; Hein et al., 2020; La Notte et al., 2022b; Nedkov et al., 2022). National MAES assessments will need to be updated to enable the actual monitoring of ecosystems and their services, but also to reflect the shifts in policy attention and the availability of new concepts and methods. Therefore, an evaluation of current and concluded assessments can identify pitfalls and lessons learned for future work and accounting of ecosystems and their services.

The conceptual framework for MAES in Europe is built upon the ES cascade (Haines-Young and Potschin, 2010; Maes et al., 2013). The cascade identifies the various 'stages' of the flow of the services from nature towards society, with different versions being proposed and applied, linked to a conceptual evolution (e.g., Spangenberg et al., 2014; La Notte et al., 2017; Heink and Jax, 2019; Vári et al., 2022b), and a gradual convergence with concretisation and operationalisation of the cascade framework and its elements. The most common starting point of the workflow towards an assessment along the cascade in MAES projects is a map of ecosystem types (ET), classifying each spatial unit into the categories of an ecosystem typology. ET can be further refined with variables describing their condition (ecosystem condition; EC). The type and condition of ecosystems (together with site-specific factors) determine the capacity of ecosystems to deliver ES sustainably. Nevertheless, this capacity (or, "potential") differs from the flow of ES (or, "actual use") that is also influenced by the societal demand at a given place and time, as well as the human inputs expended to obtain the ES (Villamagna et al., 2013).

The specific elements of the cascade framework need to be customised for the particular context of a concrete MAES assessment: the selection of a relevant set of ecosystem types, the list of ecosystem services covered by the assessment, the indicators to be used at the different cascade levels, the ecosystem condition variables (typically different for each ET), the spatial resolution of the ET map, the datasets used, and the modelling and valuation techniques applied, to name but a few. In a particular MAES assessment the decision on these elements is not a purely scientific task: they also need to reflect societal and policy priorities (e.g., Crouzat et al., 2019; Grunewald et al., 2017; Stępniewska, 2016; Tanács et al., 2022a), respect numerous limitations (in data and knowledge availability, funding, time and energy) and be adapted to the respective biogeographical and ecological differences.

Guidance from the European Commission – in the form of regular MAES working group meetings and MAES reports (EC, 2019b; EC et al., 2014; Erhard et al., 2016; Maes et al., 2013, 2018) – strengthened an EU-wide multidisciplinary community of practice with a shared understanding about the most important MAES concepts. The glimpses gained from available publications and oral presentations make the implementation of the national MAES projects appear nevertheless still rather heterogeneous. For analysing the different ways the MS advanced and for deriving common features, solutions and lessons learnt we need therefore a strict stock-taking approach.

Apart from the elements of the MAES conceptual framework, there are several further aspects of the assessments that influence their quality and eventual policy uptake. One important aspect is the (scientific) credibility of the outputs, which can be ensured by clear and transparent documentation (reproducibility) as well as the validation of the main outputs and the assessment of their uncertainties (Inácio et al., 2020; Jacobs et al., 2015; Wardekker et al., 2008).

Synthesizing the separate assessment outputs (e.g. a set of different ES maps) into a more complete picture, showing interactions between ES, including causal relationships, is another step essential for arriving at valuable policy support (Bennett and Chaplin-Kramer, 2016; Tanács et al., 2023; Vallet et al., 2018). Integration between the single elements of an assessment (e.g. between ES flow and capacity of one ES) is also vital for giving a holistic picture of the flow of ES and to show the dependency of society on ecosystems (Brown et al., 2021). For this, integrating EC indicators into ES models is essential, but proves challenging. Many earlier assessments only mentioned the importance of EC (as 'intact nature' or as 'biodiversity') (e.g., Becerra-Jurado et al., 2015; Stevens, 2014) but rarely modelled it, or built in any dependence on EC into the ES models. In fact, there is little knowledge about quantitative relationships between these two items (see also La Notte et al., 2022a; Tanács et al., 2022a; Vári et al., 2022b) and there are only few reviews available targeting their relationship (Harrison et al., 2014; Smith et al., 2017; van der Plas, 2019).

While the results of a single MAES project are typically idiosyncratic and of restricted regional relevance, an overview of the thematic and methodological choices of these projects can be useful. However, it is

[1] https://www.esmeralda-project.eu

[2] https://www.ecologie.gouv.fr/levaluation-francaise-des-ecosystemes-et-des-services-ecosystemiques

challenging to find information on national projects (i.e., often available only in national languages), which makes the in-depth specificities of the different projects difficult to compare. Furthermore, it is hardly possible to assess the overall achievements, or success of the single projects and see the challenges that had to be overcome in order to realise the project. Comparatively assessing multiple national MAES projects, comparing practices, analysing commonalities and divergences, will allow us to distil patterns and lessons learned that advance a common methodology.

National ecosystem assessments have been reviewed in 2016 (Schröter et al., 2016) based on the peer-reviewed literature available at that time. However, the work of Schröter et al. represents an early stage in the development of MAES work, with spatial representations being still rather rare in national ecosystem assessments, the mandate for these projects not being uniformly derived from the EU Biodiversity Strategy (BDS), and much less guidance available. Furthermore, there are several types of key lessons (e.g., about the advantages and disadvantages of specific methods, or the perceived difficulties in project implementation) that are typically not published as "results". With the deadline of the Biodiversity Strategy 2020 many previously inactive MS embarked on their MAES projects, also unavailable for Schröter et al.. In addition to the 2016 review, there is also a monitoring mechanism established in the frame of the EU H2020 ESMERALDA project, which provides regular updates on the progress of the EU Member States in their MAES work and produces an aggregated progress indicator (the "MAES barometer", see Maes et al., 2021). Nevertheless, this progress indicator did not provide any in-depth overview on the thematic and methodological choices of the MS. Other European overviews targeted case studies at different levels (regional: Geneletti et al., 2020, EU Overseas: Sieber et al., 2022).

This paper aims at providing a new structured overview on how MS implemented the EU MAES conceptual framework in their national MAES projects. To achieve this, we invited key participants of national MAES projects in EU MS to share information about the national MAES projects that they took part in. The topics addressed involve:

a. the structure and organisation of the national MAES work in the member states (MS);
b. the elements aligned along the ES cascade (ecosystem types, ecosystem condition, ES capacity, flow, demand);
c. the methods used for modelling and the integration of ecosystem condition into ES models;
d. the validation and uncertainties of model results and uptake of results;
e. as well as a set of subjective criteria on success

2. Methods

2.1. Survey

In 2021 and 2022 two conference sessions were organized for the EU MAES community at the European regional Ecosystem Services Partnership (ESP) conferences (session "National & large scale MAES projects in Europe, including the EU Outermost Regions and Overseas Countries and Territories: challenges, solutions and lessons learned" at the ESP Europe 3, Tartu, Estonia, 07–11 June 2021; and session "National & large scale MAES projects in Europe - road towards policy uptake and implementation" at the ESP conference Europe 4, Heraklion, Greece, 10–14 Oct 2022) by the leading authors. Session speakers were invited to join the author team by providing information on their projects. For this purpose, a detailed online questionnaire was created and tested for collecting relevant information on each national MAES survey. The responses to this survey form the backbone of this article. We asked for one response per member state, emphasizing that respondents should check with project colleagues if they felt they did not have the full knowledge. After receiving the survey responses, several rounds of further clarifications were performed with participants. The obtained information and resulting insights were discussed with participants during the writing process. In order to retain comparability, we excluded those few (2) whose report deviated too much (e.g. was not directly MAES related but to the Millenium Assessment).

Respondents were expected to give an overview of and responses towards those projects components that actually fulfilled the Target 2 Action 5 obligations of the EU Biodiversity Strategy (i.e., that actually mapped and assessed ES in that MS). However, in some cases, these obligations were fulfilled in a combination of multiple projects, or as a part of a longer-term national initiative. We distinguished four main types of national approaches based on the structure and level of institutionalisation of national MAES activities:

- 'single (+follow-up)' projects: one single project that fulfilled Target 2 Action 5, potentially with follow-up projects going into more depths in specific aspects;
- 'multiple': several projects leading together to accomplishing Target 2 Action 5 of the EU BDS to 2020, the BDS target was broken up into several smaller projects. The respondents filled in the forms for all the MAES (sub)projects combined;
- 'programs': longer term MAES programs, with autonomous governance structures at the national level, the fulfilment of the BDS targets is just one milestone in the longer-term vision of these national "programs". The respondents filled in the survey for those program components that actually answered the Target 2 Action 5 obligations;
- 'miscellaneous' projects: science-driven single or multiple projects covering major tasks towards a national MAES, but not issued by the national authorities, not primarily funded for fulfilling Target 2 Action 5. Respondents chose those projects being closest in terms of targets and coverage to a national MAES/to fulfilling Target 2 Action 5 goals.

We collected information about the different MAES projects with a standardised set of questions targeting assessed items, modelling methods, calibration/validation and perceived challenges and successes. We created and tested detailed explanations to each question, including multiple choice questions. For the different components of the MAES conceptual framework we also asked whether components were "explicitly quantified/addressed" in order to exclude those items which were just mentioned in the discussion, but not assessed and mapped in a strict sense. The complete questionnaire can be found in Appendix A, an overview is given here with the main blocks being the following:

- Basic information on the projects, including the project name, duration, and main funding source.
- An overview of the challenges, shortcomings and advancements as experienced/perceived by the respondents and scored on a Likert-scale. Here we attempted to ask indirectly and from several aspects at critical points, with questions covering the same topic from different angles.
- An overview of the ecosystem types (ET) covered by the study. In the context of MAES assessments an ecosystem typology is a set of exhaustive and mutually exclusive ETs which are distinguished based on land cover, land use, species composition, or ecological functioning, and which designate operatively distinguishable and socio-ecologically meaningful functional units of the landscape. Each European country has a long and slightly different tradition of classifying ecosystem types, reflecting differences in several ecological, cultural, and historical factors. To compare the thematic /spatial scope of the different typologies we offered the broad ecosystem types listed in the EU MAES typology (Maes et al., 2013) as a checklist.
- An overview of the ecosystem condition (EC) characteristics covered by the study. In line with the more recent definitions (e.g., Czúcz and

Condé, 2017; UN, 2021) we interpreted EC as the quality of an ecosystem measured in terms of its abiotic and biotic characteristics, using variables with a normative meaning (i.e. distinguishing 'bad' condition from 'good' condition, cf. Czúcz et al., 2021b). We applied the classes of the SEEA Ecosystem Type Classification (Czúcz et al., 2021a; UN, 2021) as checklist categories to get an overview of the EC characteristics covered by the studies. We also collected information about whether EC indicators were integrated into ES models, the type of methods applied for assessing EC, as well as the presence of any validation (see below).
- An overview of the ecosystem services (ES) assessed in the study. These were recorded as a free list. Starting from the ES cascade framework, we distinguished three 'levels' for assessing ES: ES capacity, ES demand, and ES flow. Respondents had to report the levels at which ES were assessed. For each level, we also asked for the types of methods used, whether monetary valuation was performed at the respective level, as well as the validation techniques applied (see below).

To get an overview of the assessment methods (both model types and data sources) used for mapping and assessing EC variables and ES indicators, we developed categories based on the SEEA Guidelines for Biophysical Modelling (UN, 2021) and the categories used by Campagne et al. (2020), combining them in a single list for the purpose of this research. This way, four "data types" that can be used with minimal processing and where the type of data itself mostly determines the way the assessment is implemented, were added to the list of "real methods" and the term "methods" used subsequently sensu lato for both. For each method the respondents had to specify an approximate number of ES (or EC) variables for which that specific method type was applied. The following method types were distinguished:

- Primary data - measured or surveyed data in the field / on the ground
- Statistical data: data taken from national or other data collections
- Remote sensing data: data from satellites, UAV, or other remote sources
- Literature data: values for assessment taken from literature (primary research, reviews, assessments)
- Simple expert based or participatory model: models based on assessment (scoring) of several experts in the field, possibly also by including (local) stakeholders; relying only on LULC data (e.g., simple ES matrix models, look up tables)
- Rule based expert or participatory model: models based on assessment (scoring) of several experts in the field, possibly also by including (local) stakeholders; incorporating also spatial rules refining the scoring (e.g., soil types, slope aspect refining the modelled capacity of ES matrix models)
- Statistical model: quantifying statistical relationships among environmental or management variables and ecosystem services
- Process-based model: predicting ecosystem services supply (or other variables) through the simulation of ecosystem processes and their interactions, based on a set of environmental properties, management variables and/or other spatial data sources (e.g., crop models, USLE approaches, hydrological models…)
- Machine learning model: application of computer algorithms that improve automatically through experience and by the use of data (e.g.: convolutional neural networks, random forests)
- Agent-based model: bottom-up approaches, where the decisions of individuals are simulated and scaled up to the level of a system (i.e., ecosystem).
- Other: the respondents also had the opportunity to specify other method types, not represented in the categories above.

We also aimed to map the efforts and approaches followed by national MAES studies for validating the EC and ES indicators they used. We distinguished the following validation types (building on Boerema et al., 2017; Jacobs et al., 2015):

- no validation
- validation with experts
- cross-validation with other models
- validation with higher tier models
- validation with primary data / field data
- other types of validation (to be explained in comment)

Finally, information on the degree to which national MAES studies performed economic valuation of the ES indicators, and at which cascade levels this valuation is performed was collected (cf. Ansink et al., 2008; Czúcz et al., 2018; La Notte et al., 2015).

The survey was implemented using the open source KoBoToolbox system[3] and Enketo webforms.[4] To make the questionnaire more ergonomic and error-proof we added a skip logic excluding the non-applicable parts of the survey based on the responses. The 'source code' of the full survey can be found in Appendix B in an xlsform format.

2.2. Data processing

To identify the major challenges, participant's answers were analysed using scores and median values of the question items (see Appendix A) that were ordered accordingly, also taking the frequency distribution of the answers and the means into account. The scores for the two questions on "biggest challenges" and "need for further elaboration" were taken as they were, whereas the scores for the question on the "biggest advances" were inverted to enable a comparison with the two other questions.

The combined and ordered list was divided into issues supported by the respondents to be a) the greatest challenges (with scores of the top one third), b) greatest advances (scores in the lowest one third), c) contradictory or ambivalent (with several relevant items scored both high and low) and d) unclear or neutral issues (scores in the medium range).

The ES given as a free list were assigned to CICES 5.1 categories and backchecked with respondents.

3. Results

A total of 13 EU MS (equalling 48 % of the EU MS) responded to our survey, ranging all over Europe from Austria, Bulgaria, Czech Republic, Denmark, Estonia, France, Germany, Hungary, Lithuania, Malta, Poland, Romania to Spain (Fig. 1, Table 1).

As called for by the Biodiversity Strategy, most of the national MAES studies covered the whole territory of the MS, with half of them conducting additional case studies or regional studies, sometimes extending beyond continental Europe, into the Overseas Regions of the countries (see France). The MS followed slightly different approaches and project structures reflecting national scientific traditions and actual policy settings. In the following paragraphs we introduce these to give a concise overview of their background.

While several countries approached their assessments along major ecosystem types (e.g., Poland, Spain), starting from these and assessing all relevant ES in that type (or even systematically all ES: Bulgaria), others designed their assessments primarily along functions and services (e.g., Austria, Germany, Hungary, Lithuania) or followed both approaches, with differing foci (Czech Republic, France, Estonia, Malta).

The EU MS also exhibited considerable differences in the way how their MAES projects were structured and coordinated. Few countries established national 'programs' with long-term, autonomous governance and funding mechanisms, with the potential to branch into a

[3] https://www.kobotoolbox.org/

[4] https://enketo.org/

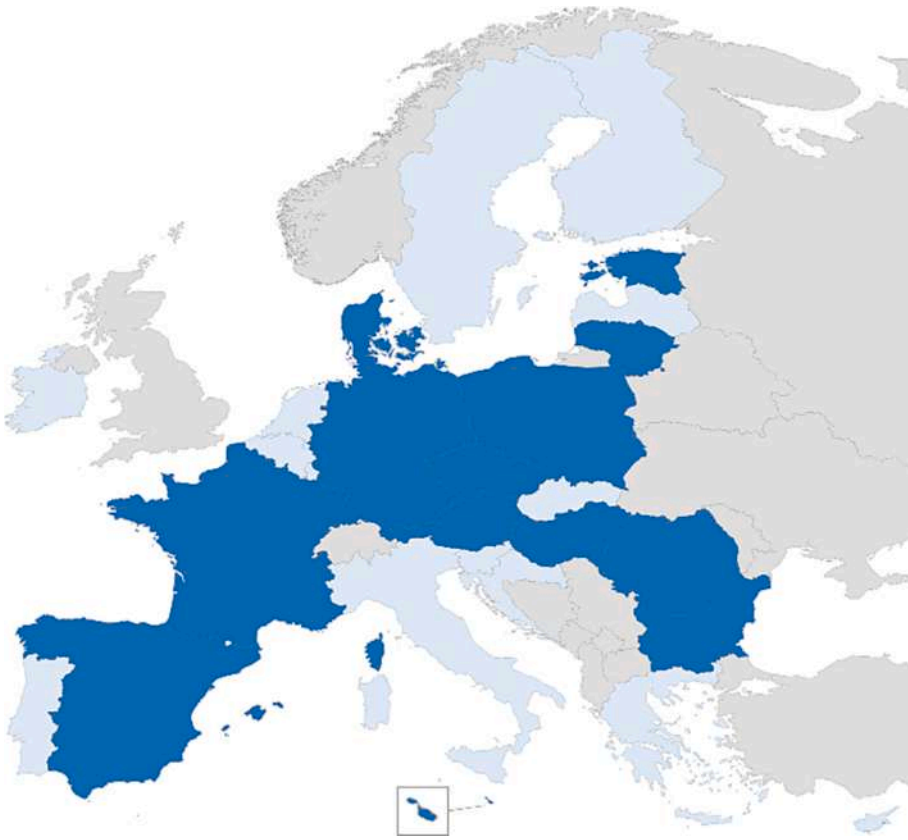

Fig. 1. European Union member states participating in the present survey: dark blue; EU member states: light blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

diversity of thematic ES assessment (sub)projects responding to a broad range of sectoral and national priorities. Other MS funded a single dedicated MAES project with the goal to fulfil the national obligations towards the Biodiversity Strategy 2020. Several of these MS implemented or are now planning follow-up projects to dive deeper into certain aspects of an ES assessment, the necessity of which was recognised during their first national MAES project (see Spain, Estonia, Lithuania). Finally, there were also a few MS among the respondents (e.g. Malta and Czech Republic) that have not yet had any official national MAES projects initiated by their respective authorities, but have extensive experience on ES assessments from several science-driven ES projects.

3.1. Short description of the national MAES projects

Austria conducted a study mapping and assessing 15 ES from 2017 to 2019 (Sonderegger et al., 2019). The study was based on available EC and ES data. Criteria for selection of ES to be mapped and the respective indicators were: relevance and importance for Austria, comparability to published studies dealing with ES at the European level, availability of current data which will also be surveyed in future to detect trends, and availability of well-established methods to quantify ES. In consequence of this report another study is conducted now at a more regional level (Lower Austria), which will prove that ES mapping can serve as a sound basis for land use decisions.

Bulgaria launched a two-stage program in 2015, with the first stage creating a set of methodologies that were horizontally compatible across ecosystem types, fitted into a standardised database, accommodating for both EU and national classifications and indicator systems in the context of eLTER's (European Long-Term Ecosystem Research) system, and combined both EC and ES assessment. This resulted in an extensive framework with mapping and assessment of nine broad ecosystems emphasizing in situ verification, and including a guide for long-term ecosystem condition and services monitoring in line with the MAES framework and the eLTER's Whole System approach (Katrandzhiev et al., 2022). While very flexible by design, this approach requires good knowledge of the basic principles and primary data collection and processing for any subsequent update. Further ongoing research includes ecosystem services production capacity, adjusting indicator weights based on their ecological significance, and integrating EC and ES indicator sets. The Bulgarian assessment developed two integrated indices: an aggregated EC metric and a single ES capacity metric that characterise the ecosystem condition, and the service provision capacity, respectively. At the present, about $^{2}/_{3}$ of the country have been mapped and assessed, and stage two of the program is still being awaited.

The MAES process in the Czech Republic was initiated by a national assessment of grassland ecosystem services (Hönigová et al., 2012). Later, an integrated assessment of ecosystem services was performed using value transfer and the Consolidated Layer of Ecosystems of the Czech Republic (Frélichová et al., 2014). Meanwhile, ecosystem services assessments were a component of several case studies focusing on ES modelling, trade-off analysis, participatory mapping, evaluation of nature-based solutions and ecosystem-based disaster risk reduction. All assessment projects were conducted as part of research initiatives funded by national or European projects and provided improved knowledge on ES and uptake in policy (Daněk et al., 2023), but no official MAES program was launched in Czechia. Currently, LIFE IP One Nature for Natura 2000 network aims at improving methodologies for the assessment of selected ES in biophysical and monetary terms, to support applications and mainstreaming of ES in decision-making.

In Denmark a series of projects have targeted the assessment of ecosystem services from 2014 onwards. The emphasis has been on developing a land use model to provide support for the analysis and evaluation of alternative policies. Specific emphasis was on identifying

Table 1

Overview of the national MAES studies in the EU Member States. Assessment structure: 'single (+follow-up)': a single project fulfilling EU Biodiversity Strategy 2020 Target 2 Action 5, potentially with follow-up projects; 'multiple': several projects achieving together goals of Target 2 Action 5; 'programs': longer term MAES programs; 'miscellaneous' projects: science-driven single or multiple projects (see Methods for details). Funding source acronyms: NG: National Government and other public sources (NG is only mentioned if national funding sources contributed beyond compulsory co-funding rates); EAFRD: European Agricultural Fund for Rural Development (Rural Development Programmes); EEA: European Economic Area (EEA) and Norway grants; LIFE: LIFE Programme; ERDF: European Regional Development Fund; CF: EU Cohesion Fund.

MS	Acro-nym		assesment structure	Time-frame	Funding source	References	Project page
AT	MAES-AT	Assessment and mapping of ecosystem services	single (+follow-up)	2017–2019	EAFRD	Sonderegger et al., 2019	https://www.umweltbundesamt.at/studien-reports/publikationsdetail?pub_id=2302&cHash=88bfb6c72b62521b17a52ff6086bde8a
BG	–	Mapping and assessment of ecosystems in Bulgaria outside Natura 2000 (a total of 9 projects performed in parallel)	program	2015–2017	EEA	Katrandzhiev et al., 2022; Bratanova-Doncheva et al., 2017a, b;	–
CZ	–	Evaluation of socio-economic benefits of the Natura 2000 network	miscellaneous	2019–2026	LIFE	Daněk et al., 2023; Frélichová et al., 2014; Hönigová et al., 2012;	https://www.jednapriroda.cz/en/
DE	–	Development and implementation of a methodology for the nationwide assessment of ecosystem services in the context of the implementation of Target 2, Measure 5 of the EU Biodiversity Strategy for 2020 (and follow-up projects)	multiple	2014–2021	NG	Grunewald et al., 2017, 2020; Albert et al., 2015; Schweppe-Kraft et al., 2023	https://www.ioer.de/en/projects/weiter-oesl
DK	MAES-DK	Development of the mapping and valuation methodology for assessment of contributions of land use meassures to ecosystem services and biodiversity in Denmark	miscellaneous	2014-present	NG	Termansen et al., 2017*; Hasler et al., 2022*; Termansen et al., 2023*	–
EE	ELME	Establishment of tools for integrating socioeconomic and climate change data into assessing and forecasting biodiversity status, and ensuring data availability	single (+follow-up)	2016–2023	CF	Helm et al., 2021*; Map catalogue: https://arcg.is/1z1iO10*	https://loodusveeb.ee/en/countrywide-MAES-EE
ES	EME	Spanish National Ecosystem Assessment	single (+follow-up)	2010–2016	NG	Santos-Martín et al., 2013; Santos-Martín et al., 2019a, b;	https://www.ecomilenio.es/
FR	EFESE	French assessment of ecosystems and ecosystem services	program	2012-present	NG	Tibi and Therond, 2017*; Crouzat et al., 2019; EFESE, 2020*; Mongruel et al., 2019*;	https://www.ecologie.gouv.fr/levaluation-francaise-des-ecosystemes-et-des-services-ecosystemiques
HU	MAES-HU (NÖSZTÉP)	Strategic Assessments supporting the long term conservation of natural values of community interest as well as the national implementation of the EU Biodiversity Strategy to 2020	single (+follow-up)	2016–2021	ERDF	Tanács et al., 2022b; Vári et al., 2022b; Tanács et al., 2022a; Tanács et al., 2023	https://termeszetem.hu/hu/okoszisztema-szolgaltatasok/feladatok-1
LT	LINESAM	Lithuanian National Ecosystem Services Assessment and Mapping	single (+follow-up)	2018–2021	NG	Gomes et al., 2021; Inácio et al., 2020; Kalinauskas et al., 2023	https://linesam.mruni.eu/
MT	LIFE IP RBMP	Mapping and assessing valley ecosystem services	miscellaneous	2019–2020	LIFE	Balzan and Tanti, 2020;	https://www.rbmplife.org.mt/https://lifeip-rbmp-geoportal-valleymanagement.hub.arcgis.com/pages/ecosystem-services
PL	ECOSERV-POL	Services provided by main types of ecosystems in Poland – an applied approach	single (+follow-up)	2020–2023	EEA	Mizgajski and Stępniewska, 2012;	https://ecoservpol.amu.edu.pl/en/
RO	N4D	Demonstrating and promoting natural values in support of decision-making processes in Romania -Nature4Decision-Making-N4D	single (+follow-up)	2015–2017	EEA	NEPA et al., 2017;	https://maesromania.anpm.ro/

* available in national language.

areas with synergetic effects and potential conflicts. The Danish approach was based on the UK NEA analytical framework (Bateman et al., 2013). In the first few years the approach was developed and tested for a large catchment (Limfjord catchment). This developed the ES model with sixteen ES and biodiversity indicators (Termansen et al., 2017). Based on this model a national scale model focusing on seven ES and biodiversity indicators. The model has been used to evaluate policy scenarios for implementation of the water framework directive and the co-benefits of achieving water quality targets (Hasler et al., 2022). The current version of the model allows analysis of ES policy targets across forest and agricultural land (Termansen et al., 2023). Spatially explicit policy scenarios are used to analyse the interactions and potential effects of policies with multiple impacts across several ES and biodiversity indicators. As an example, the model has been used to evaluate the cost effectiveness of marine based measures to meet coastal water quality targets (Filippelli et al., 2022).

In Estonia, the national MAES project ELME was launched in 2016 aiming to develop and implement novel biodiversity monitoring methods and perform EC and ES mapping and assessment in the country. After conducting several preliminary works, incl. compiling a roadmap for MAES, a countrywide mapping and assessment of the EC and ES of the main natural and semi-natural terrestrial ETs was completed in 2020 (Helm et al., 2021). In 2021–2023 in continuation of the ELME project, further methodological refinements and updates of the biophysical assessments are conducted, and a comprehensive socio-economic assessment and mapping (including monetary valuation) of the main terrestrial ES is being undertaken. Marine ecosystem services (covering the exclusive economic zone area of Estonia) were assessed and mapped in 2019 within ELME, and are being further elaborated in the course of the other projects (e.g., project MAREA[5]). Several projects have also addressed urban and freshwater ecosystem services, but further work needs to be done to compile a countrywide assessment and mapping framework for these ETs.

In France, the EFESE program produced six big reports on six different ecosystem types, using a working group structure (agro-ecosystems; Tibi and Therond, 2017), forests, continental waters, marine ecosystems (Mongruel et al., 2019), urban ecosystems, mountainous ecosystems (Crouzat et al., 2019), which are reviews about the ecosystem types, their condition and their services. These reports include assessments and maps of those ecosystem types and ES relevant to these ecosystem types (e.g., 14 assessments and maps for agricultural areas). When sufficient data was available, the monetary value of ecosystem services was assessed using various economic valuation methods. There are also 5 reports focusing on specific ES case studies on local to national scale: pollination (national without overseas), carbon sequestration (national including French Overseas), forest recreation (national without overseas), coastal erosion (on a regional scale in Aquitaine), ecosystem services mappings in the region Ile-de-France (regional case study). Two reports also focus on services associated with wild species: one case study of vulture reintroduction in two protected areas, and a national assessment of wild ungulates in France (national without overseas). Data and ES mapping in French Outermost Regions is fragmented, compared to continental France.

In Germany, the national MAES process in the broad sense started already around 2010 with “Natural Capital Germany - TEEB-DE” (https://www.naturkapital teeb.de). Building on the valuations in this project, recommendations for the development of a first national indicator set for the assessment of ecosystem services (for ca. 20 priority ES), were suggested (Albert et al., 2015) and further developed and agreed with experts (e.g. Grunewald et al., 2017). The German MAES Report presents comprehensive information on terrestrial and marine ecosystems and their state in a condensed form, including agricultural and forestry soil condition surveys and modelling, monitoring of forest condition, and focuses on the links between use, pressures, services and biodiversity (Schweppe-Kraft et al., 2023). Starting from ecosystem classification, the changes of the different ecosystem types in recent years (see also Grunewald et al., 2020), followed by the most important indicators of ecosystem condition for the main ET. Nationwide assessments and maps are presented for 13 ecosystem services. Finally, an overview of strategies and measures to avoid the degradation of natural capital or the loss of ES is given, but also ways to invest in nature for welfare enhancement are shown. Drawing on information in individual chapters on foreign trade relations, the final chapter briefly addresses Germany’s responsibility for the conservation of ecosystems and ecosystem services at the global level.

Hungary completed its first national MAES project between 2016 and 2021 (Vári et al., 2022b). The project aimed at supporting national nature conservation, providing a sound basis for management and decision-making. This work covering the whole country produced a high-resolution ecosystem map (Tanács et al., 2022b), with three hierarchical levels of ET. The project also assessed ecosystem condition, and, in parallel, some EC indicators linked to specific ES (Tanács et al., 2022a). 12 ES were chosen for mapping and assessment through prioritisation in a participatory approach. Six technical working groups focused on different thematic groups of ES (e.g., on hydrological, cultural or energy-related ES). They assessed these ES with biophysical, some economic and several social indicators at the four levels of the cascade. The interrelationships between these were also analysed (Tanács et al., 2023). Some regional assessments complemented the national mappings: several regulating ES for urban areas (four case studies) and for hydrologic ES (Zala watershed). All the assessments were based on existing (mainly national) databases. A planned follow-up project will further improve the methods, create new maps suitable for studying change and elaborate possible scenarios.

The project Lithuanian National Ecosystem Services Assessment and Mapping (LINESAM) established the first MAES in Lithuania between 2018 and 2022. The project was developed at a national scale for terrestrial (Kalinauskas et al., 2023) and marine environments (Inácio et al., 2020), cropland (Gomes et al., 2021), woodland and forest, and urban environments. LINESAM considered different ES domains (e.g., regulation and maintenance, provisioning and cultural) and components (capacity, flow and demand). ES were also forecasted for terrestrial and coastal/marine environments (Gomes et al., 2021). Currently, three national projects are ongoing, the first targeting Lithuanian lake ecosystem services and impacts of climate and land-use change (LACLAN) focused on lake environments, the second on Mapping and Assessment of Lithuanian national and regional Parks Ecosystem Services (MALPES) focused on protected areas and the third mapping and forecasting ecosystem services in urban areas (MAFESUR), focused on cities.

Work carried out in Malta has included prioritising ecosystems and ecosystem services for mapping and assessment and determining the level of detail best applicable to Malta. The available data sources were identified that can be used in this regard along with the data gaps that will need to be addressed and the stakeholders/experts that need to be consulted in the process, in particular for selection of the indicators to be used. While the national ecosystem assessment has not yet been finalised, several projects have been carried out and have led to the development of ecosystem assessments at local and national scales. These include the mapping and assessment of ecosystem services at water catchment scale (LIFE 16 IPE MT 008) and for the Valletta urban agglomeration (the MAES project EnRoute and the ReNature Horizon 2020 project).

The nationwide MAES project in Poland was carried out in 2020–2023. The project aimed to increase the scientific capacity of the Polish researchers to develop ES approach, as well as raise officials’ awareness of the potential of ES from the political, social and ecological point of view. Within the project, inter/transdisciplinary research teams formulated relevant indicators for capturing ecological, cultural, and

[5] https://marea.balticseaportal.net/

economic values provided by ecosystems typical for the landscape-ecological structure of the country. The analysis covers ES provided by agroecosystems, forests, urban ecosystems, freshwaters, marine ecosystems, degraded ecosystems, and ES on the landscape level. The scope of the project includes: the selection of relevant ES and their indicators for main ecosystem types in Poland, mapping and assessment of ES in national, regional and local scale, cross-cutting analysis of ecological, cultural and economic values of ES, identification of significant ES synergies, trade-offs and relevant ES bundles. The results were communicated to interested stakeholders through seminars and thematic workshops for administration representatives and expert-practitioners. The project results will be summarized in a handbook on ES approach for environmental management.

A project was implemented in Romania for the mapping of ES at national level as a support tool for the implementation of the EU Biodiversity Strategy 2020. The project entitled "Demonstrating and promoting natural values in support of decision-making processes in Romania (N4D) was developed by several institutions including National Environmental Protection Agency (NEPA), WWF-Romania, Romanian Space Agency and the Norwegian Institute for Nature Research. The financial support was provided by the EEA program. Nine major ecosystem types were identified: croplands, forest ecosystems, grasslands, marine and coastal ecosystems, urban ecosystems, wetlands, shrublands, rivers and lakes, and rocks. The analysis was based on mapping the ecosystems and consequently a series of specific indicators for each of the ecosystem categories at national level. Different methods were used in pilot cases at local levels to identify and map ES. The assessments relied on expert opinion in the assessment for some of the ES, but in-depth stakeholder involvement was not implemented. This was implemented in the pilot projects and only locally.

The Spanish national ecosystem assessment (EME) implemented from 2010 to 2016, aimed at contributing to the National Strategy on Green Infrastructure, Connectivity and Ecological Restoration, for maintaining and improving the provision of ecosystem services of the elements linked to the development of green infrastructure. The assessment has been developed at different scales, i.e. national (for 14 ecosystems), sub-national (i.e. Andalucía and Murcia regions), and many case studies at local level. It consisted of a biophysical assessment and a spatially explicit analysis of biodiversity, ecosystem services, land use change and socioeconomic variables, developing also future scenarios and a social *meta*-analysis with data from the different Spanish case studies to uncover ecosystem services bundles through social preferences. For five ES also monetary valuation was performed, and a socio-economic valuation also taking the non-use values into account, as well as a plurality in terms of valuation methods (monetary and non-monetary methods related with market prices, stated preferences techniques, and demand ranking). Within the framework of the LIFE Integrated Project INTEMARES, an assessment of the state of ecosystems and their services within the Natura 2000 marine network is currently on the way. In this context, an economic valuation of four different services is being conducted.

3.2. Survey results on mapping and methods

Mapping ES relies mostly on base maps showing actual land use and land cover (ET) for which the creation or augmentation of national ET maps was required. Some MS selected few ET to focus on, while others assessed all ET in their territories, resulting in ranges from 6 to 14 ET mapped (Table 2). The ET mapped most frequently were forests (by all respondents), followed by croplands (92 % of respondents), and Grasslands, Water (Rivers and lakes) and Wetlands (85 % each). Heath- and shrubland, urban areas and sparsely vegetated land were mapped by 69, 54 % and 46 % respectively. Some marine ecosystem types (marine inlets and transitional waters, coastal ecosystems) were also mapped by about half of the member states (Marine inlets and transitional waters 62 %; Coastal areas 46 %), while other, more distant marine ET much less frequently (shelf and open ocean, 31 and 23 % respectively).

The Czech assessment also included groundwater ecosystems, while the French added mountainous areas to enrich and customise their national assessments.

All MAES assessed and mapped ecosystem condition (EC) explicitly, quantifying indicators of EC in some form in their assessments. Categorizing the variables assessed along the SEEA Ecosystem Condition Typology (Table 3), the most popular ECT classes were landscape characteristics (ECT class C1, used by 85 % of MS), closely followed by physical state characteristics (A1), compositional state characteristics (B1) (each used by 77 %), and structural state characteristics (B2) (by 69 %). The MS also applied several condition variables, that fall into the category of 'ancillary data' and do not meet the strict SEEA EA definition of EC, with some variables describing ecosystem management (69 %), protected areas (69 %), ecosystem extent (62 %), accessibility (54 %), and pre-aggregated indices (46 %).

In line with their central role in MAES, all of the national assessments addressed many ES, but they differed in terms of the cascade levels at which ES indicators were quantified and mapped. There were two MS that only mapped 'capacities', and two MS exclusively focussing on 'flows', while most of the countries assessed (some) ES at both of these levels. In addition, five MS also mapped/assessed indicators for ES 'demand'. The number of CICES classes covered by the assessment ranged between 5 and 56, with a mean at 19. The most frequently targeted ES (Table 4) were cultivated crops (CICES 1.1.1.1), erosion control (CICES 2.2.1.1), hydrological cycle and flow regulation (2.2.1.3), pollination (2.2.2.1), carbon sequestration (greenhouse gas regulation; 2.2.6.1) and recreation in some form (3.1.1.1). The national MAES assessments typically quantified all ES capacity and flow indicators in biophysical units, but in four MS this was also complemented with a monetary valuation in the case of selected ES (Table 2).

The frequency of the different methods used for the assessments were similar across all levels of the cascade (Fig. 2, Appendix C). Mostly statistical data were used (e.g., taken from national or other data collections; 19 % for all methods, all levels) or data (values) taken from literature (published primary research, reviews, assessments; 17 %). More labour-intensive methods like process-based, machine learning or agent-based models were the least popular (used to 6, 2, and 1 %). From the "data type" methods, remote sensing (11 %) and primary data (12 %) were less present. Among the "real model" types, simple expert-based models and statistical models were used most frequently (at 8 and 11 %). Most assessments used a great diversity of methods, up to 10 different types.

Some validation of the assessments was performed in most of the projects (85 and 69 % of countries indicated at least some validation for EC and ES capacity, respectively) usually for selected indicators or methods, however, for 'flow' and 'demand' only to a much lesser degree (46 % and 15 %). In cases where there was validation, it was mainly performed by expert judgement (37 % of validation cases), to a lesser degree by using primary data (29 %). More demanding validation methods e.g., cross-validation with other models at least for certain areas or using higher tier models at least for certain areas were used in 20 % and 10 % of the cases, respectively.

3.3. Survey results on challenges and success

Overviewing the challenges and successes as they were perceived by the respondents (Table 5), we can see that the greatest achievements were seen in relation to the large-scale coverage of the national projects, both in terms of spatial and thematic scale: in assessments, which were mostly spatially explicit (thus indeed "mapping"), covering the whole country or large areas, and the large number of ES assessed. The high quality of maps was also something participants appreciated.

The biggest challenges were found by all respondents to ensure uptake by policy and the synthesis of multiple aspects (trade-offs, synergies). Even though these are two aspects relevant rather towards the

Table 2
Overview of the performed ES mapping and assessment elements in each country: ecosystem types, ecosystem services and ecosystem condition indicators assessed (i.e. actually quantified) and mapped. The number of ecosystem services assessed is given in terms of CICES classes (not the number of indicators used). The 'methods' give the number of method types used for each of the cascade levels (EC, ES capacity, flow and demand) and '$' whether monetary valuation was performed at that level; blanks: not assessed. For typologies and methods see Section 2.1.

EU MS	Ecosystem types	Ecosystem condition		Ecosystem services			
	number mapped	number of ECT classes	number of methods	number assessed	number of methods		
					capacity	flow	demand
AT	6	5	4	15	3	3	
BG	10	11	8	56	6		8
CZ	7	3	5	5		5	
DE	9	11	10	13	7	5	4
DK	6	8	5	9	4	5	4
EE	9	9	8	28	10 $	2	
ES	9	8	4	10		3	
FR	14	9	2	19	5 $	2 $	2
HU	6	8	5	12	5 $	2 $	
LT	11	12	7	36	5	5	3
MT	10	6	3	12	5	5	
PL	9	9	4	56	7	7 $	7
RO	4	4	3	17	3		

end of a MAES, they were seen by all respondents as important, no matter how advanced they were within their respective projects.

A major point regarding challenges were issues on the uncertainty and reliability of the assessments ("data gaps or data reliability", "assessed uncertainty of valuations", and "validating results"). Validating results was seen by 69 % of the respondents as a big challenge (scores 4 & 5; Fig. 3).

Some items were scored in a somewhat ambiguous way. Although the assessment of more cascade levels did not seem to be an important target for further elaboration, the future inclusion of additional items (like integration of EC, human well-being, demand) obtained high scores. Surprisingly, conflicts between sectors were not seen as a big challenge, the transfer of knowledge was seen as more or less successful, but nevertheless was rated as needing some further work.

Financial and time limits were seen as least challenging, along with the task of filling knowledge gaps, e.g., by finding the right specialists.

4. Discussion

4.1. State and development of MAES projects

Most responding countries had either completed the project or had arrived at a mature state, where processes and results can be evaluated, and opinions can be meaningfully formulated. As respondents were involved intensely in their respective projects, and their perceptions of the project reflected upon a large amount of first-hand experience, the received answers and the resulting picture were regarded as representative. The countries participating show a good coverage of recent work on MAES in Europe, with only few of the recently established projects not participating in the present survey (e.g. Slovakia, see Mederly et al., 2020; Cyprus, see Vogiatzakis et al., 2020; and Greece, see Kokkoris et al., 2020). There are several MS that started their assessments earlier, often with a bit different framing and focus (see below), for example Luxemburg (Becerra-Jurado et al., 2015), Sweden (for forests: Hansen and Malmaeus, 2016), the United Kingdom (UK NEA, 2011), Ireland (Parker et al., 2016), part of Belgium (Flanders: Stevens, 2014), or Finland (Mononen et al., 2016). Some of the projects surveyed here also have older roots, with a history of several follow up projects (e.g. France, Germany, Spain), some others have been only taking flight in recent years (e.g. Estonia, Hungary).

Differences in the structure of MAES assessments were obvious, ranging from single projects designed specifically to fulfil Biodiversity Strategy 2020 Action 5 Target 2 objectives, potentially with follow-up projects that were most frequent, to rare examples with initiatives planned for long-term implementation pursuing overarching conservation targets. While intention might be present in all EU MS, the implementation of any long-term commitments is probably far more difficult in countries with a high degree of political instability that prompts very short-term political horizons and frequent changes in policy at both the national and local level. In countries with no centrally initiated national MAES project yet, science-driven research projects can provide a valuable basis for policy decisions.

Compared to earlier findings (Schröter et al., 2016, see Table 6), our assessment shows a development towards more spatially explicit approaches, actually producing maps. While in the initial phase of the European MAES, MS first focused on non-spatial assessments, ecosystem mappings, and case study mappings (Kopperoinen et al., 2016; Schröter et al., 2016) most of the more recent MAES assessments are covering their entire country in a spatial way. The policy background and mandate of the national assessments has also become more homogenous in recent years with assessments prescribed by the Biodiversity Strategy 2020. The Biodiversity Strategy 2020 was translated into increasingly concrete recommendations and methodological guidance by the EU MAES working group (Burkhard et al., 2018; EC et al., 2014; Maes et al., 2013, 2018). Together with the development of an EU "MAES community" this has led to a much more specific and aligned understanding of terms and applicable solutions.

The conceptual framework of the EU MAES projects also has become more harmonised: whilst Schröter et al., 2016 found that many assessments did not yet differentiate between ES capacity and flow, now the ES cascade is well recognized, and assessments usually cover several elements.

Overall, a steady evolution of the ES assessment methods and frameworks can be observed, moving towards standardisation (Polasky et al., 2015; Steger et al., 2018), but as we see from the results of the present survey, full harmonisation is not yet achieved in all areas. Some topics are less present in recent works, despite earlier assessments' potential to provide some guidance in these areas, e.g. the UK NEA assessed the impact of different scenarios on ES import needed to cover the population needs (Haines-Young et al., 2011). The question of ES needed from outside of the EU, or the respective country was also addressed by (Maes et al., 2012; Schröter et al., 2016. Also, assessing the trends of ES seemed to be a more popular topic (see Schröter et al., 2016), which however might be revived nowadays with policies stepping from assessing ES further on towards monitoring of ES.

As actual mapping proceeds, a territorial expansion of included areas can also be observed towards EU Overseas. Some of the EU Outermost Regions and Overseas Countries and Territories have also picked up the ES concept and first applications of EU MAES can be found (Sieber et al., 2022, 2021, 2018). Yet, MAES implementation in the EU Overseas still

Table 3
Ecosystem condition indicator types used by the surveyed national MAES based on the SEEA-Ecosystem Characteristic Typology (UN, 2021).

short name	description	assessments using this ECT %	n
Abiotic ecosystem characteristics			
Physical state characteristics (A1)	physical descriptors of the abiotic components of the ecosystem (e.g. soil structure, water availability)	77 %	10
Chemical state characteristics (A2)	chemical composition of abiotic ecosystem compartments (e.g. soil nutrient levels, water quality, air pollutant concentrations)	54 %	7
Biotic ecosystem characteristics			
Compositional state characteristics (B1)	composition / diversity of ecological communities at a given location and time (e.g. presence / abundance of key species, diversity of relevant species groups)	77 %	10
Structural state characteristics (B2)	aggregate properties (e.g. mass, density) of the whole ecosystem or its main biotic components (e.g. total biomass, canopy coverage, chlorophyll content, annual maximum NDVI)	69 %	9
Functional state characteristics (B3)	summary statistics (e.g. frequency, intensity) of the biological, chemical and physical interactions between the main ecosystem compartments (e.g. primary productivity, community age, disturbance frequency)	38 %	5
Landscape level characteristics			
Landscape and seascape characteristics (C1)	metrics describing mosaics of ecosystem types at coarse (landscape, seascape) spatial scales (e.g. landscape diversity, connectivity, fragmentation)	85 %	11
Embedded landscape elements	the abundance of "subgrid fragments" of an ET in another embedding ET (e.g. woodland (hedgerows) in an agricultural ET)	54 %	7
Ancillary data			
Pre-aggregated indices	synthetic information aggreagted from different data types / sources (e.g. Water Framework Directive ecological condition index)	46 %	6
Ecosystem extent	the area/ cover/ share of the main ETs in the landscape	62 %	8
Protected areas	protection status	69 %	9
Management	ecosystem management (e.g. grazing, felling, fishing, agriculture) characterized with its intensity	69 %	9
Accessibility	accessibility for humans (e.g. distance from roads / settlements)	54 %	7
Other pressures	other pressures (e.g. pollution) characterised by fluxes (i.e. rates of emission / immission / transformation)	54 %	7
Other environmental variables	other variables often reflecting stable environmental characteristics (e.g. geology, climate)	15 %	2

Table 4
The most frequently assessed ecosystem services in the surveyed MAES assessments (based on CICES 5.1).

ES short name	CICES class	n assessed	in %
global climate regulation	2.2.6.1 Regulation of chemical composition of atmosphere	13	100 %
cultivated crops	1.1.1.1 Cultivated terrestrial plants for nutrition	12	92 %
water quantity regulation	2.2.1.3 Hydrological cycle and water flow regulation	12	92 %
recreation	3.1.1.1 Characteristics of living systems that enable activities promoting health, recuperation and enjoyment	12	92 %
erosion control	2.2.1.1 Control of erosion rates	11	85 %
pollination	2.2.2.1 Pollination	10	77 %
timber	1.1.1.2 Fibres and other materials from cultivated plants (timber)	9	69 %
reared animals	1.1.3.1 Animals reared for nutritional purposes	8	62 %
habitat maintenance	2.2.2.3 Maintaining nursery population and habitats	8	62 %
filtering wastes	2.1.1.2 Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	7	54 %
water quality regulation	2.2.5.1 Regulation of chemical condition of freshwaters	7	54 %
microclimate regulation	2.2.6.2 Regulation of temperature and humidity, including ventilation and transpiration	7	54 %

lags far behind continental Europe (Sieber et al., 2018), and even where EU Overseas are included in national assessments, (e.g., France), they are not considered to the same extent. This can largely be attributed to the lack of appropriate data, knowledge, and research capacity (Sieber et al., 2022), which are being addressed by current anchor projects such as MOVE and MOVE-ON.[6] To protect ecosystems all across the EU and meet the objectives of the EU Biodiversity Strategy 2030, an inclusion of the EU Overseas is vital. The assessment of a greater diversity of ET goes along with the geographic expansion, for example with the extension towards marine ecosystems, which haven't been included in earlier works thoroughly (Chalkiadakis et al., 2022; Maes et al., 2012), but seem to get increasing attention in the presently surveyed national works.

4.2. Assessment elements and methods

The prevalence of ecosystem condition as a regular component of ecosystem assessments is a relatively recent development. Within the European MAES process, attention has turned rather late to assessing EC and guidance on its implementation has come forth much later (cf. (Erhard et al., 2016; Maes et al., 2018). In many earlier assessments, EC (or some of its synonyms) was only mentioned, but not actually assessed and mapped, or addressed only using a rough landcover based categorization or biodiversity as sole aspect (Table 6; Becerra-Jurado et al., 2015; Mizgajski and Stępniewska, 2012; Schröter et al., 2016). The evolution of the EC concept started from "structures and processes" (as in Haines-Young and Potschin, 2010) and a parallel set of "supporting services" as used in the MA (MA, 2005) and turned into an increasingly operational term with a clear distinction from the related concept of ES capacity (Keith et al., 2020; UN, 2021). This process was significantly stimulated by the UN developing the new SEEA EA that proposed operational criteria for condition indicators (Czúcz et al., 2021a, 2021b). These criteria exclude several types of variables, like stable environmental characteristics, or human pressure from the definition of condition indicators. The use of pressure or management variables to describe EC also obscures EC-ES relationships (Rendon et al., 2019; Tanács et al., 2022a). Such variables can nevertheless be observed in many national MAES assessments (with 37 % of the used EC types representing ancillary data, see Table 3),where data availability

[6] https://moveon-project.eu/https://moveon-project.eu/

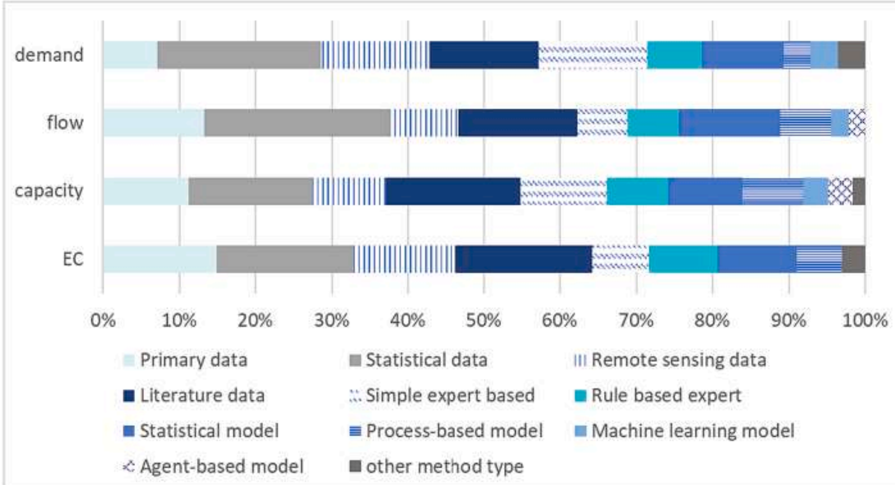

Fig. 2. Method types used for assessing different levels of the ES cascade.

Table 5
Greatest advances and biggest challenges in the surveyed national MAES projects. Valuations based on the combined results of the three main blocks of questions (see Fig. 3).

Greatest challenges
uncertainty & reliability: data gaps and reliability and assessing uncertainty of valuations were both scored as highly challenging; validating results (with some primary data collection and/or higher tier modelling), was seen as of medium importance
policy uptake: the need for strengthening uptake, and uptake of results by (national) decision makers seen as strong challenges
synthesis of multiple aspects - interactions (trade-offs, synergies) between ES
data gaps or data reliability
explored possible futures / scenarios
Greatest advances
maps covering the whole country/large area
high quality maps
large number of ES assessed; consistent with scoring the importance of assessing (even) more ES as very low
Least challenging /less further work needed
financial limits
time limits
gaps in knowledge, finding (the appropriate) specialists
Contradictory /ambivalent issues
conflicts between the sectors to be involved was both scored as least challenging and as needing more effort; related to this: the transfer of knowledge between different sectors was scored to be of medium importance
Involvement: involvement of stakeholders was scored as being more or less successful, while an even greater future involvement was seen as most necessary
ES & levels assessed: including more cascade levels scored as least needed for further elaboration, but items for including demand or human well-being into assessments scored as most needed; integrating EC into the models was seen as of medium importance
neutral /unclear
compiling the models
provided possibility for valuable primary data collection
institutional structures, administrative difficulties
assessments (non-spatial) covering the whole country
higher tier models for assessing ES, and validating results was seen as a challenge and elaborating better models as less needed

constraints made for the choice of the “second best” options (e.g. pressure variables) acceptable.

Integration of the EC indicators into the modelled flow of ES can be ensured by selecting EC variables that feed into the ES models (La Notte et al., 2022b, 2022a; Vári et al., 2022a). Neither quantifying, nor integrating EC variables into ES models was often performed in the past (Schröter et al., 2016). Currently, 85 % of the national MAES surveyed reported integration between some EC variables and the ES models. Finding and especially quantifying these links is challenging (Rendon et al., 2019; Vári et al., 2022a), while it is broadly acknowledged that only healthy ecosystems can provide ES at the appropriate levels (EC, 2020).

The ES items most often selected comply roughly with those chosen as top priority in the EU Ecosystem Assessment (Maes et al., 2021) and for integration into ecosystem accounts (La Notte et al., 2021) with ‘Erosion control’ additionally prioritized by most surveyed assessments. While in the early assessments ‘Drinking water’ appeared on the top list (Schröter et al., 2016), this ES has lost its popularity in the newer MAES studies – probably due to the underlying discussions on the abiotic origin of this service (also reflected in the new position of this service in CICES 5.1, (Haines-Young and Potschin, 2018). ‘Global climate regulation’ outran all other ES, being now the only ES assessed by all respondents, probably mirroring intensified concerns about recent climate developments. ‘Cultivated crops’ is still one of the ES assessed most frequently, mainly without accounting for the immense amounts of human input required to generate this ES (Schröter et al., 2021; Vallecillo et al., 2019), as suggested in the more recent guidelines of SEEA EA, and EU Ecosystem assessment (Maes et al., 2021).

For assessing EC and ES, a variety of methods was applied, often also in combination, with more easily accessible, low effort methods (e.g. statistical data, literature data) chosen most frequently for all elements of the ES cascade, similar as in earlier MAES studies (Schröter2016). We included these data types in our overview among the methods, as these are often not further processed but useful (and being used) as is. While a

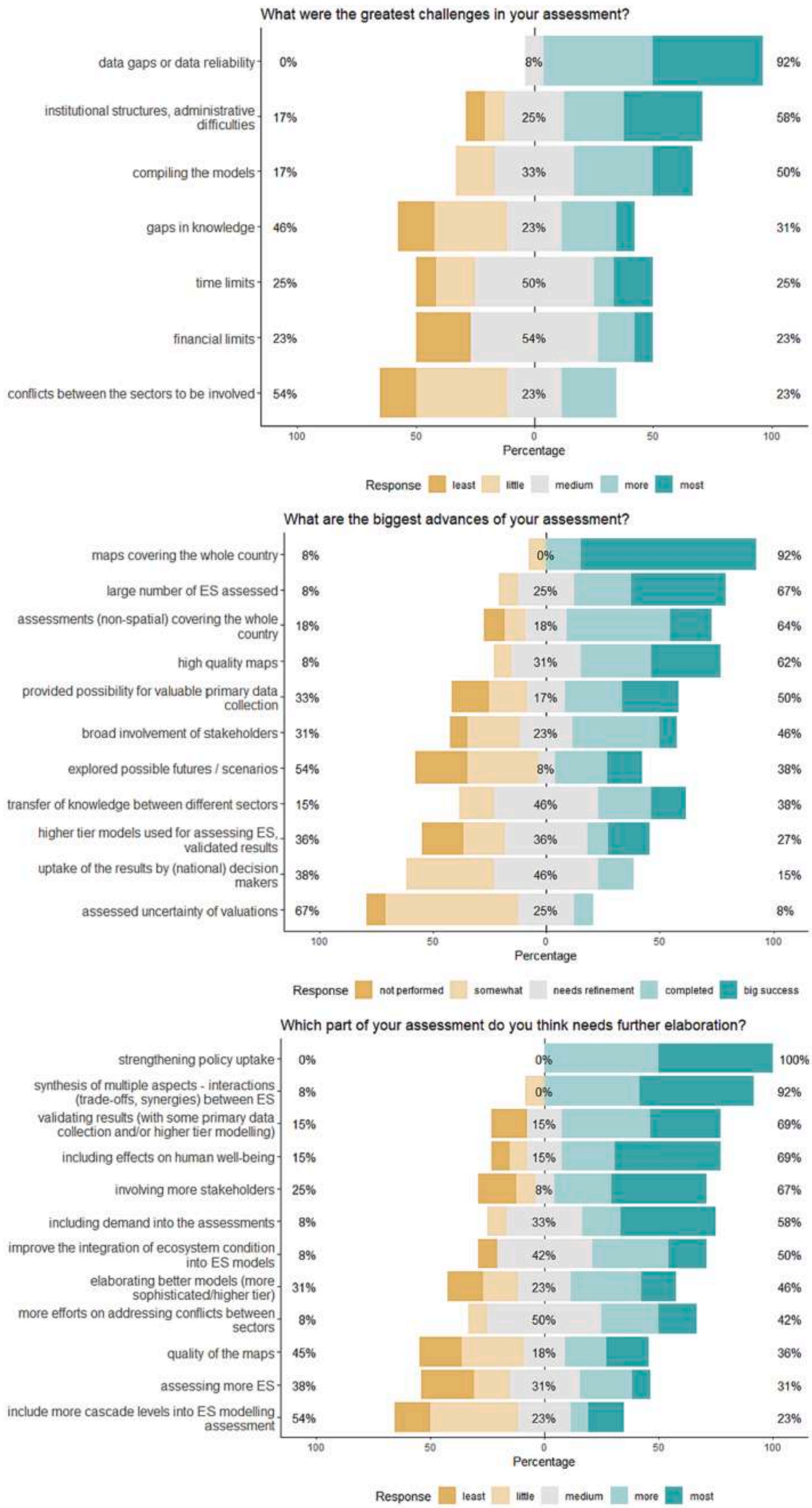

Fig. 3. Distribution of responses to 'greatest advances and biggest challenges' in the surveyed national MAES.

Table 6
Features of earlier and more recent national MAES assessments (based on Schröter et al., 2016 and the present study).

	trend	recent assessments	earlier assessments
geographic coverage	more mapping, greater emphasis on spatial dimension	mapping is an integral part of the MAES assessments	few assessments mapped ES systematically; 63 % (5 out of 8) mapped "state of ES"
ecosystem condition (EC)	greater focus on EC, with biodiversity as one component of EC	92 % (12 out of 13) assessed and mapped (some) EC variables for (some of) the ETs; EC assessment is performed with a variety of approaches (7.7 different ECT classes covered on average per assessment)	63 % (5 out of 8) assessed EC; focus on biodiversity or on structures
selected ecosystem services (ES)	no trend in number of ES; slight change in top ES: flow regulation and erosion control instead of drinking water supply and pest control	number of ES assessed and mapped ranging from 5 to 56 (according to CICES 5.1 items); most popular: carbon sequestration (greenhouse gas regulation; 100 %); cultivated crops, hydrological cycle and flow regulation, recreation (all at 92 %); erosion control (85 %); pollination (77 %)	6–28 ES (according to CICES 4.3) top ES: provision of food, drinking water, fiber and materials, carbon sequestration, and recreation (100 %); followed by: pollination and the regulation of soil fertility (7 out of 8); further: pest control (6 out of 8), and air-quality regulation, biomass for energetic use (5 out of 8)
EC-ES integration	improving integration of EC variables into ES models	EC indicators are integrated into ES models in 85 % of the cases to some degree	relationship between biodiversity and ES is the only way that the role of EC in ensuring ES delivery is considered, in a few cases (50 %, 4 out of 8)
ES capacity, flow	more consistent distinction and inclusion of ES capacity and ES flow	all assessments distinguished ES capacity and flow (both mapped by 85 %) and some added demand (46 %)	the majority (5 out of 8) did not distinguish between capacity, flow and demand; 2 MS mapped ES capacity, of which 1 compared capacity with demand and 1 additionally flow. 1 flow and "total use"

direct input to assessments is sometimes chosen (e.g., Pechanec et al., 2019), this should be rather performed critically, and better adapted to incorporate own settings and purposes (Campagne and Roche, 2018).

The choice of methods is influenced by several factors, including the availability of data, the target object as well as the expertise and the disciplinary background of the teams doing the work (Harrison et al., 2014).

Primary data collection is often impossible within a national MAES process - only about half of the MS reported the assessment to be an opportunity to collect primary data. Data gaps and data reliability are constantly recurring issues, in every assessment – as also shown by the responses to the perceived challenges. Definitely, any assessment can be only as good as the data on which it is based (Jakobsson et al., 2020; Maes et al., 2012; Tanács et al., 2023). While more and more remote sensing methods are available that can alleviate the need for spatially fine-scaled data, this type of data source also needs to be validated with ground data, checked and processed, before it is suitable for input into ES models (Nagai et al., 2020). This leaves us with calling once again for maintaining a permanent, consistent monitoring, as the basis for filling data gaps and enhancing data reliability.

4.3. Synthesizing results for policy uptake

Generating a policy relevant synthesis from the diverse outputs (EC and ES variables and their maps) is one of the greatest challenges of a MAES assessment. There is a large body of literature giving recommendations on the aggregation of a set of ES (Langhans et al., 2014), delineating ES-bundles and looking at synergies and trade-offs with a set of methods (Martín-López et al., 2012; Mouchet et al., 2014; Raudsepp-Hearne et al., 2010; Vallet et al., 2018), the inclusion of stakeholder's or societal values (Manning et al., 2018; Martín-López et al., 2012), or calculating multifunctionality indices (Hölting et al., 2019; Manning et al., 2018; Tanács et al., 2023). This further, complementary step is needed to show the individual ES in relation to each other, e.g., on a hotspot map, defining priority areas for protection or restoration (Chaplin-Kramer et al., 2021; Mitchell et al., 2021). Interpreting the obtained complex indicators, correlation matrices, or hot-spot maps, is also challenging, specifically to recognise differences between correlations and causation (Bennett et al., 2009; Sugihara et al., 2012; Vallet et al., 2018). Further caveats are obtaining differing results with different aggregating algorithms for a set of ES, or different options to weigh them (e.g. by stakeholders: Manning et al., 2018; or by monetary values: Vermaat et al., 2020). All these issues pose serious challenges, as also indicated by our survey results. Nevertheless, a synthesizing step - the capstone of an ES assessment - is essential if we want to ensure that ES assessments can support land use management decisions. Exploring future scenarios might help to elicit the causal links, and find optimal solutions for all ES and stakeholders (e.g., Dade et al., 2019; Felipe-Lucia et al., 2014; Haines-Young et al., 2011; Harmáčková and Vačkář, 2018).

Involving all relevant stakeholders as soon as possible into the process - potentially already for scoping and the selection of indicators - is crucial. Participants experienced stakeholder involvement in their projects as more or less successful, but said at the same time that it needs to be strengthened. With a timely and more in-depth stakeholder involvement, uptake is considered to be more successful (Balvanera et al., 2017; Norström et al., 2020; Posner et al., 2016). Stakeholders in a national assessment might be mostly representatives of different sectors, with potentially conflicting interests and decade long disputes. Overcoming these can be a major challenge, and if successful, in itself a major achievement. Due to the policy background of the national MAES projects, these works are mainly issued by governmental institutions, and either conducted by consortia of non-government research institutions (e.g. Estonia, Hungary, Germany, Spain) or internal government research agencies (e.g. France). This anchorage in policy can add to a better policy uptake but does not necessarily entail it – care needs to be taken to involve all participants in a balanced and equitable way and not let any of the participants dominate the process (Norström et al., 2020).

Both the lack of indicator validation (e.g. accuracy assessment, sensitivity analysis) of assessment products, and the insufficient quantification of uncertainty are major points of criticism towards ES assessments in general (Bryant et al., 2018; Schröter et al., 2014; Schulp et al., 2014). According to the precautionary principle, environmental policy needs a good understanding of the uncertainties of any data that are used to support environmental decision making (Kriebel et al., 2001). Yet, there are no widely accepted norms or methods for estimating and transparently presenting the uncertainties of ecosystem assessments. Thus, it is not surprising that the question of uncertainties was addressed only to a limited degree in the surveyed MAES projects. Some methods of quantifying uncertainty specifically for matrix models are suggested by Jacobs et al. (2015), several others, with different applicability overviewed for example in Bryant et al. (2018) and the work of Campagne et al. (2017) and Roche and Campagne (2019) present some aid in assessing reliability of expert estimates. For a specific type of uncertainties (confidence in temporal trends) the EU ecosystem assessment also provides a simple grading system (Maes et al., 2021).

The presence of uncertainty inevitably comes with a risk of misinterpreting the assessment outputs – including potentially also intentional misinterpretation. On the side of the authors, simple and clear standards for uncertainty reporting, following e.g. the IPCC/IPBES reporting protocols (Mastrandrea et al., 2010; Wardekker et al., 2008) can be a good starting point, for thinking, communicating and visualizing non-spatial assessment conclusions. Nevertheless, the skills of policy readers in interpreting results (including complex maps and uncertainties) can and should also be actively strengthened (e.g., with plainly written manuals, webinars, or with the help of knowledge brokers). Another way of fostering understanding is by turning the audience into participants, with active involvement in knowledge co-production, developing together more action-oriented research (Norström et al., 2020).

The participants of our survey seemed to be very much aware of the limitations of their assessments, calling for careful interpretation before real-life adoption and integration into policy. Balancing between concerns by experts regarding the validity and uncertainty of results for generalisation and broad-scale application, and the need for action, for implementation of conservation measures is an often-discussed issue (e.g., Baustert et al., 2018; Jacobs et al., 2015; Jakobsson et al., 2020).

Policy uptake itself was seen as one of the greatest challenges still ahead. Establishing a legislative background specifically for the protection of ES is in some countries on its way, but national legislation is usually much stronger (and more concrete, with less uncertainties) for protected species and areas (e.g. Stępniewska et al., 2018). On the other hand, implementation of EU level directives might have higher priority in some countries, motivated by fear of losing EU funds, or having to pay fines.

The newly signed Kunming-Montreal Global Biodiversity Framework (GBF), specifically Goal B and Target 11 might strengthen the position of ES in this sense (UN, 2022). Countries will need a coherent evaluation of current policy and legislative frameworks to effectively protect ecosystem services.

4.4. Towards ecosystem accounting

Both the EU BDS and the GBF (Target 14) expect countries to “ensure the full integration of biodiversity and its multiple values” into their national accounting systems (UN, 2022). These natural capital accounts are supposed to abide by SEEA EA as the newly adopted international statistical norm (Edens et al., 2022). Most recently, the European Commission passed a legislation to create the first ecosystem accounts, with MS reporting on accounts of ecosystem extent, EC and ES every two years (EC, 2022). Implementation of these accounts can be based on methods and tools developed recently for a set of ES (INCA tool: Buchhorn et al., 2022, ARIES for SEEA,[7] La Notte et al., 2021; Vallecillo et al., 2019).

While at the present only biophysical accounts of ecosystem services are required under the SEEA EA as well as the EU legislation, an extension towards monetary accounts of ecosystem services might be a future step once consensus on the most appropriate methodologies to assess monetary values is reached (Brown et al., 2021; Eigenraam and Obst, 2018; Obst et al., 2016). Therefore, developing monetary valuations - as has been done by some MS, for few ES at the capacity and at the flow levels, as presented here - in national MAES is a way forward. While expectations are high regarding the potential applications of monetary valuation, one mustn’t forget about its strong limitations in terms of incorporating multiple values of nature (IPBES, 2022).

[7] https://aries.integratedmodelling.org/aries-for-seea-explorer/

5. Conclusion

The present MAES projects are much more streamlined compared to an earlier overview of national ecosystem assessments where a rather diverse set of motivations, approaches and objectives were found (Schröter et al., 2016). ES assessments are on a road towards standardisation: from a boundary concept towards formal Ecosystem Accounting, getting a major role in the Natural Capital Accounts based on the recently published SEEA EA, with methods on how to include ES in NCA being more and more developed.

Synthesising knowledge and the state of the art across national MAES works, as the present paper does, sheds light on common values, well-working solutions, and shared challenges, while making the development and implementation of future MAES assessments towards more streamlined processes more readily accessible.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, athttps://doi.org/10.1016/j.ecoser.2023.101592.

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