SELINA
SCIENCE FOR EVIDENCE-BASED AND SUSTAINABLE DECISIONS ABOUT NATURAL CAPITAL

D6.1 Report on indicator review, selection and integration

29/12/23

Lead Author/s: Sabine Lange, Joana Seguin
Contributing Author/s: Ildikó Arany, Benjamin Burkhard, Chiara Cortinovis, Bálint Czúcz, Panayotis Dimopoulos, Helena Duchková, Nicolas Grondard, Victoria Guisado Goñi, Miguel Inácio, Jarumi Kato Huerta, Ioannis P. Kokkoris, Solen Le Clec'h, Mark Mansoldo, Stoyan Nedkov, Isabel Nicholson Thomas, Paulo Pereira, Hristina Prodanova, Paula Rendón, Daniela Ribeiro, Jonas Schwab, Mateja Smid Hribar, Małgorzata Stępniewska, Eliška Tichopádová, Vince van 't Hoff, Sofia Vaz, Joana Vincente

Funded by the European Union

SELINA receives funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101060415. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the EU nor the EC can be held responsible for them.

Prepared under contract from the European Commission
Grant agreement No. 101060415
EU Horizon 2020 Research and Innovation Actions

Project acronym:	**SELINA**
Project full title:	**Science for Evidence-based and sustainabLe decIsions about NAtural capital**
Project duration:	01.07.2022 – 30.06.2027 (60 months)
Project coordinator:	Prof Dr Benjamin Burkhard, Gottfried Wilhelm Leibniz University Hannover
Call:	HORIZON-CL6-2021-BIODIV-01
Deliverable title:	Report on indicator review, selection and integration
Deliverable n°:	D6.1
WP responsible:	WP6
Nature of the deliverable:	Report
Dissemination level:	Public
Lead beneficiary:	LUH
Citation:	Lange, S., Seguin, J., Arany, I., Burkhard, B., Cortinovis, C., Czúcz, B., Dimopoulos, P., Duchková, H., Grondard, N., Guisado Goñi, V., Inácio, M. Kato Huerta, J., Kokkoris, I.P., Mansoldo, M., Nedkov, S., Nicholson Thomas, I., Pereira, P., Prodanova, H., Rendón, P., Ribeiro, D., Schwab, J., Smid Hribar, M., Stępniewska, M., Tichopádová, E., van 't Hoff, V., Vaz, S. & Vincente, J. (2023). SELINA D6.1. Report on indicator review, selection and integration.
Due date of deliverable:	Month 18
Actual submission date:	Month 18

Deliverable status:

Version	Status	Date	Author(s)	Reviewer
1.0	First Draft	18 October 2023	Sabine Lange, Joana Seguin (LUH)	T6.1 taskforce
1.1	Second Draft	24 November 2023	T6.1 taskforce	
1.2	Draft For Review	04 December 2023	Sabine Lange, Joana Seguin (LUH)	Davide Geneletti (UniTrento), Nicolas Grondard (WU), Paulo Pereira (MRU)
1.3	Final	29 December 2023	Joana Seguin, Sabine Lange (LUH)	

Table of Contents

Table of Figures

List of Tables

1. Preface

The importance of biodiversity, natural capital and healthy ecosystems and the services they deliver has increasingly been acknowledged in diverse policy initiatives (e.g. EU Biodiversity Strategies 2020 and 2030, Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), Intergovernmental Panel on Climate Change (IPCC) and Convention on Biological Diversity (CBD)).

The Horizon 2020 Research and Innovation Action Science for Evidence-based and sustainabLe decIsions about NAtural capital (SELINA) aims to provide robust information and guidance that can be harnessed by different stakeholder groups to support transformative change in the EU to halt biodiversity decline and to secure essential ES-sustainable supply and use in the EU by 2030.

SELINA builds upon the Mapping and Assessment of Ecosystems and their Services (MAES) initiative that has provided the conceptual, methodological and data base for comprehensive assessments on different spatial scales, including the EU-wide assessment (Maes 2020) and assessments in EU member states. Knowledge and data for different ecosystem types are increasingly available. The overall objective of Work Package (WP) 6 "Integrated assessment" is to integrate the different MAES components (ecosystem mapping, condition, services, and accounting) and to serve as a knowledge broker between the different project Strands, to foster the uptake of ES in decision making. This knowledge brokerage will take place by further processing and integrating ecosystem assessment results in the different value domains (biophysical, economic and social-cultural) as well as bringing together the different MAES components. The findings will be provided for the application- and decision-making-oriented Strand C (WPs 8 and 9) on different spatial and temporal scales. The information exchange is designed as an iterative loop, including feedback and adaptation loops between Strands B and C, focussing on research and decision-making as well as the stakeholder interaction of Strand A and WP2. Finally, based upon all this integrated knowledge, SELINA will propose guidance material fitting the specific decision-making questions and various stakeholders' needs.

The Deliverable 6.1 ("Report on indicator review, selection and integration") presents the results of a systematic literature review. Its objectives include determining gaps in knowledge, and summarising key findings on linking ecosystem condition, ecosystem services, and ecosystem accounting. The review focuses on the identification of applied indicators and their features linking ecosystem condition and services, as well as their application in ecosystem accounting.

2. Summary

The overall objective of SELINA Work Package (WP) 6 is the appropriate integration of outcomes of the research-oriented Strand B related to better understanding ecosystem conditions and their impact in ecosystem services supply. Additionally, WP6 serves as communication and knowledge transfer between the different project Strands making sure that information is further processed and integrated. Deliverable (D) 6.1 summarises the outcomes from Task 6.1, a systematic literature review on the identification of existing indicators linking ecosystem condition (EC), ecosystem services (ES), and ecosystem accounting (EA). The main aim was to synthesise all the available EC and ES indicators from pre-SELINA work to identify existing knowledge gaps, summarising key findings, and build upon this knowledge base in other SELINA Tasks (e.g. T3.2, T6.3, and T6.4).

D6.1 presents the conducted literature review and its outcomes. A total of 2720 scientific publications were screened by a large task force of members from the SELINA consortium. For the full text review, 659 papers were considered. Finally, 142 papers were included in the final review stage. In total, 1745 indicators have been identified in this review. Hereof, 908 have been identified as EC indicators and 837 as ESs indicators. The review revealed a diverse and complex landscape of relations between EC and ES indicators. The findings from the review are structured according to different ecosystem typology groups.

After evaluating the results, different key gaps have been identified: (i) In specific ecosystem types (ET), there is a lack of integration of EC indicators in ES assessments, in particular in marine ecosystems and wetlands; (ii) there is an ET specific lack of fully spatially explicit EC and ES indicators, in particular in marine and coastal ETs, and to a lesser extent in heathland and shrubs, wetlands and agroecosystems ETs; (iii) we identified a lack of association between EC indicators and reference conditions or reference levels; (iv) a lack of relation between EC indicators and provisioning and cultural ES was found; and (v) a lack of prevailing clear differentiation between EC and ES indicators was discovered multiple times.

Besides, we derived some practical recommendations to guide future research on the discussed topics. As multiple publications lack comprehensive documentation and reporting, which may cause potential inconsistencies, uncertainties, and misunderstandings, we highly recommend transparent and explicit reporting. The variation in concepts and definitions across the research domain poses additional challenges and limits the collaborative development of a holistic understanding of EC in general and with regard to ES. Thereby, the uptake of research results, e.g. in the decision-making context, may be restrained. Hence, we argue for streamlining future research with international efforts and established classifications. EC indicators would benefit from being assigned to the corresponding SEEA EA ECT. This approach would also be beneficial for the efficient incorporation of this information for future developments of ecosystem accounts.

Generally, the findings and limitations identified in D6.1 provide a solid foundation for the upcoming SELINA Tasks to integrate and build upon existing links between EC indicators and ESs, while addressing the specified gaps.

3. List of abbreviations

AI	Artificial intelligence
CICES	Common International Classification of Ecosystem Services
CBA	Cost-benefit analysis
CBD	Convention on Biological Diversity
CoG	Compendium of Guidance
DP	Demonstration Project
EA	Ecosystem Accounting
EC	Ecosystem Condition
ECT	Ecosystem Condition Typology
ET	Ecosystem Type
EU	European Union
ES	Ecosystem Service
KIP INCA	Knowledge Innovation Project on an Integrated system of Natural Capital and ecosystem services Accounting
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
MAES	Mapping and Assessment of Ecosystems and their Services
MSFD	Marine Strategy Framework Directive
n_i	Number of indicators
n_p	Number of publications
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
sd	Standard deviation
SEEA	System of Environmental-Economic Accounting
SELINA	Science for Evidence-based and sustainabLe decIsions about NAtural capital
WFD	Water Framework Directive
WoS	Web of Science
WP	Work Package

4. Introduction

There is a long-standing demand for operational indicators that could give vital feedback for policy and the society on the state of nature and biodiversity. In the current biodiversity and climate change crisis policy-makers increasingly require suitable and reliable sets of indicators that they can use to set environmental goals and evaluate their fulfilment. Nevertheless, ecosystems are inherently complex and multidimensional, and it is notoriously hard to define and operationalise (quantify) their condition and the underlying concepts (e.g. ecological integrity, biodiversity) in the form of quantitative indicators (Andreasen et al. 2001, Czúcz et al. 2021). Since the early 1990s, when such concepts were still often regarded as too vague to be applicable to "real-world regulatory and management problems" (Noss, 1990), considerable research efforts have been invested into both the theoretical and the practical side of operationalising EC, positioning it appropriately in the broader context of interactions between nature and the human society / economy.

From a theoretical perspective, the most important direction of evolution is a consistent integration of the EC concept in the "glossary" of relevant disciplines and researcher communities, including "biodiversity ecologists" (Andreasen et al. 2001, Roche & Campagne 2017, Keith et al. 2020), and "ecosystem service scientists" (Heink & Jax 2019, Keith et al. 2020, La Notte et al. 2022). In the last decade several major international frameworks for reporting on biodiversity and ESs have embraced EC as a component. The most important such framework is the System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA-EA) established by the United Nations (UN) in 2021 (UN et al. 2021, Hein et al. 2020, Edens et al. 2021), which highlights EC as one of its five core "accounts" and offers standardised definitions and approaches for its operationalization. In Europe, a closely related framework has been developed by the EU Mapping and Assessment of Ecosystem Services programme (MAES, Maes et al. 2018, 2020) and the Knowledge Innovation Project on an Integrated system of Natural Capital and ecosystem services Accounting (KIP INCA, Buchhorn et al. 2022, La Notte et al. 2022), which also have EC in their focus. The "ecosystem condition" part of these initiatives, including the theoretical framework, as well as a "work in progress" practical list of condition indicators was recently published in an "EU-wide methodology to map and assess ecosystem condition" (Vallecillo et al. 2022). Nevertheless, as also the subtitle of this work ("towards a common approach consistent with a global statistical standard") suggests, the work on aligning concepts and developing indicators has only started, and there are still a lot of details to be sorted out, as the major elements are getting settled, until EC indicators become fully operational (Czúcz and Arany 2016, European Commission 2014, van Oudenhoven et al. 2012, Balvanera et al. 2013; Kandziora et al. 2013).

Although these conceptual frameworks suggest that the availability of ESs should depend on the condition of the ecosystems, on the concrete nature of this dependence there is very little understanding, yet. Fortunately, ES has become one of the most popular domains in applied ecological research, with an immense number of studies trying to measure the capacity / supply of a specific ES together with the characteristics of the local ecosystems, trying to establish a relationship between the two (Czúcz et al 2018). These studies provide an important resource for knowledge synthesis, because they can help to establish an evidence-based link between condition and services. Furthermore, there is also an increasing number of ecosystem assessment studies, that apply some indicators designed for assessing EC (in addition to ES, e.g. Wübbelmann et al. 2021, Burkhard et al. 2018a, Burkhard et al. 2018b, van Oudenhoven et al. 2018; Albert et al. 2016; Maes et al. 2016; Geijzendorffer et al. 2015), and some recent studies even focus purely on assessing condition (without ES, e.g.: Maes et al. 2023, Bruzon et al. 2023, Tanács et al. 2022). As these practical assessments aim to implement the (rapidly evolving) theoretical frameworks in a concrete geographic and policy context, such studies also constitute an important, yet often underrated source of practical lessons, which can also be exploited by knowledge synthesis methods (systematic reviews).

Nevertheless, to date, only few researchers have studied systematically the indicators used for assessing EC, the underlying assumptions and methods, as well as the linkages between EC and ES (Rendón et al. 2020, Geneletti et al. 2020, Burkhard et al. 2018a, Maes et al. 2018, Harrison et al. 2014, Smith et al. 2017, van der Plas 2019, Czúcz et al. 2018, Weiskopf et al. 2022). The relationship between EC and services seems to be a particularly critical knowledge gap (Czúcz et al. 2018, La Notte et al. 2022), connecting the two most “understudied” components of an EA framework (Comte et al. 2022). In addition, there is an increasing attention and demand for a better integration of EC in ES models (UN 2021, Comte et al. 2022, La Notte et al. 2022, Weiskopf et al. 2022). Hence, the present Deliverable Report presents a systematic approach to reveal the state of the art on indicators integrating information on ESs, condition and/or accounting.

Deliverable 6.1 (D6.1) is a product of WP6 in the SELINA project. It describes a systematic literature review that covers the period between 2018 and 2022, the period between the end of the preceding ESMERALDA project[1] and prior to the SELINA project[2]. The reasons to conduct this literature review at the beginning of the project are (i) to identify knowledge gaps and unresolved issues in the scientific context that SELINA may address during the project, (ii) to agree on a common theoretical framework and terminology that guides collaborative efforts in WP6 and (iii) to provide a synthesis of the key findings on interlinking the three pillars EC, ES, and EA in research. This review is targeted to identify various types of information relevant for different user groups (e.g. researchers, practitioners, managers or decision-makers).

The concrete objective of this systematic review is to identify the scientific publications that contain indicators addressing (i) the linkage between EC and ESs and (ii) the application of EC or ES(s) in an EA context. It follows that this work compiles the knowledge base on linking EC, ES, and EA available in the recent scientific literature from prior SELINA work (2018-2022). Existing indicators, aggregated indicators and composite indicators that are used in combined application studies were identified and categorised. It needs to be noted that the terms indicator and variable are commonly used as synonyms to describe a number or qualitative descriptor generated with a well-defined method that reflects a phenomenon of interest (the indicandum) (Burkhard et al. 2023). However, an important exception is the use of these terms in the context of EC accounts (UN 2021), where they are defined individually: (i) EC variables as quantitative metrics describing individual characteristics of an ecosystem asset; and (ii) EC indicators as rescaled versions of EC variables. Nevertheless, as this review deals

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

[2] https://project-selina.eu/

with a broad spectrum of EC-related application studies, both terms will be used synonymously, specifically referring to the less restrictive definition.

Gaps were identified and highlighted in order to address some of them in follow-up work within the SELINA project. The findings from this work will also feed into the real-world Demonstration Projects (DP) in WP8 and WP9 to support them with the selection of indicators and the reference to useful indicator databases. Moreover, the analysed literature items will feed into the successor of the MAES Method Explorer[3], currently developed in Task 6.6.

The scientific review is guided by the following two research questions:

RQ1: Which ecosystem condition indicators are deduced to assess which ecosystem services in recent scientific publications (pre-SELINA)?

RQ2: Which indicators are integrated into ecosystem condition and service(s) accounts in recent scientific publications (pre-SELINA)?

The methodological approach used for this systematic review is presented step-by-step in Chapter 5. The results were grouped according to different ET groups, laid out in Chapter 5.6, and are expounded in Chapter 6 followed by a discussion of the main content-related and remarkable methodological aspects. The information that was gathered here will be of valuable use in other Tasks of the SELINA project, as outlined in Chapter 8.

5. Methodology

To ensure transparency, traceability, and accurateness of the conducted approach, this systematic literature review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol (Page et al. 2021, Moher et al. 2015). As the PRISMA-P approach has its roots in the health sector (Moher et al. 2015, Page et al. 2021), some methodological steps taken were slightly modified according to our needs and are outlined in this chapter. Our understanding of a systematic review follows the definition in Page et al. (2021). The systematic approach conducted here was guided by a search query (cf. Chapter 5.1) to collate all relevant scientific publications that fit our pre-specified inclusion criteria (cf. Chapter 5.2) to answer our specific research questions (outlined in Chapter 4). Screening the queried literature was divided into a two-step-approach (cf. Chapter 5.4) and for all included literature items the review template (cf. Chapter 5.3) was completed. The meta-analysis, statistical analysis, and the data processing to combine and summarise the results of the multiple studies were mainly accomplished using the R environment (R Core Team 2022, R version 4.2.2, cf. Chapter 5.5). The PRISMA flow diagram indicating the numbers for each review step is presented in Chapter 6.1.1.

As literature reviews are highly time-consuming, a large task force of approximately 25 members from multiple SELINA partners collaborated on this Task. The work was split

[3] https://database.esmeralda-project.eu/

according to their field of expertise and availability. With the aim to preferably follow an inclusive approach, we had regular biweekly to monthly task force meetings, where the status quo was presented and discussed, and the next steps were jointly agreed upon.

For the analysis, evaluation, and writing phase, the task force was divided into six sub-groups, assigned based upon meaningful combinations of different ETs, as identified from the reviewed literature. Their task was the reclassification of retrieved indicators to obtain a set of meaningful, standardised aggregated ecosystem indicators per ET group. One additional sub-group dealt with the review results from an EA perspective.

5.1 Search query

The T6.1 search query was developed to be executed upon the SELINA project internal literature database (Seguin et al. 2023). This literature database was developed as a collaboration between multiple SELINA WPs and partners in early 2023. It ensures consistency in terminology and understanding, and enables to base all SELINA literature reviews on the same paper population. The latter is based on Scopus and Web of Science (WoS) databases and was filtered to consist only of English-language scientific peer-reviewed publications[4] published from 2018 to 2022.

The development of the T6.1 search query was carried out involving a series of methodological steps:

- Definition of the scope of the search query;
- Identification of key concepts and pertinent keywords;
- Inclusion of synonyms, variations, and controlled vocabulary;
- Utilisation of Boolean operators (AND, OR, etc.) to establish logical combinations of keywords;
- Use of truncation and wildcards to capture word variations;
- Identification of relevant fields to be queried in the databases;
- Application of search filters and limiters to fine-tune search results;
- Continuous testing and refinement of the query to enhance its precision;
- Recording of the final query to ensure transparency and reproducibility;
- Processing, organisation, and management of harvested literature items to create; final literature database and supporting material.

A series of focused meetings took place, bringing together the task force to develop and refine the search query. These collaborative sessions played a crucial role in the ongoing development, incorporating insights from all task force members. Throughout these meetings, the query underwent several rounds of refinement, guided by the collaborative input of the team and its impact on the relevance of retrieved results. These extensive co-creation sessions aimed to ensure that the search query would meet the aimed requirements of the review objectives and its consistency. To facilitate collaborative progress and changes to the search query, an online Excel file with semi-automated functionality was set up. This Excel file had multiple tabs, each serving specific functions. The creation of the search query

[4] All literature items beyond scientific peer-reviewed publications (e.g. conference proceedings and book chapters) were excluded.

was subdivided into two parts (Fig. 1) based upon the research objectives outlined in the introduction: The first one focusing on the indicators used in scientific publications, where EC assessments are linked to ESs assessments, and the second one focussing on the indicators integrated in EC or ES(s) accounts.

Figure 1: Conceptual overview of search query setup.

Due to the task force members' common understanding of the WoS syntax, the latter was used representatively within the developmental phase of the search query. Within the online Excel table, individual tabs were dedicated to the development of these two sections of the query allowing for streamlined progress on the term selection, collection of synonyms, spelling considerations, and wildcards. These tabs also included variations with regard to the implementation of Boolean operators, different search logic and fields to query. In another tab, the relevant combinations from the two sub-queries were automatically combined. When formulating the search query, emphasis was placed on utilising, where suitable, the terminology and logic developed in the common procedure during the creation of the SELINA literature database (Seguin et al. 2023). To ensure the participatory development of search queries within the process, various query variants were voted on within the task force using an online survey (for an example see excerpt from the working material in Tables 1 and 2).

Table 1: Estimated number of papers retrieved for different search queries of query part 1, estimation based upon WoS.

ID	Estimated Nr. of Paper	Description	Operators	FIELDS
#1a	3'500	Ecosystem synonym, ecosystem service synonym, condition synonym and indicator synonym must be found somewhere in the FIELD topic	OR, AND	Topic
#1b	1'500	Ecosystem synoym must be found NEAR both, ecosystem service synonym AND condition synonym, in the FIELD topic AND indicator synonym must be found somewhere in the FIELD topic	OR, AND, NEAR/X	Topic
#1c	800	Ecosystem synonym, ecosystem service synonym and condition synonym must be found somewhere in the FIELDS title or author keywords AND indicator synonym must be found somewhere in the FIELD topic	OR, AND	Title, Author Keywords, Topic

Table 2: Estimated number of papers retrieved for different search queries of query part 2, estimation based upon WoS.

ID	Estimated Nr. of Paper	Description	Operators	FIELDS
#2a	850	Ecosystem synonym, the terms "condition*" or "service*", account synonym and indicator synonym must be found somewhere in the FIELD topic	OR, AND	Topic
#2b	400	Ecosystem synonym, the terms "condition*" or "service*", account synonym and indicator synonym must be found somewhere in the FIELD topic; some NOT terms are considered to remove "to account (for sth.)" etc.	OR, AND, NOT	Topic
#2c	15	Ecosystem synonym, the terms "condition*" or "service*", and account synonym must be found somewhere in the FIELDS title or author keywords AND indicator synonym must be found somewhere in the FIELD topic	OR, AND	Title, Author Keywords, Topic

5.2 Inclusion criteria

To systematically support and streamline the literature review screening process, a set of eligibility or inclusion criteria was developed (cf. Annex). Inclusion criteria are specific characteristics or parameters used to determine which publications are eligible for inclusion in the literature review. They serve as explicit guidelines, ensuring that the selected literature aligns with the aim and objectives of the study.

The elaboration of the inclusion criteria relevant to this review went through a careful process within the task force, involving multiple interactive meetings. Through collaborative discussions and iterative refinement, the task force members collectively shaped and fine-tuned the criteria to ensure precision and relevance in selecting literature. This dynamic and participatory approach enriched the criteria and fostered a shared understanding among team members. This enhanced the effectiveness of the inclusion criteria in guiding the literature review. A first set of inclusion criteria was developed for the first screening phase. Before the actual first screening phase, the inclusion criteria were tested in the first screening pilot run. For the full screening and review phase, slight adaptations were implemented, e.g. refining criteria and adding further description. Again, the criteria were tested in a full screening and review pilot run (for an example of on inclusion criterion see Table 3).

The final set of inclusion criteria (Annex) for the full screening and review included eight criteria. Seven were content-related, whereas the last criterion (“General requirements”) verified whether the publication fulfilled all three general requirements of the review: (i) Language: English; (ii) Year of publication: 2018 to 2022; (iii) Type: Peer-reviewed scientific article. In previous steps, the list of publications was already filtered for these aspects. However, this inclusion criterion was found to be necessary as, in a few instances, the original underlying databases (Scopus and WoS) wrongly assigned these kinds of metadata. For each of the inclusion criteria, an elaborated explanation and an example for inclusion and exclusion was provided to the task force in order to support and facilitate the decision process. At the same time, it made the process more transparent and objective.

Table 3: Excerpt from the list of inclusion criteria for the final full-text screening of the T6.1 review.

Variable	**Inclusion criteria**	***Example for inclusion***	***Example for exclusion***
Directional link from ecosystem condition to ecosystem service(s)	The paper links the assessment of ecosystem condition (or related concept which revolves around the quality of an ecosystem measured in terms of its abiotic and biotic characteristics) to an assessment of ecosystem service(s). Possible links or "relations" include the comparison of results from this indicator to the results of ES assessments, input-output relations, thus, the EC results are integrated into the ES assessment and the integration of both EC and ES results for a third purpose/ product.	*The study correlates the condition of an ecosystem to the ecosystem's delivery of ecosystem services, such as biomass production for human nutrition/ fodder or energy.*	*The study assesses the condition of an ecosystem in study area ABC and unrelated to the condition assessment, the delivery of (a) ecosystem service(s) in the same study area or elsewhere.*

5.3 Review template

To organise, systematise and analyse the content of the reviewed literature items, we developed a well-structured review template within MS Excel (see Annex). It represents a thoughtfully designed system, incorporating various functionalities aimed at achieving coherence, uniformity, consistency, and fostering a comprehensive data collection. The review template contains several tabular sheets (tabs), each tailored to specific aspects of the review that were structured with the help of notes, formulas, and macros to ensure an understandable, uniform, and comparable review and evaluation process. Each query field was annotated giving supplementary explanations or definitions on the type of information that needed to be collected there as well as the available options to choose from. As some fields required multiple selection of options, a code was included in the relevant tabs allowing (i) multiple selection of items from a drop-down list (without repetition) and (ii) deselection of items. Only a few entries allowed for free text to reach high inter-reviewer consistency and standardisation of entries.

The template was divided into several tabs: (1) a "readme" as well as six additional tabs with important and/or useful information for the reviewer on the completion of the template; (2) the full-text review results "t0_fullscreening" with pre-defined Boolean type yes/no answers to all inclusion criteria, and a corresponding auto-filled field with the decision on including/ excluding the literature item (based upon that decision, the list of literature items to include was automatically filled into the subsequent tabs and based upon the specific combination of answers to the inclusion criteria, in the subsequent tabs all columns considered irrelevant for the respective literature item were shaded) (cf. Chapter 5.2); (3) three different tabs where the reviewed information from the included papers was recorded. The latter were subdivided into (i) "t1_review" (short: t1), where the general information and characteristics of the publication had to be filled in; (ii) "t2_review_EC_indicator" (short: t2), where the information on EC per EC indicator were recorded; and (iii) "t3_review_ES_indicator" (short: t3), where the information on ES per ES indicator was captured. All fields were identified via a Q_ID (A.01 - C.25). In the first part (t1), the general information for each paper was stored in one single row, amongst which (i) the number of assessed EC indicators (B.01), and (ii) the number of assessed ES indicators (C.01). Based upon the integer value inserted in B.01 and C.01 the number of rows in t2 and t3 respectively were unblocked and automatically filled with the general information (A.01 - A.06). Hence, the information gathered in t2 and t3 respectively were completed by indicator. In tabs 1-3, some fields were only relevant for the literature items or indicators under specific conditions. To further enhance user friendliness, whenever, based on previous answers a column was considered irrelevant for a specific literature item or indicator, it was shaded using conditional formatting. This adaptiveness enhances efficiency by tailoring the review process to the specific requirements of each literature item or indicator.

Throughout the fields and predefined response options, we prioritised and build upon standardised methodologies, common classifications and definitions, amongst which the SEEA EA Ecosystem Condition Typology (ECT, UN 2021), which is a hierarchical typology for organising data on EC characteristics, the Common International Classification of Ecosystem Services (CICES v5.1[5], Haines-Young and Potschin 2018) and the ES method type according to the (ESMERALDA) MAES Method Explorer[6] (Burkhard et al. 2018).

5.4 Screening and review process

The literature screening and review process was divided into a two-step approach. Initially, all literature items were screened based on their title, authors, and abstracts, and each literature item was evaluated against specific inclusion criteria in an Excel table format. To validate this process and refine the criteria, a pilot first screening run involved reviewing ten literature items. The reviewers screened these items and provided feedback on document usability and inclusion criteria relevance. Subsequent updates were made based on this feedback, leading to the actual first screening round. Selected items marked as included through the first screening round had their full-text PDFs retrieved and shared among task force members via a shared Zotero[7] group folder.

The second phase combined full-text screening and review into a comprehensive process. The review template is outlined in Chapter 5.3. Every reviewer received a review template with his/her share of literature items. Hence, he/she thoroughly assessed each inclusion criterion based on the entire manuscript of each relevant literature item, ensuring a comprehensive evaluation. All literature items that met specific combinations of inclusion criteria (see Annex) entered the actual detailed review process. Again, before full implementation, a pilot phase

[5] https://cices.eu/

[6] https://database.esmeralda-project.eu/home

[7] https://www.zotero.org/

for the full-text screening and review involved screening and potentially reviewing two literature items each. This pilot phase played a crucial role in refining the process and evaluating the suitability of all relevant materials.

5.5 Data processing

To provide a clear and comprehensive overview of the data processing, in the following the processes are delineated separately for the phases: "Pre-review processing steps" and "Post-review processing steps." Generally, the software MS Excel (MS Office Standard 2019) and R (R version 4.2.2, packages: "readxl" (Wickham and Bryan 2023), "tidyverse" (Wickham et al. 2019), "writexl" (Ooms 2023), "dplyr" (Wickham et al. 2023), "ggplot2" (Wickham et al. 2016), "revtools" (Westgate 2019a and b), "tidyverse" (Wickham et al. 2019), "xlsx" (Dragulescu and Arendt 2020)) were used.

5.5.1. Pre-review processing steps

The developed search query (cf. Chapter 5.1) was translated into R syntax (R Core Team 2022, see Box 1) and applied to filter the SELINA database. That resulted in a total of 3430 literature entries. Subsequently, the R script combines and refines these filtered subsets to remove duplicate entries based on DOI and title using the "revtools" package (Westgate 2019a and b). The process includes refining the database further to remove irrelevant literature item types and journals with irrelevant foci e.g. those related to transport and civil infrastructure. After these steps, the literature items that remain (n_p = 2720) form the foundation of the database of literature items advancing into the first screening phase.

```
# query ~ 1a and 2a
selina %>%

filter(grepl(("ecosystem|forest|agroecosystem|wetland|heathland|grassland|urban|rive
r|lake|freshwater|coast|marine|transitional water|environment|natural capital"), title)
|
grepl(("ecosystem|forest|agroecosystem|wetland|heathland|grassland|urban|river|lak
e|freshwater|coast|marine|transitional water|environment|natural capital"), abstract) |
grepl(("ecosystem|forest|agroecosystem|wetland|heathland|grassland|urban|river|lak
e|freshwater|coast|marine|transitional water|environment|natural capital"),
author_keywords)) %>%
  filter(grepl("service|nature's contribution to people|nature's contributions to people",
title)|grepl("service|nature's contribution to people|nature's contributions to people",
abstract)| grepl("service|nature's contribution to people|nature's contributions to
people", author_keywords)) %>%
  filter(grepl("condition|state|status|health|integrity|function|qualit|capacit",
title)|grepl("condition|state|status|health|integrity|function|qualit|capacit", abstract)|
grepl("condition|state|status|health|integrity|function|qualit|capacit",
author_keywords)) %>%
  filter(grepl("indicator|variable|prox", title)|grepl("indicator|variable|prox",
abstract)|grepl("indicator|variable|prox", author_keywords)) -> data1
```

```
selina %>%

filter(grepl(("ecosystem|forest|agroecosystem|wetland|heathland|grassland|urban|rive
r|lake|freshwater|coast|marine|transitional water|environment|natural capital"), title)
|
grepl(("ecosystem|forest|agroecosystem|wetland|heathland|grassland|urban|river|lak
e|freshwater|coast|marine|transitional water|environment|natural capital"), abstract) |
grepl(("ecosystem|forest|agroecosystem|wetland|heathland|grassland|urban|river|lak
e|freshwater|coast|marine|transitional water|environment|natural capital"),
author_keywords)) %>%
  filter(grepl("condition|service", title)|grepl("condition|service", abstract)|
grepl("condition|service", author_keywords)) %>%
  filter(grepl("indicator|variable|prox", title)|grepl("indicator|variable|prox",
abstract)|grepl("indicator|variable|prox", author_keywords)) %>%
  filter(grepl("account", title)|grepl("account", abstract)|grepl("account",
author_keywords)) -> data2

query1 <- rbind(data1, data2)
```

Box 1: Final T6.1 search query executed in R.

For the pilot run of the first screening phase (cf. Chapter 5.4) a limited amount of papers was extracted from the database and processed to be distributed amongst the reviewers. After execution of the pilot run, various R packages like “dplyr” (Wickham et al. 2023), “revtools” (Westgate 2019a and b), “xlsx” (Dragulescu and Arendt 2020), and “readxl” (Wickham and Bryan 2023) were used to manage the distribution of literature items for the actual first screening phase. Each task force member received an individual set of literature items, with an additional five papers reviewed collectively by the entire group for consistency. Through the R script, a random segregation of literature items was enabled. Relevant columns, corresponding to the inclusion criteria relevant for the first screening phase (cf. Chapter 5.2) were added to the sets before they were exported to be distributed amongst the reviewers. The results from the first screening phase were collected and merged. They were categorised and filtered based on the reviewers’ results, and only entries that exhibited the relevant combinations of inclusion criteria were retained (n_p = 664).

For the pilot run of the full-text screening and review phase (cf. Chapter 5.4), again, a limited amount of papers was extracted from the updated database and processed to be distributed amongst the reviewers. The respective sets of literature items were exported and then, outside of the R environment, manually copied into the elaborated review templates (cf. Chapter 5.3). Eventually, the same general process was followed for the actual full-text screening and review phase. However, all relevant literature items were distributed in a way that each reviewer received an individual set of literature items, with an additional five papers reviewed collectively by the entire group for consistency.

5.5.2. Post-review processing steps

After the review results were submitted, the raw excel tables were manually checked for any general issues or inconsistencies (cf. Chapter 5.6.1). Afterwards, in the tabs 0 to 3 all “unnecessary” information and formatting was deleted. Subsequently, these tabs were exported into individual csv files. With R, these csv files were systematically processed and the individual tabs from each reviewer were merged in order to compile a clean, tab-specific (t0, t1, t2, t3) database of all review results. Next to the R base package, the script is based upon the "tidyverse" (Wickham et al. 2019), "readxl" (Wickham and Bryan 2023) and "writexl” (Ooms 2023) R packages for data manipulation, reading and writing Excel files, respectively. In the process, the R script goes beyond mere consolidation. It actively examines and corrects inconsistencies within the data, ensuring uniformity across all incorporated datasets. This involves modifying particular entries to align with standardised formats and cross-validating information for integrity.

Subsequently, R was used for relevant data manipulation, plotting, and analysis using various R packages such as “tidyverse” (Wickham et al. 2019), "readxl" (Wickham and Bryan 2023) and “ggplot2” (Wickham et al. 2016). The process involved filtering data based on specific criteria, employing techniques for categorising, evaluating trends and creating visualisations (such as bar plots). The script is structured to generate diagrammes on specific individual elements of the review as well as to illustrate the distribution and relationship of different elements across different fields, topics and ETs.

Furthermore, we have initiated a detailed examination to focus on column B.02, which contains free-text indicators for EC. The goal was to reclassify and aggregate these indicators to broader categories for greater consistency and clarity based on similar features, e.g. ecosystem characteristics, functions and state. In the process, also different variations in spelling or labels referring to the same concept, such as "PH," "pH," or "soil pH," had to be summarised or renamed to unify the representation of specific findings. Thereby, it was crucial to differentiate between distinct concepts, like "soil pH" and "water pH," which should not be conflated. Therefore, the indicator reclassification was done in subgroups working on the specific ETs covered in the individual Sections of Chapter 6.2.

5.6 Quality assessment

The need for quality assessments and consistency tests in literature reviews arises from the inherent subjectivity involved in evaluating and categorising the content of relevance (McHugh 2012). Multiple reviewers, each with their own (academic) background, field of expertise, perspectives and interpretations, may not always arrive at the same judgments when screening and reviewing items. Inconsistencies in the assessments made by the reviewers can compromise the integrity of the review process, have the potential to introduce bias and undermine the reliability of the results. Consequently, it is essential to systematically assess the consistency of the review team and address discrepancies aiming to maintain a high level of inter-rater reliability within the review process. In order to design the review process as transparently, consistently, and objectively as possible, several quality checks were implemented throughout the process.

5.6.1. Manual and semi-automated quality checks

Ensuring the integrity and reliability of the review process in a multi-reviewer literature review is paramount. To maintain the highest standards, a robust quality assurance system involving both manual and semi-automated checks have been implemented. Each phase of the review underwent manual inspection by a dedicated team of reviewers. The experts thoroughly scrutinised the included items to validate their alignment with the predefined criteria. Even though the largest share of the literature items was only reviewed by one reviewer, emphasising precision, the general validity of all review results was assessed prior to the evaluation, ensuring they meet the specified standards.

Complementing the manual checks, semi-automated procedures have been integrated into the R script. These semi-automated assessments streamlined the validation process. They enable rapid identification of potential discrepancies or irregularities within the included items, allowing for swift corrective actions. Next to the identification of gaps and errors, they focused on intra-reviewer consistency. Thereby, in particular, plausibility checks and cross-checks between the entries of the reviewer in the different columns and across different tabs were executed. Furthermore, an AI-supported author's analysis was performed using Research Rabbit (Cole & Boutet 2023, Sharma et al. 2022) to gain insights into possible connections and collaborations between different authors (see Box 2).

5.6.2. Fleiss' Kappa for consistency assessment

To assess the consistency among the reviewers in the task force, we employed Fleiss' Kappa, a widely recognised and well-established statistical measure (Kassambra 2019, McHugh 2012). Fleiss' Kappa is a robust and versatile statistic, especially suitable for situations involving multiple raters or reviewers, each of whom evaluates a set of items (Fleiss 1971, Fleiss et al. 2003), in our case, scientific publications. To enable the consistency assessment, we included two publications in the set of publications to be reviewed by each reviewer (team). These individual screening and review results of these two publications were excluded from the manual and semi-automated quality checks outlined in the previous section in order to guarantee an unbiased assessment. The key advantages of using Fleiss' Kappa include:

- Suitability for multiple reviewers: Fleiss' Kappa is designed to handle situations where multiple reviewers assess the same items, making it particularly relevant for our study, where a dedicated share of scientific publications was screened and eventually reviewed by each reviewer (team).
- Categorical Data: Fleiss' Kappa is well-suited for categorical or nominal data.
- Adjustment for Chance Agreement: It considers the possibility of agreement occurring by chance, providing a more robust measure of inter-rater reliability.

For our consistency assessment, we focused on the Inclusion Criteria corresponding to the fields in the "t0" sheet from our review template. These criteria defined the full-text screening process, involving specific binary judgments for each paper, indicating whether it met the predefined Inclusion Criteria (cf. Chapter 5.2). The binary judgments for each reviewer were used as the basis for the consistency calculation. Fleiss' Kappa was calculated to quantify the level of agreement among multiple reviewers for the binary judgments on each of the Inclusion Criteria. The formula for Fleiss' Kappa considers the observed agreement and the agreement expected by chance, providing a comprehensive measure of inter-rater, aka inter-reviewer, reliability (Fleiss 1971, Fleiss et al. 2003, Kassambra 2019). The calculation results in a Kappa coefficient that ranges from -1 to 1, where negative values indicate less agreement than expected by chance, values close to 0 suggest agreement similar to what would occur by chance, and positive values represent greater agreement than expected by chance. This method allowed us to systematically evaluate and address potential inconsistencies, ensuring the robustness and validity of our literature review.

6. Results

The results section is structured into three main parts: firstly, presenting general findings that include outcomes from the scientific review as well as methodological insights; secondly, detailed results focussing on the reviewed EC and ES indicators categorised by ET; and finally, a description of the outcomes related to the EA framework.

6.1 Methodological findings

6.1.1. PRISMA

Our search query was executed on the SELINA literature database, followed by a comprehensive cleaning process (cf. Chapter 5.5.1), involving cleaning and refining the database to eliminate irrelevant literature item types and journals with unrelated focuses. Despite these measures, 2 720 literature items remained that moved into the first screening phase (Fig. 2). Through the first screening phase, 2 062 items were excluded. Subsequently, for the remaining 664 items, PDFs containing the full text were obtained. Only in 5 instances, we were unable to access the complete text. As a result, 659 literature items proceeded to the full-text screening phase. From this stage, 142 items met the relevant inclusion criteria and were eventually incorporated into the review.

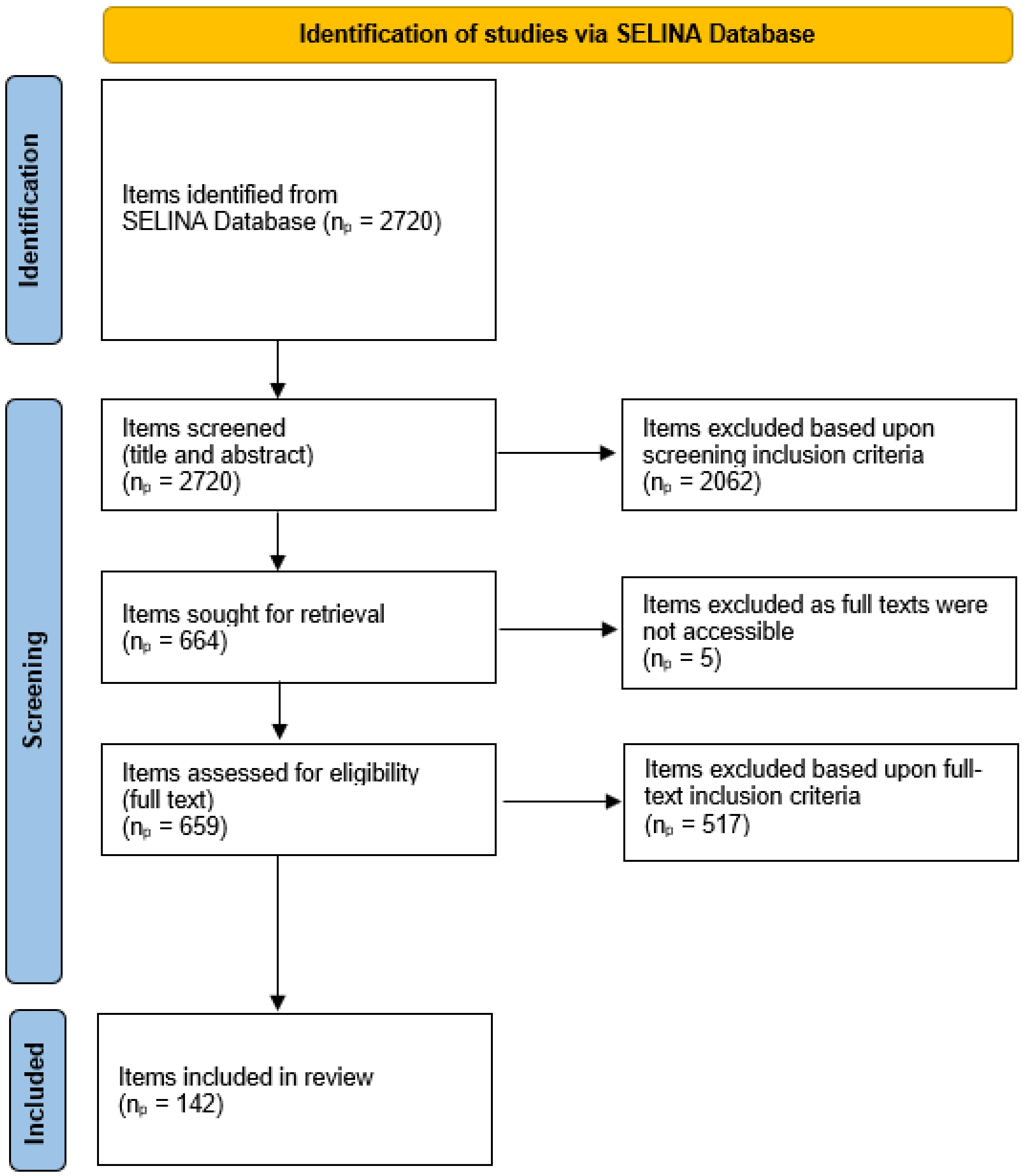

Figure 2: PRISMA flow diagram of the review (adapted based upon Page et al. 2021).

6.1.2. Fleiss' Kappa Consistency

The Fleiss' Kappa consistency test was applied to assess the consistency of our reviewer team's across two distinct groups of publication. The first 'set' (Set 1) consisted of both publications that were screened by all reviewers, providing an overall evaluation of inter-rater reliability for this subset of the review. Subsequently, the analytical approach was further refined (Set 2) to focus solely on the publication that had garnered a consensus among a significant majority of 21 out of 23 reviewers, marking it as relevant for our review. By separately examining these two groups, our aim was to gain insights into the consistency of reviewer assessments, with a particular emphasis on understanding the reliability and agreement in the screening and inclusion decisions.

Table 4: Fleiss' Kappa assessment.

	Set 1	Set 2
Kappa	0.706	0.856
z	63	52.7
p-value	<0.0005*	<0.0005*

*p-value indicates Fleiss' Kappa coefficient is statistically significantly different from 0.

In the analysis involving both publications (Set 1), there is already a notable level of agreement among the 23 raters, with a Kappa of 0.706 (Table 4), which is considered moderate to substantial (Kassambra 2019). In the second analysis (Set 2), focusing on the publication that was screened to be included in the review, the level of agreement is even higher, with a Kappa of 0.856. Both analyses show statistically significant agreement with low p-values and high z-scores. The large majority (21 out of 23) of reviewers were in strong agreement that this single paper is relevant for the review. The screening results for the included publication show exceptionally high agreement among the reviewers, indicating strong consensus on its relevance. This level of agreement is even higher than the already substantial agreement observed when considering both papers. These results reinforce the validity and robustness of the screening process.

Research Rabbit is an AI-supported literature mapping tool, developed in 2021 (https://researchrabbitapp.com, Cole & Boutet 2023), that aims at supporting the process of an unstructured literature review and exploring relevant papers (Sharma et al. 2022). Furthermore, it provides quick visualisations in the form of network graphs that depict the selected works, related works, or author connections. Once publications are gathered in a collection, ResearchRabbit's algorithm opaquely generates recommendations and graphs.
For this scientific review, the potential benefits that this tool provides have not been used except for the author's network "explore people - these authors". A list of all literature items that have been marked as "included" during the review process, outlined in Chapter 5, have been uploaded into the tool.
The results show that 869 authors have contributed to writing this share of scientific papers. Automatically, a network graph for the connections of 57 authors was generated (see Fig. 3). Regrettably, the selection of recorded authors was not transparent and could not be modified either. Each dot in the network graph represents an author and its size is determined by its collaborations. Each line represents a co-authorship relationship, meaning the thicker a line the more papers have been co-authored together. The graph view may help to understand how papers or authors respectively are linked in a network (https://researchrabbitapp.com).

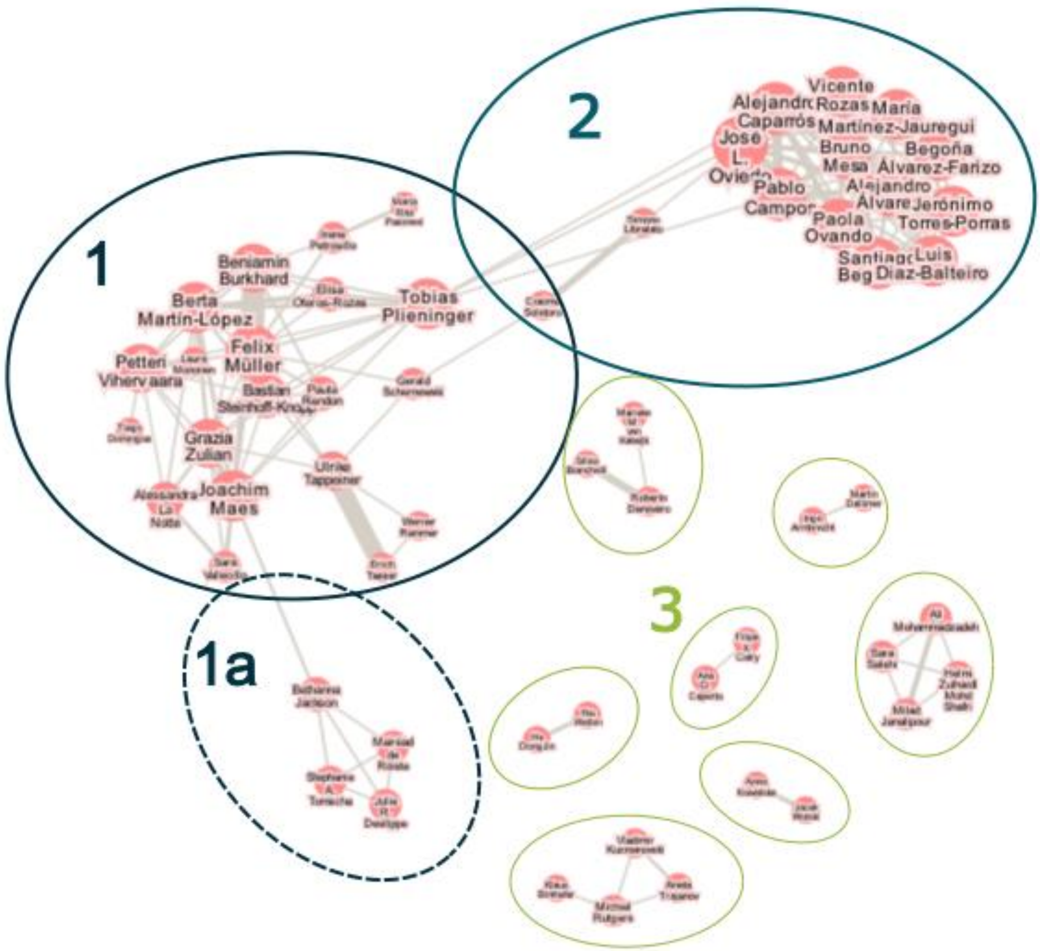

Figure 3: Network of 57 relevant authors generated with ResearchRabbit.

In this case, we identified two large clusters of authors (1 and 2) in the network with intensive collaboration, loosely linked by a few authors. Besides, there were seven mini-clusters (3) each consisting of two to four authors without connection to the main network. Cluster 1 stretches around its most prominent members Benjamin Burkhard, Felix Müller, Berta Martín-Lopez, Petteri Vihervaara, Grazia Zulian, and Joachim Maes. For decades, these authors have been intensely involved in the development of the ES concept and/or have collaborated in different research projects. Benjamin Burkhard as project coordinator of SELINA was surrounded by colleagues based in Germany and collaborations from previous common research projects. Joachim Maes, Grazia Zulian and closely connected colleagues represented the input from the European Commission's Joint Research Centre (JRC), which is likewise involved in SELINA and which has initiated the Mapping and Assessment of Ecosystems and their Services (MAES) process in Europe. Through Joachim Maes, cluster 1a with four authors affiliated with the Victoria University of Wellington, New Zealand, linked to the group and revealed a connection based on a collaborative effort in the SEEA EA EC working group.

The links to cluster 2 were mainly established via Tobias Plieninger, affiliated to the University of Göttingen and Kassel, Germany, who has no direct connection to SELINA or precursor projects but works on human-environmental interactions and ESs in agricultural systems and sustainability transformations.

Cluster 2 consisted of 14 authors of which 12 had close relations or affiliations to the Spanish National Research Council and show very close collaborations.

The separate subgroups in cluster 3 included authors from diverse nationalities and academic backgrounds. This fragmentation could be read as a mirror of the open approach that was chosen for the choice of synonyms when creating the search query for the review. Not only papers explicitly using a narrow ES' terminology were meant to be found, but also more specialised papers addressing e.g. EC for one specific ES were included. Cluster 3 compiled these rather "side studies" that were nevertheless highly relevant as they added new, useful indicators to the toolbox.

ResearchRabbit seems to be a useful initial tool, if one aims at exploring the literature landscape to get a first overview or identify highly relevant papers or connections related to a specific topic. However, when analysing the resulting author's network graph, the drawbacks and limitations prevailed. The record of authors was incomplete and untransparent. As Cole and Boutet (2023) detected, the author's visualisation maps often had trouble with author disambiguation and some even appeared twice in the plot. In addition, we also spotted incorrect affiliations in this experiment. It was important for us to stay informed about the latest methodological developments and give promising tools a try to potentially facilitate the work. However, in this case we concluded that ResearchRabbit was not (yet) a support when it came to a systematic review proceeding.

Box 2: Authors' network as per ResearchRabbit

6.2 General findings related to content

In the following, we present some general findings from the review, providing information on the level of the included publication and some first results on the specific of the assessed EC and ES indicators.

From the corpus of 659 papers that were included in the full-text screening phase, 142 publications were eventually included in the full review. A list of the reviewed papers can be found in the Annex. 23 papers (15.5%) were marked as addressing EA, while the other studies were mainly assessment (n_p = 129) and/or mapping studies (n_p = 56). The 22 accounting papers were reviewed once again by an expert group on accounting. In this validation phase, 12 papers were subsequently identified as being no real accounting studies (see Chapter 6.3 for details). However, for the indicator analyses in the ET groups (cf. Chapter 6.2), these papers continued to be included.

As we considered a limited time period, the trend in the number of papers published per year could not be considered meaningful. In 2018 and 2020 around 20 papers were found. For 2019 and 2021 around 30 papers were found and 40 papers from 2022 were included in the review (Fig. 4). Due to the short time period, it is impossible to deduce whether this strong increase in 2022 was a coincidence, an aftermath of the Covid-Pandemic or a content-related increase e.g. because of a motivation arising from the global developments with regard to SEEA EA, the publication of the EU biodiversity strategy for 2030 in 2020, or the EU-wide MAES and KIP INCA advancements.

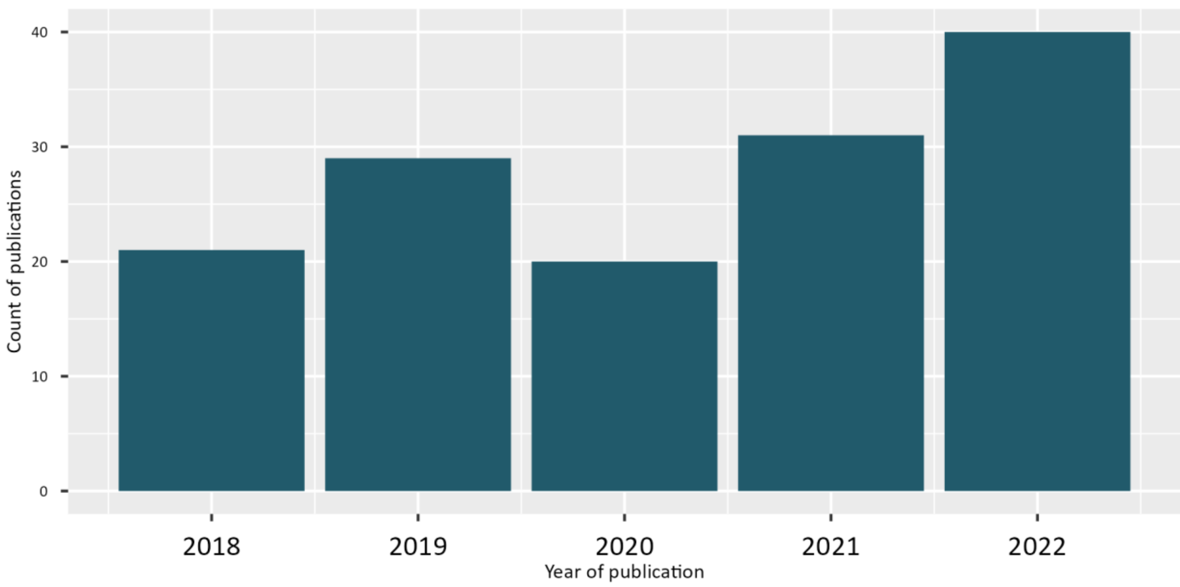

Figure 4: Year of publication of all reviewed publications.

With regard to the spatial scale of the assessments, a clear tendency towards regional (n_p = 69) and local (n_p = 63) studies could be detected (Fig. 5). The national and multinational scale (both n_p = 13) were less commonly used. The majority of the studies referred to Europe and/or European countries (n_p = 51). Looking at individual countries, China was studied the most (n_p = 29). Antarctica was the only continent without any study site and Australia was only addressed once in a comparative exotic study on the removal of faecal pollutants through wetlands in Victoria, Australia and California, United States (Huang et al. 2018).

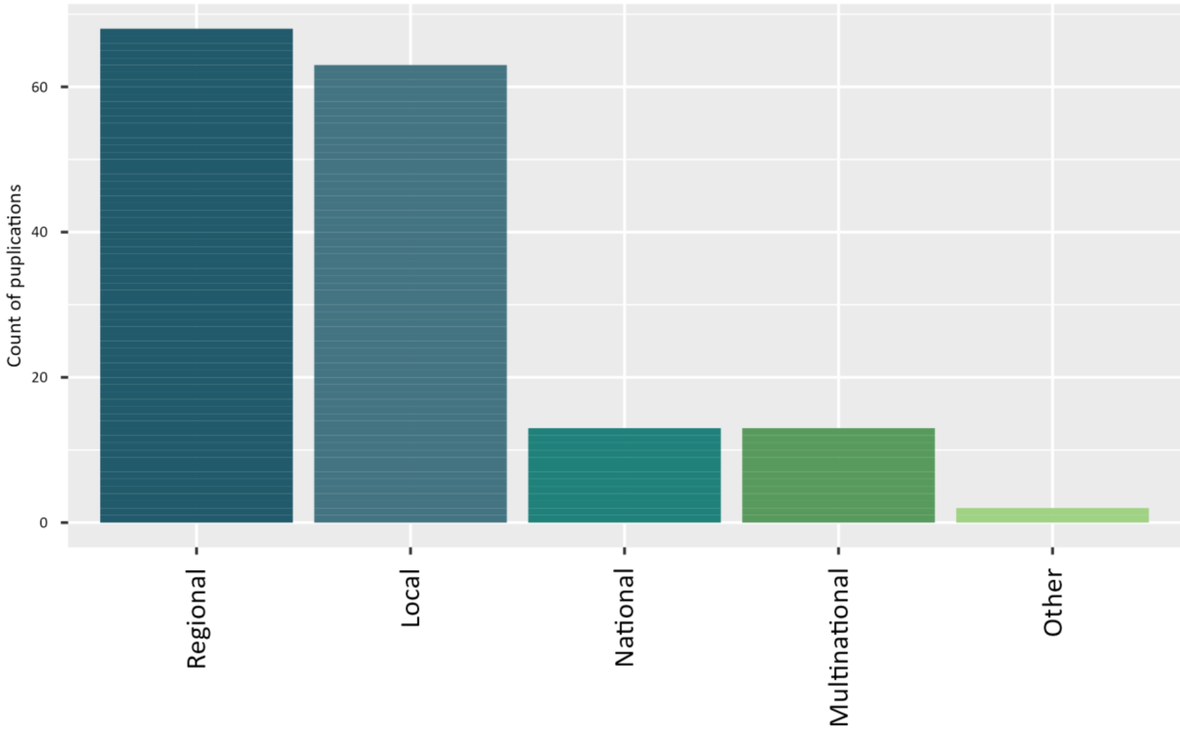

Figure 5: Spatial scales of ecosystem condition and service applications considered in reviewed publications. Review aspect allowed for multiple responses.

In total, 1745 indicators have been identified in this review. Hereof, 908 have been identified as EC indicators and 837 as ES indicators following the author's evaluation. Statistically, it follows that one publication addressed on average 6.4 EC indicators (range = 0 - 58, standard deviation (sd) = 8.7) and 5.9 ES indicators (range 0 - 63, sd = 8.9).
The EC indicators were predominantly obtained through field data, while the source of input data for ES indicators is more equally balanced with field data and literature being the most relevant input data sources.

Approximately two thirds of the EC indicators have been specifically linked to ESs. For 333 EC indicators, they were directly integrated into the ES assessment (Fig. 6, e.g. Bae et al. 2021, Riegels et al. 2020, van Leeuwen et al. 2019, Zhao et al. 2022). For 198 EC indicators, the results of the EC assessment were quantitatively compared to ESs (e.g. Li et al. 2018, Måren et al. 2021) and for 80 indicators the results were qualitatively compared to ESs (e.g. Ding et al. 2022, Feng et al. 2022). For 97 EC indicators the assessment was conducted independently from the ES assessment and the results were combined afterwards into a new product for a third purpose, e.g. into an ecosystem health condition assessment (e.g. Fang et al. 2021, Mallick et al. 2021) or for restoration, conservation, or land use planning (e.g. Edrisi et al. 2020, Marull et al. 2021).

Regarding the relation of the link between EC and ES indicators, predominantly positive relations (n_i = 155) were identified, followed by negative relations (n_i = 71), a high share of unclear relations (n_i = 60) and no relations (n_i = 28); for 30 EC indicators multiple options were chosen, which in most cases was due to a link to >1 ES and hence different results of the link depending on the ES.

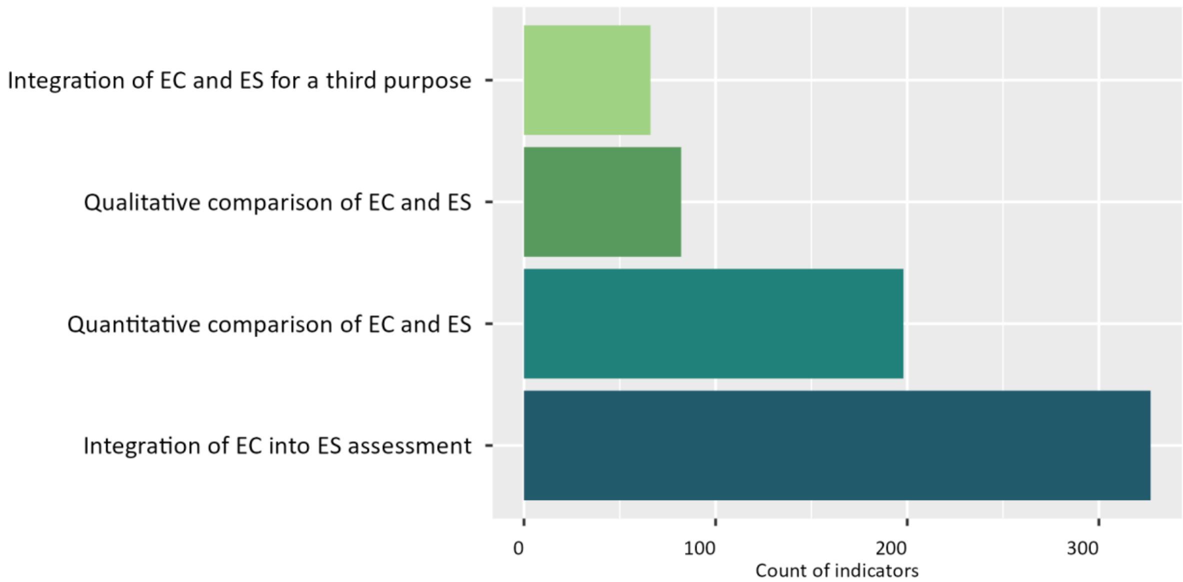

Figure 6: The nature of relation for the EC indicators that are linked to specific ecosystem service(s). Review aspect allowed for multiple responses.

For the EC indicators, we additionally differentiated whether the used indicators were aggregated into a composite indicator (UN 2021). Here, 424 indicators were recorded to be aggregated into 69 composite indicators. These composite indicators could consist of 2 up to 58 individual indicators (e.g. Korpilo et al. 2018, Tasser et al. 2020).

The ES indicators that were assessed in the reviewed publications, could predominantly be classified into CICES v5.1 section regulation & maintenance (Biotic). More than 600 of the 836 ES indicators were related to that section (Fig. 7). In this context in particular the ES *2.2.6.1 regulation of chemical composition of atmosphere and oceans*; *2.2.1.3 hydrological cycle and water flow regulation (including flood control, and coastal protection)* and *2.2.2.3 maintaining nursery populations and habitats (including gene pool protection)* were commonly assessed. The distribution of ES indicators from the cultural (biotic) and provisioning (biotic) section was rather balanced ($n_{i \text{ for cultural (biotic)}}$ = 235 and $n_{i \text{ for provisioning (biotic)}}$ = 237). For these sections, the ES indicators were commonly related to the ES *1.1.1.1 cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes* and *3.1.1.1 characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions*.

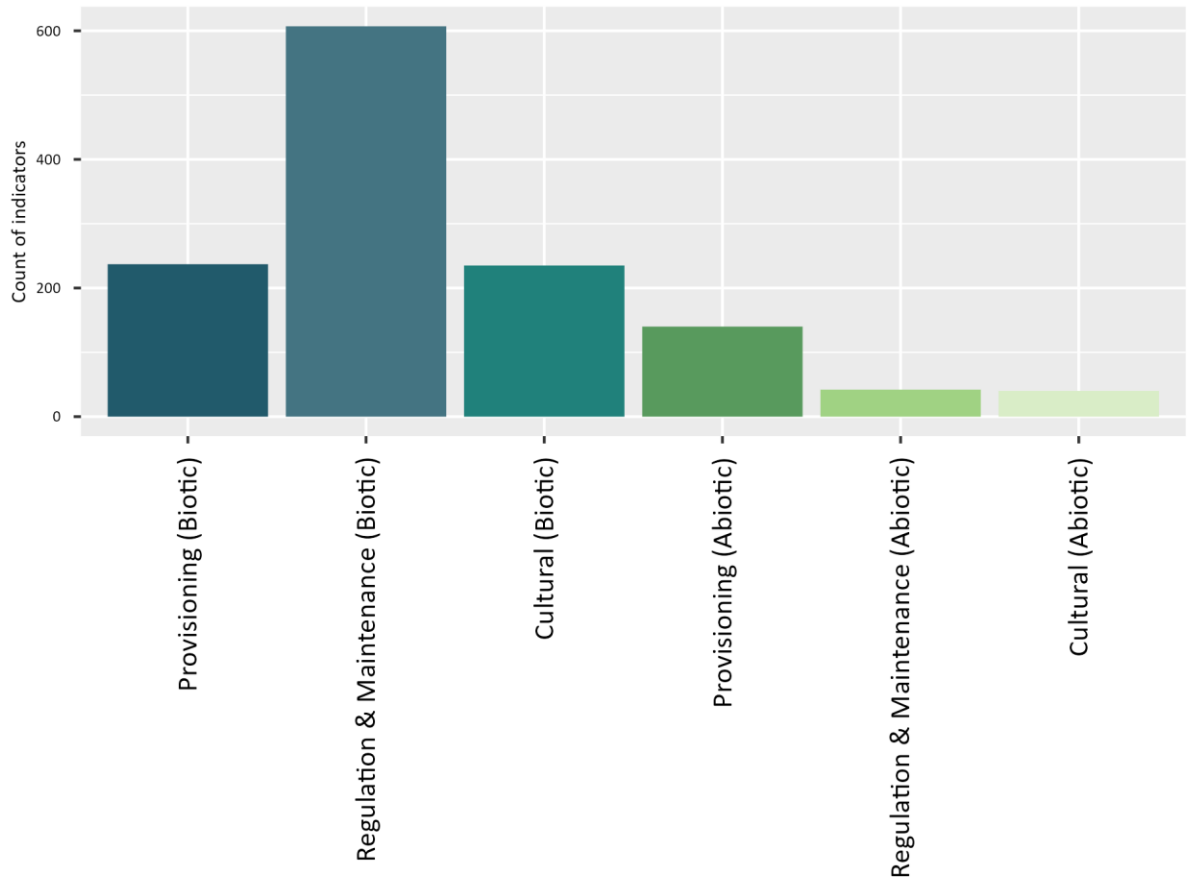

Figure 7: Ecosystem services indicators according to CICES v5.1 section. Review aspect allowed for multiple responses.

6.2.1. Terminology and classifications

One clear challenge was the heterogeneity and inconsistency in the used terminology. The review query was structured in a broad way allowing for the inclusion of papers referring to the ES concept as well as applying the nature's contributions to people terminology. Although the search approach was rather broad including a large range of synonyms from different terminology, it is interesting that none of the included papers referred to the concept of Nature's contributions to people (NCP), but 90% (n_p = 128) of the authors proactively categorised the study as related to the ES concept.

Different classification systems exist to organise the ET (e.g. MAES, EUNIS, IUCN, CORINE, LULUCF) as well as the ESs (CICES v5.1) in a structured way. In most of the reviewed publications the used ET classification was not specified (Fig. 8). However, when it was specified, mostly none of the predefined typologies were recorded but the classification was of another kind, e.g. a national ecosystem typology or a typology related to habitat or biotope mapping. From the international classifications, the CORINE LULC was predominantly recorded.

As a common underlying classification system for the ESs, all reviewers were asked to translate the addressed ES in the reviewed documents into CICES v5.1 categories.

For each publication that assessed ES, it was recorded whether it addressed the capacity/ potential of an ecosystem to provide ES; the ES demand, thus, the need for specific ES by society, particular stakeholder groups or individuals and/or the (actual) usage of ES, i.e. the flow of ES or the amount of an ES that is actually mobilized in a specific area and time (Vallecillo et al. 2019; Burkhard & Maes 2017). Most studies concentrated on ES potential (n_p = 79), followed by ES flow (n_p = 53), and fewer analysed the demand side (n_p = 8). For 13.4% (n_p = 19) of the studies, it was unclear what aspect of the ES(s) was assessed and hence it could not be assigned to any of these dimensions.

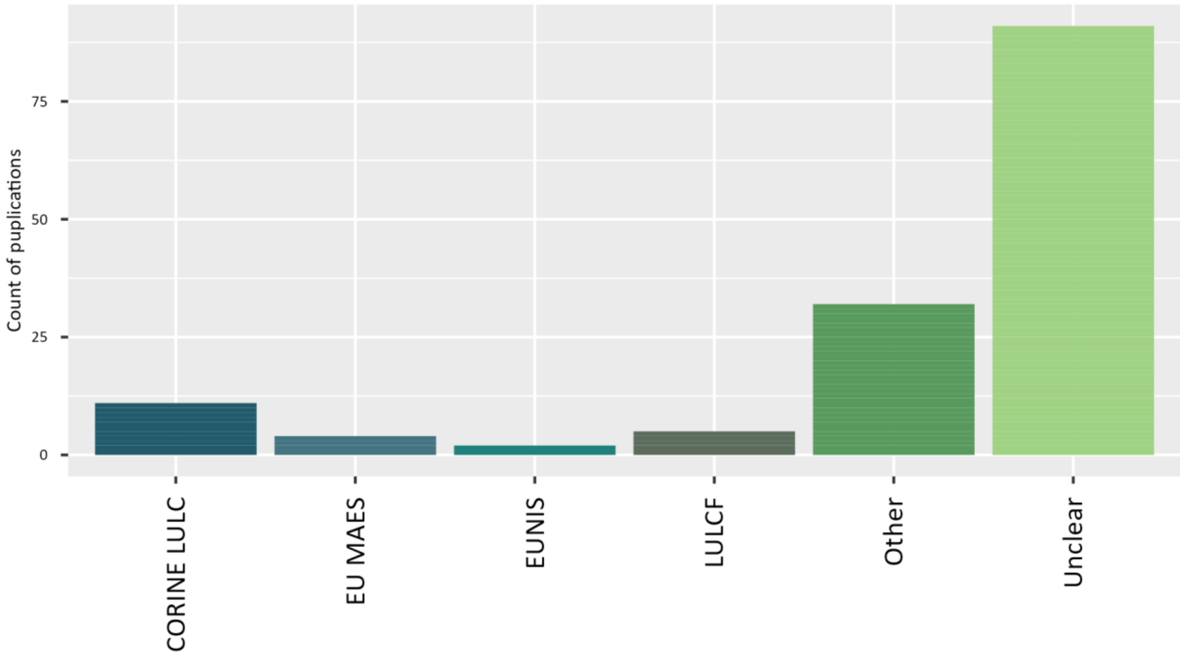

Figure 8: Ecosystem type classification used in reviewed publications. Review aspect allowed for multiple responses.

6.3. Results per ecosystem type group

In the following the review results on the EC and ES indicators are described per recorded ET. As the number of indicators applied on the different ETs varied (as an example, see Fig. 9), subsections were created, each covering one or multiple ETs together.

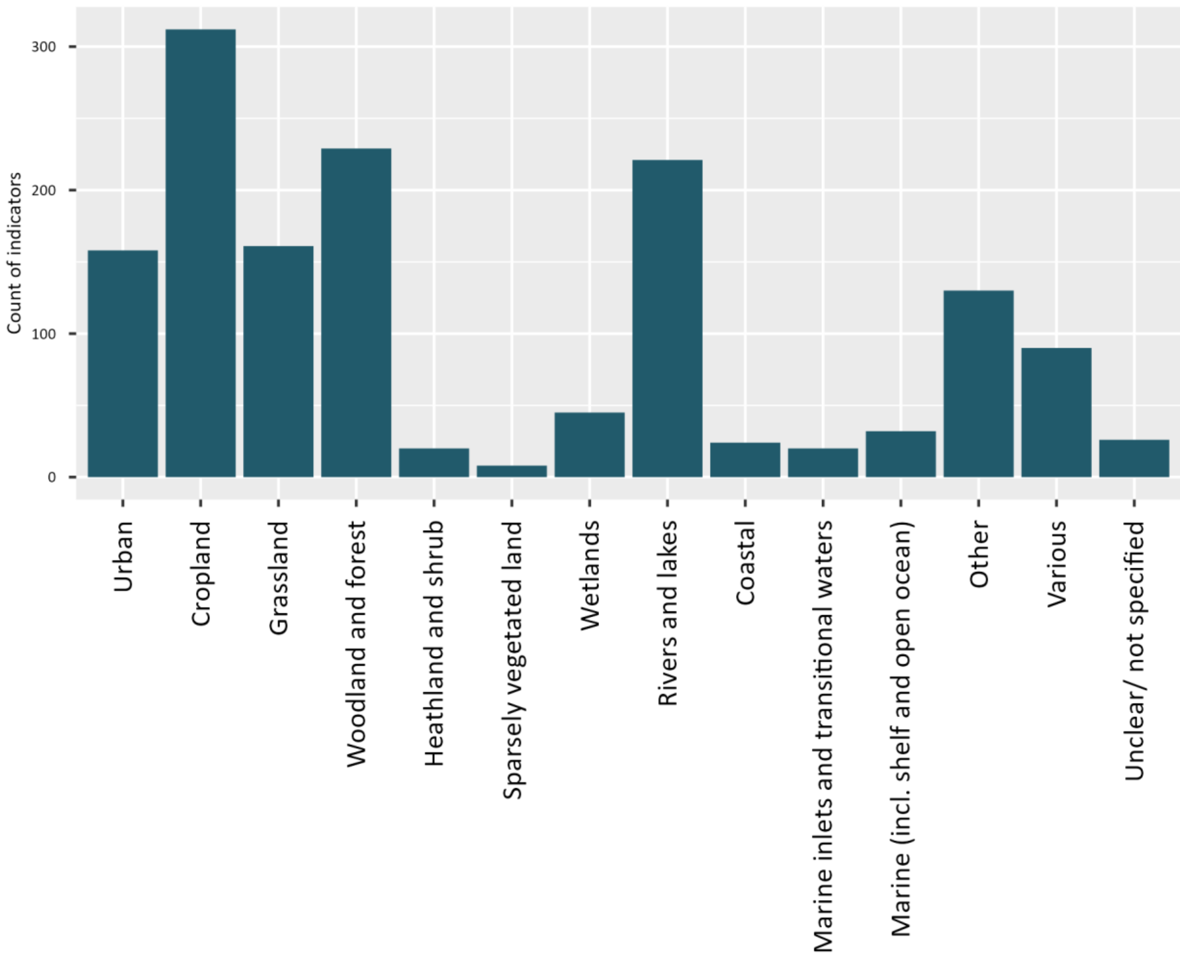

Figure 9: Overview of ecosystem condition indicators per recorded ecosystem type. Review aspect allowed for multiple responses.

6.3.1. Urban

Lead Chapter authors: Chiara Cortinovis, Jarumi Kato Huerta, Mark Mansoldo and Helena Duchková

Thirty out of the 142 publications assessed in the review focused on urban ecosystems. These included 158 EC indicators and 105 ES indicators. In 25 of these publications, EC indicators were linked to the assessment of ES with an explicit directional link.

6.3.1.1. Ecosystem condition indicators

Among the 158 EC indicators associated with urban ecosystems, 70 were part of a composite indicator, and 20 were composite indicators themselves. The individual EC indicators were clustered into 54 categories. The most assessed categories of EC indicators in studies focusing on urban ecosystems (Fig. 10) were "landscape and habitat distribution pattern" (n_i = 26) and "concentration of elements and compounds" (n_i = 19). The former category includes indicators such as landscape metrics (e.g. patch density, edge density, cohesion index) and other indicators related to ecosystem fragmentation (e.g. isolation, habitat fragmentation). The "concentration of elements and compounds" category gathers all indicators related to the concentration of chemicals in water, air, and soil, such as heavy metals and other pollutants, but also organic carbon. Other recurring categories of EC indicators include soil properties (e.g. bulk density, sand and clay content, available water capacity), species richness or diversity, and the extent of land use or land cover classes, including vegetation and impervious cover. Condition indicators related to tree structure and vegetation density were also among the most frequently studied (n_i = 5, for each category).

Overall, considering the ECT classification proposed by the SEEA-EA, condition indicators in the class "landscape/seascape characteristics" were the most commonly adopted in the reviewed publications on urban ecosystems. However, in the large majority of cases, the authors did not explicitly mention the specific ECT class to which the indicators belong.

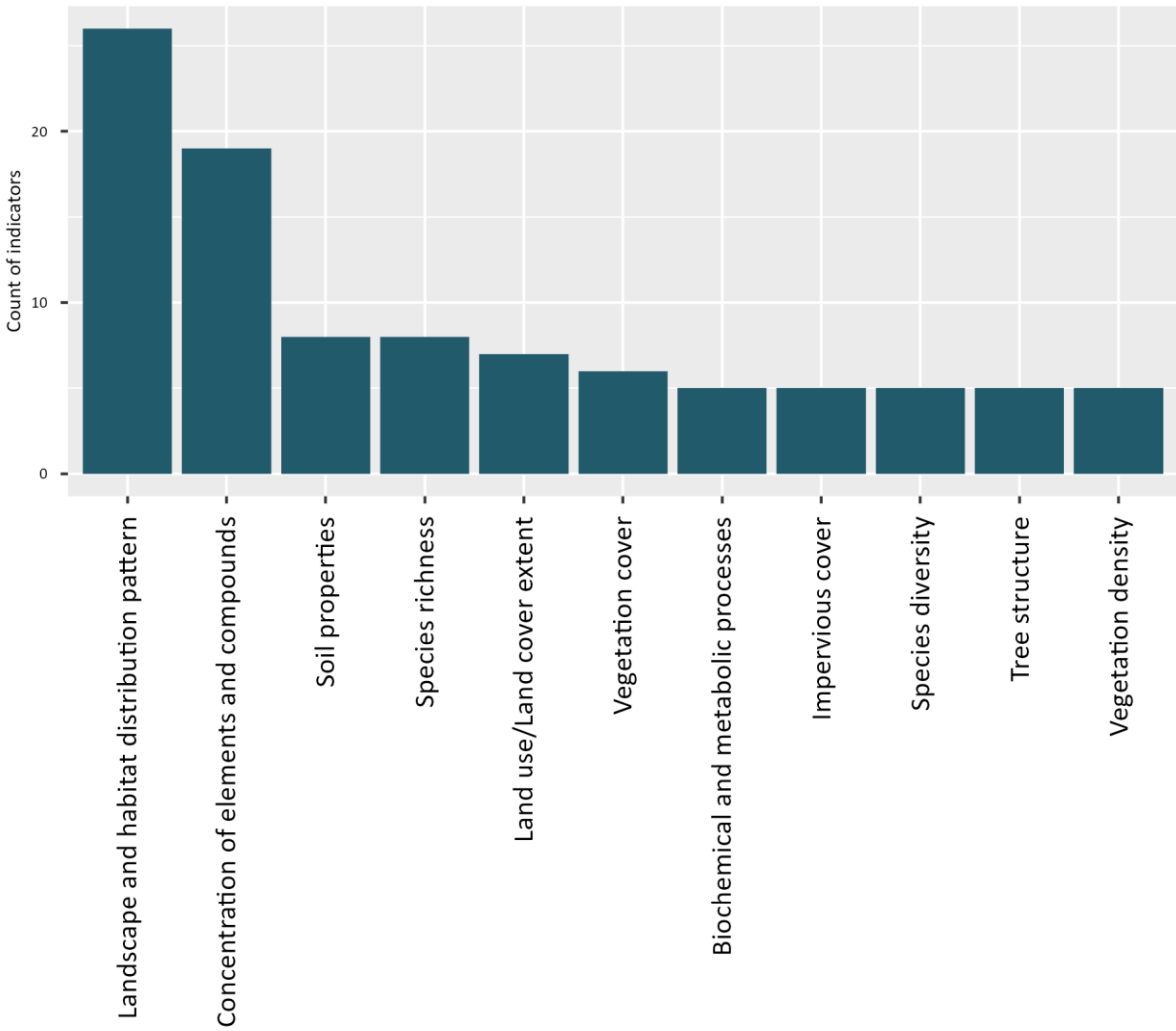

Figure 10: The 10 most frequently assessed aggregated ecosystem condition indicator classes in urban ecosystems.

The methodology applied to assess urban EC is frequently direct quantification (n_i = 88), but many studies also used input data to calculate an index (n_i = 63). Less frequent is the processing of input data through models or algorithms to assess EC (n_i = 13). The most common input datasets were, by far, field measurements, followed by remote sensing data, statistical data, and other processed spatial data (Fig. 11). Secondary data from the literature and expert opinions were not commonly applied to assess EC in the analysed studies.

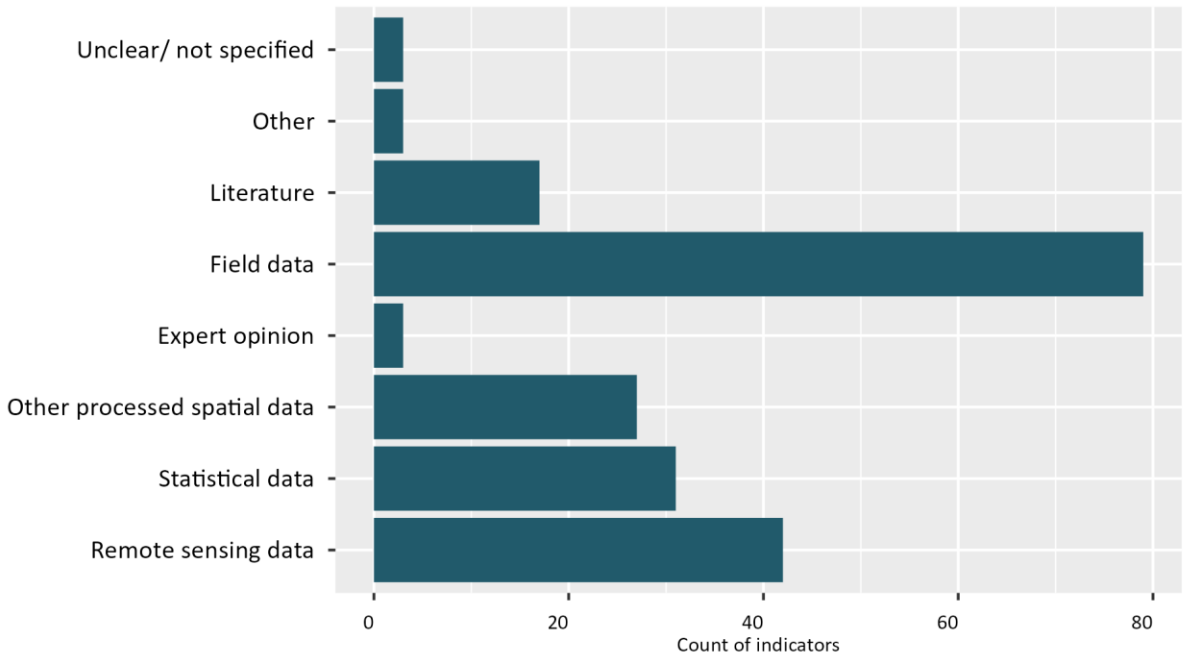

Figure 11: Input data used to assess ecosystem condition indicators applied to urban ecosystems. Review aspect allowed for multiple responses.

As a result of the input data and the methods applied, most EC indicators were – to some extent – spatially explicit (Fig. 12). However, in the majority of cases, they were aggregated at ecological or administrative scales. EC indicators adopted in fully spatially explicit assessments were only 32. More than 65 EC indicators related to urban ecosystems were not spatially explicit.

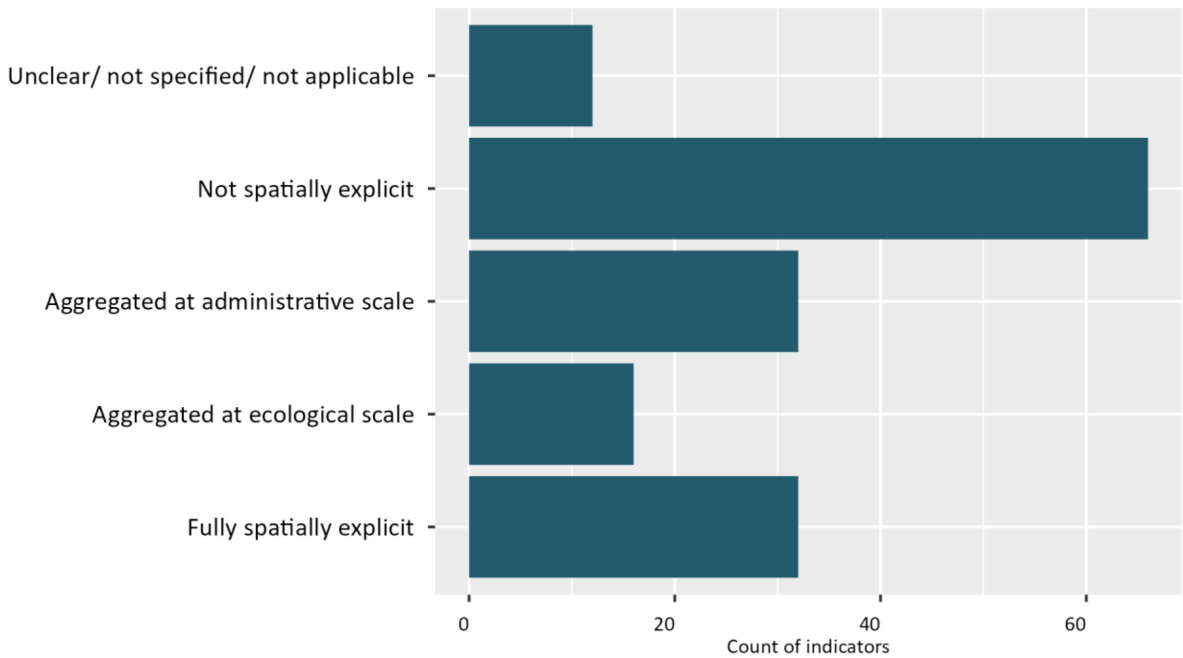

Figure 12: Spatial resolution of ecosystem condition indicators applied to urban ecosystems.

The vast majority of EC indicators found in the reviewed publication (n_i = 142) were not associated with any reference level or reference condition. Only 16 indicators were linked to a reference level, in most cases (n_i = 11) based on a natural reference condition (i.e., undisturbed or minimally disturbed state) and in three cases based on policy targets.

6.3.1.2. Ecosystem service indicators

The ES indicators included in the reviewed publications on urban ecosystems covered 33 different ESs as classified in CICES v5.1. The most frequently addressed ES is *2.2.1.3 hydrological cycle and water flow regulation*, assessed by more than 30 out of 105 ES indicators. Overall, addressing ESs in the CICES v5.1 section "regulation and maintenance" dominated in urban ecosystem studies (Fig. 13), particularly the *2.2.6.1 regulation of chemical composition of atmosphere and oceans*, and the *2.2.6.2 regulation of temperature and humidity* (n_i = 14 each). Indicators of cultural ESs were the second most frequent category. Most of them focused on *3.1.2.4 characteristics of living systems that enable aesthetic experiences* (n_i = 12) and *3.1.1.1 characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions* (n_i = 11). The CICES v5.1 section provisioning ESs was the least frequently biotic section addressed in the indicators related to urban ecosystems. Within this group, the ES most commonly assessed was *1.1.1.1 cultivated terrestrial plants grown for nutritional purposes* (n_i = 10).

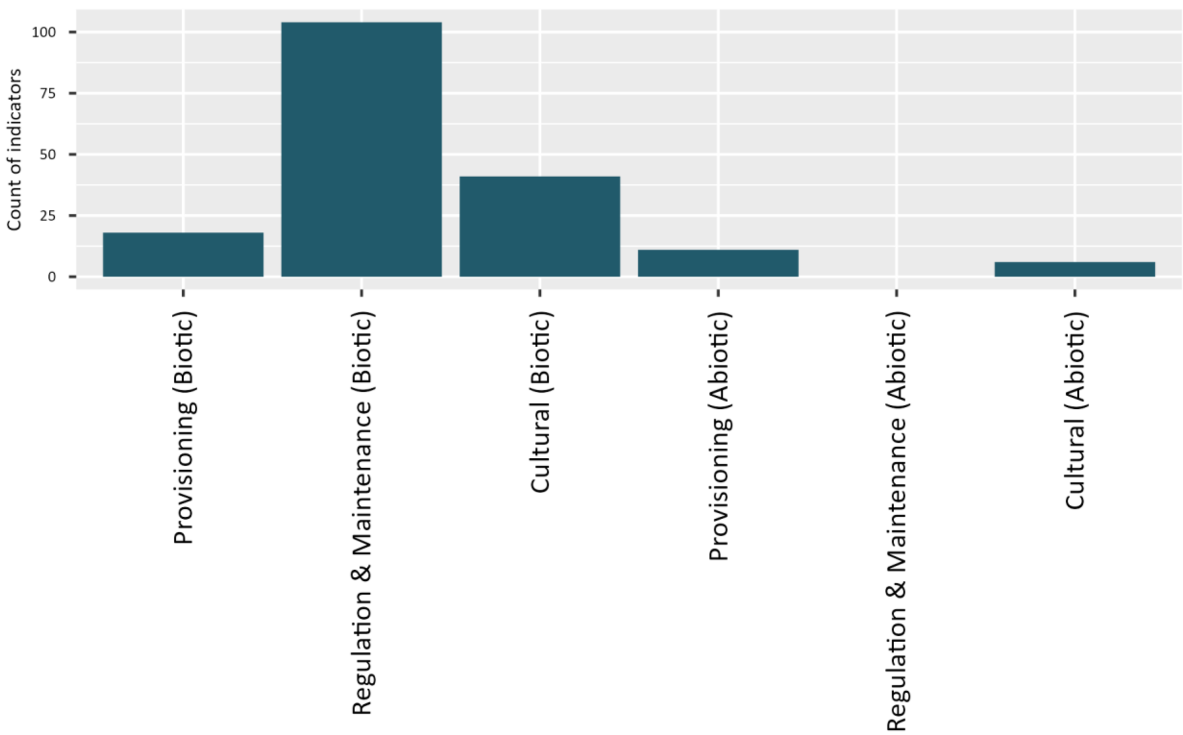

Figure 13: Ecosystem services indicators identified and classified according to CICES v5.1. Review aspect allowed for multiple responses.

The methods most commonly adopted to assess ES indicators were biophysical (Fig. 14), specifically spatial proxy (n_i = 31) and statistical models (n_i = 16). Among biophysical methods, field observations were mentioned thirteen times. Among economic methods, the only one applied for the assessment of ES with regard to urban ecosystems was value transfer/benefit transfer (n_i = 28). Finally, a variety of socio-cultural methods emerged, including deliberative assessments (n_i = 8), and participatory GIS (n_i = 4).

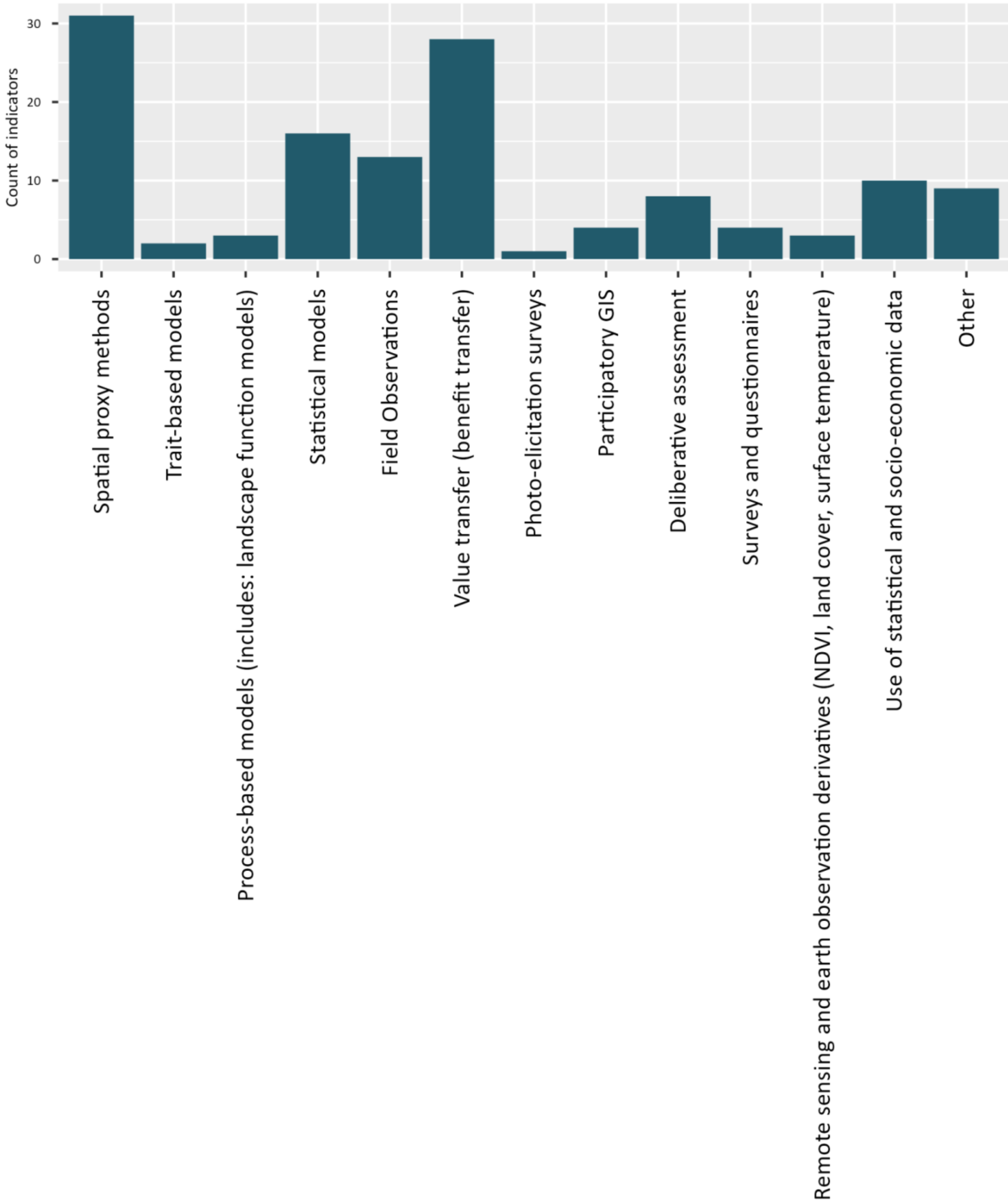

Figure 14: Methods applied to assess ecosystem service indicators in urban ecosystems. Review aspect allowed for multiple responses.

The variety of methods to assess ES indicators in urban ecosystems is reflected by the fact that several types of input data were frequently applied. The most common (Fig. 15) were remote sensing (n_i = 35) and secondary data from the literature (n_i = 34), but statistical data and other processed spatial data were also highly common (n_i = 32 each). This distribution was similar to the overarching trend. Twenty-five indicators included input data from field measurements.

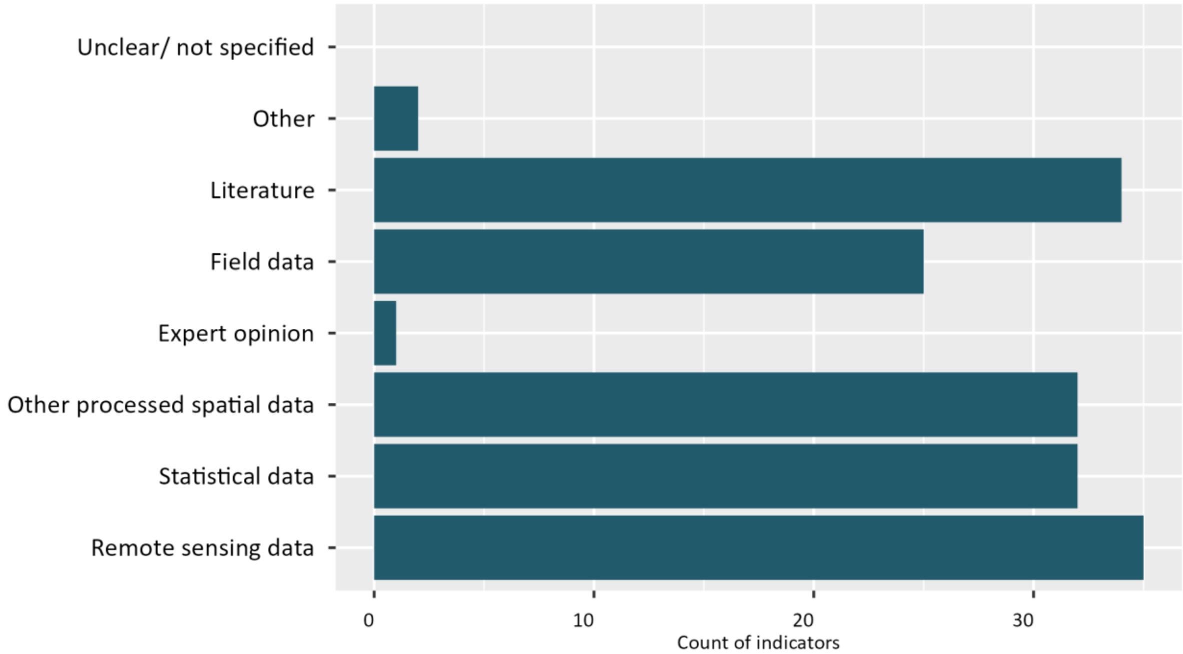

Figure 15: Type of input data used to calculate the identified ecosystem service indicators in urban ecosystems. Review aspect allowed for multiple responses.

Contrary to what has been observed for EC indicators, most ES assessments were not spatially explicit. Only twenty indicators were fully spatially explicit, and other eighteen were aggregated at a relevant administrative scale.

6.3.1.3. Relation between ecosystem condition and ecosystem service(s)

The assessed EC indicators were most frequently linked to ES from the regulation and maintenance section of the CICES v5.1 classification (Fig. 16): *2.2.2.3 maintaining nursery* population *and habitat* (n_i = 31), *2.2.6.1 regulation of chemical composition of atmosphere and oceans* (n_i = 31), *2.2.6.2 regulation of temperature and humidity* (n_i = 28), *2.1.1.2 filtration/sequestration/storage/accumulation by micro-organisms, algae, plants and animals* (n_i = 27). The second group of ES most frequently linked to EC was that of cultural ESs, among which *3.1.1.1 characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions* (n_i = 25) was the most frequently analysed class.

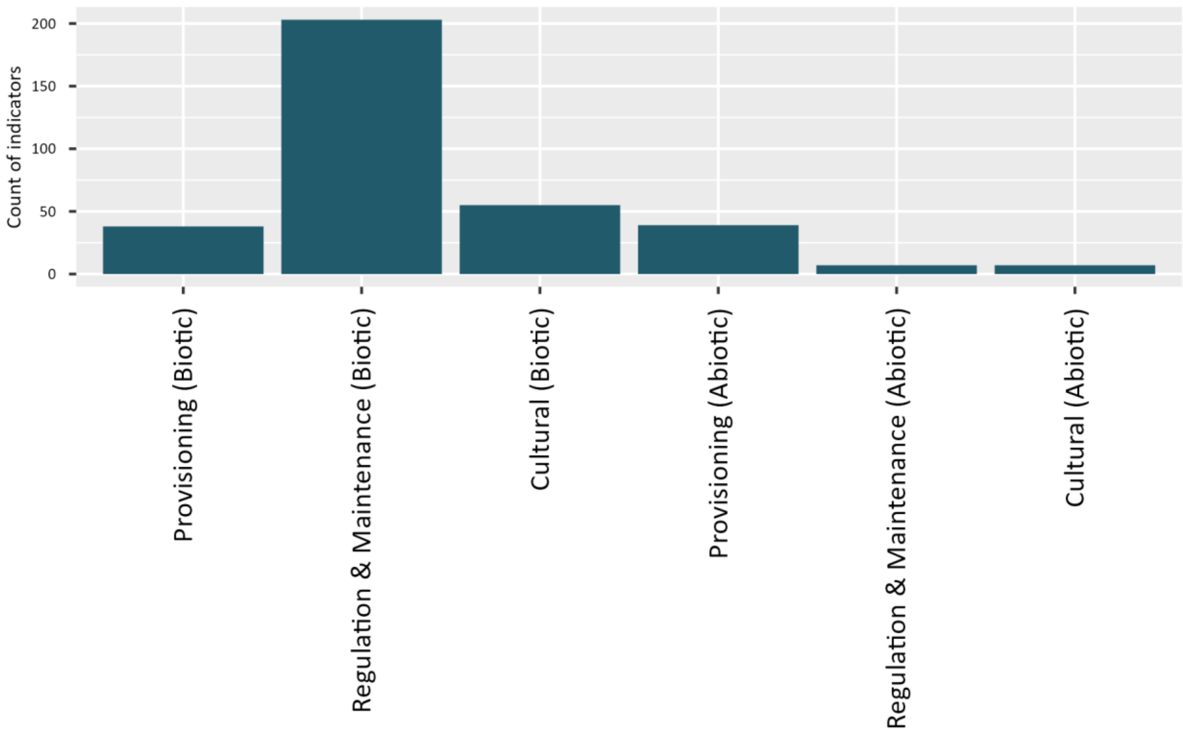

Figure 16: Ecosystem services, according to CICES v5.1 sections, to which EC indicators were linked in urban ecosystems. Review aspect allowed for multiple responses.

Among the publications that explicitly looked at the relationship between EC and ES, the majority compared the two, mainly through a quantitative approach ($n_i = 44$). However, many studies integrated EC into the assessment of ESs ($n_i = 47$). The described relationship between EC and ESs was mostly positive ($n_i = 38$) or negative ($n_i = 21$), with only a few studies finding no relation between the two.

6.3.2. Cropland and grassland

Lead Chapter authors: Paula Rendón, Eliška Tichopádová and Isabel Nicholson Thomas

In total, forty-five publications examining croplands and grasslands offered a comprehensive exploration of EC, ESs, and, to a lesser extent, EA. Thirty-nine publications focused on both EC and ES, whereof several publications made significant contributions to both mapping and assessing EC and ES. For instance, one study focused on identifying soil health indicators linked to critical ESs in a tillage and cropping system experiment (Sainju et al. 2021). Another introduced a comprehensive framework for mapping the *maintenance of nursery populations and habitats* ES, placing particular emphasis on the role of wetlands in connecting service-providing and benefit areas (Hatziiiordanou et al. 2019). A different paper delved into the trade-offs between crop production and water quality services, proposing that maintaining and restoring wetlands could yield mutually beneficial outcomes (Matsuzaki et al. 2019). In contrast, other papers explored the relationships between agroecosystems, soil erosion, and ESs (Rendón et al. 2020, and 2022), highlighting the importance of conservation management practices in mitigating soil loss.

Beyond the mapping and assessment of EC and ESs, the studies also touched upon EA, urbanisation's impact on ESs, and ecological intensification through crop diversification

(Vargas et al. 2019). Each study provided different methods to explore the relationships between human activities, land use changes, and the multiple services ecosystems supply. Whether examining the ecological health of *dehesa* properties in the Iberian Peninsula or evaluating the spatial and temporal dynamics of ESs in Chinese river basins, these papers provided an overview of sustainable land management practices and decision-making processes related to agroecosystems.

The studies assessing croplands and grasslands span multiple spatial scales, examining ecosystems and services at various levels. At the local scale, research included predicting ecosystem health conditions in Abha City, Saudi Arabia (Mallick et al. 2021); exploring an Integrated Fish-Livestock-Horticulture system in Goa, India (Mayekar et al. 2022); and investigating the impacts of agricultural land-use change in Kern County, California (Wartenberg et al. 2021). On a regional scale, studies assessed ecosystem health in the Liuxi River Basin, Guangzhou, China (Ma et al. 2022), using a grid-scale approach, and examined the impact of policies on cultivated lands in Northeast China. Research in Lake Kasumigaura watershed, Japan, delved into the trade-off between crop production and water quality services (Matsuzaki et al. 2019). The Eastern Himalayas, Orinoco River Basin, Northern Germany, and North-western Europe provided regional contexts for exploring agroecosystem conditions, biodiversity dynamics, and crop pests. Other studies covered the US Midwest and the Yellow River Basin and Yangtze River Basin, evaluating conservation practices on croplands. Transnational studies included the European Union's investigation into agroecosystems, soil erosion, and ESs, as well as an analysis of Natura 2000 shrub-grassland habitat types across the EU, focusing on the effects of grazing on their plant composition and conservation status.

6.3.2.1. Ecosystem condition indicators

In the assessment of cropland and grassland ecosystem’s condition, the variety of indicators (n_i = 333) were reclassified into aggregated categories (Fig. 17). Soil nutrients and limiting factors was the most common category with 34 indicators, underscoring the important role of soil health, including metrics such as soil pH, cation exchange capacity, and soil C:N ratio. Following closely, landscape metrics contributed 28 indicators, providing insights into the spatial dimensions of these ecosystems through measures such as edge density and patch density. The composition of soil, spanning both texture and structure, was assessed through 27 indicators, including factors such as bulk density, soil depth, and soil infiltration. Essential for understanding ecosystem dynamics, plant functional traits were represented by 21 indicators, covering aspects such as carbon content and storage, as well as root and leaf dry matter content. Agricultural practices were a focal point, featuring 18 indicators that highlight their overarching impact on the ecosystem, incorporating elements such as irrigation, fertiliser use, and tillage. Specific factors such as crop characteristics, species richness and diversity, and climate variables each were represented by 17 indicators, while soil organic matter and soil hydraulic properties were captured by 16 and 15 indicators, respectively.

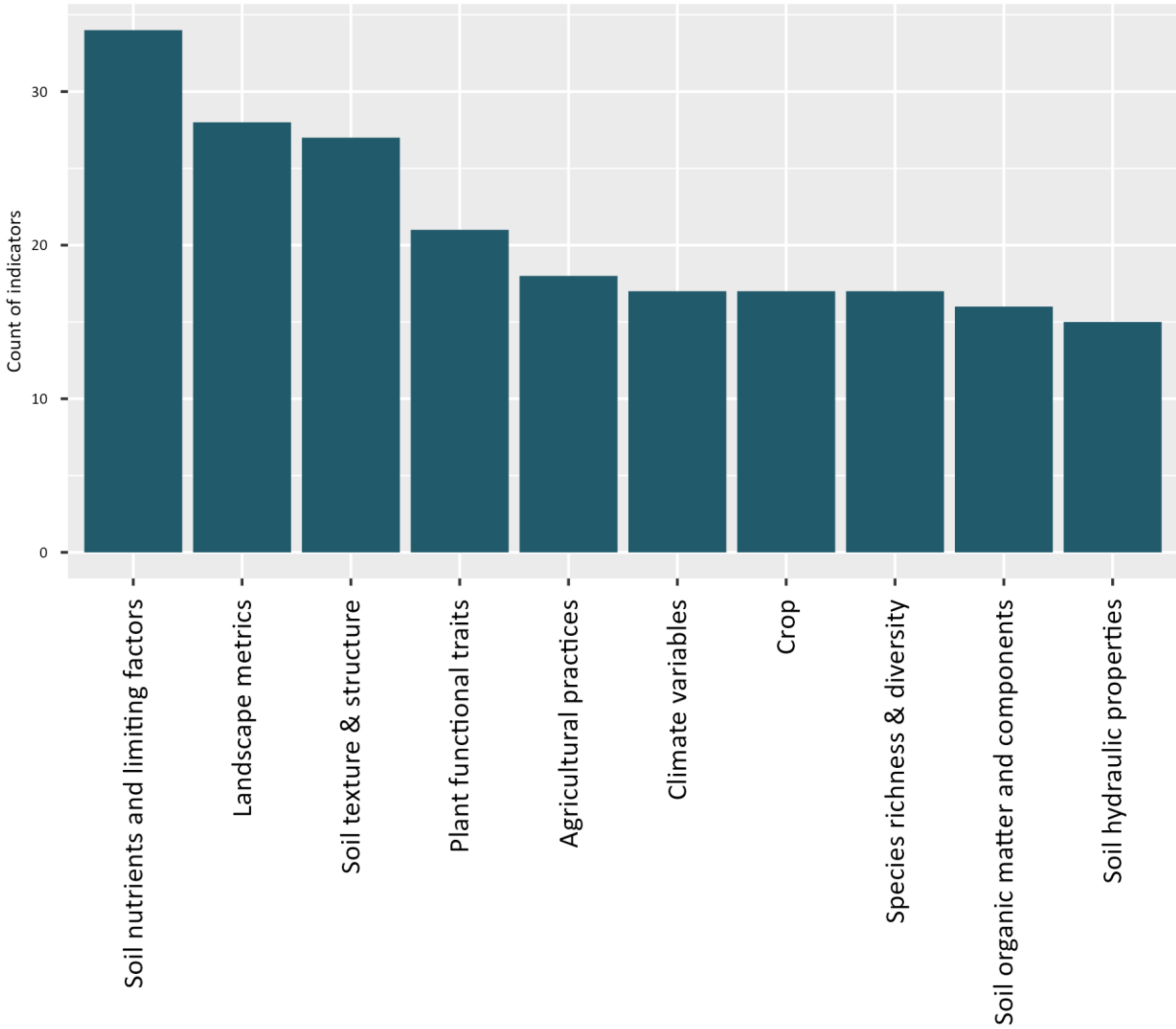

Figure 17: The 10 most frequently assessed aggregated ecosystem condition indicator classes assessed in croplands and grasslands. Review aspect allowed for multiple responses.

Diverse methodologies were employed to assess the condition of croplands and grasslands. Most of the approaches involved solely the direct quantification of input data, mentioned 200 times for cropland and 124 times for grassland (Fig. 18). The second most widely used method was index calculation, a method that distils complex data into a more manageable form ($n_{i\ \text{for cropland}}$ = 66, $n_{i\ \text{for grassland}}$ = 22). The independent use of input data processed by various models or algorithms, was mentioned 48 times for cropland and 17 times for grassland. A hybrid approach combining index calculation and data processing through models or algorithms was applied four times, showing the versatility in methodological integration. A small number of cases (n_i = 3) remained unclear or unspecified, underlining the need for transparency in reporting methodologies.

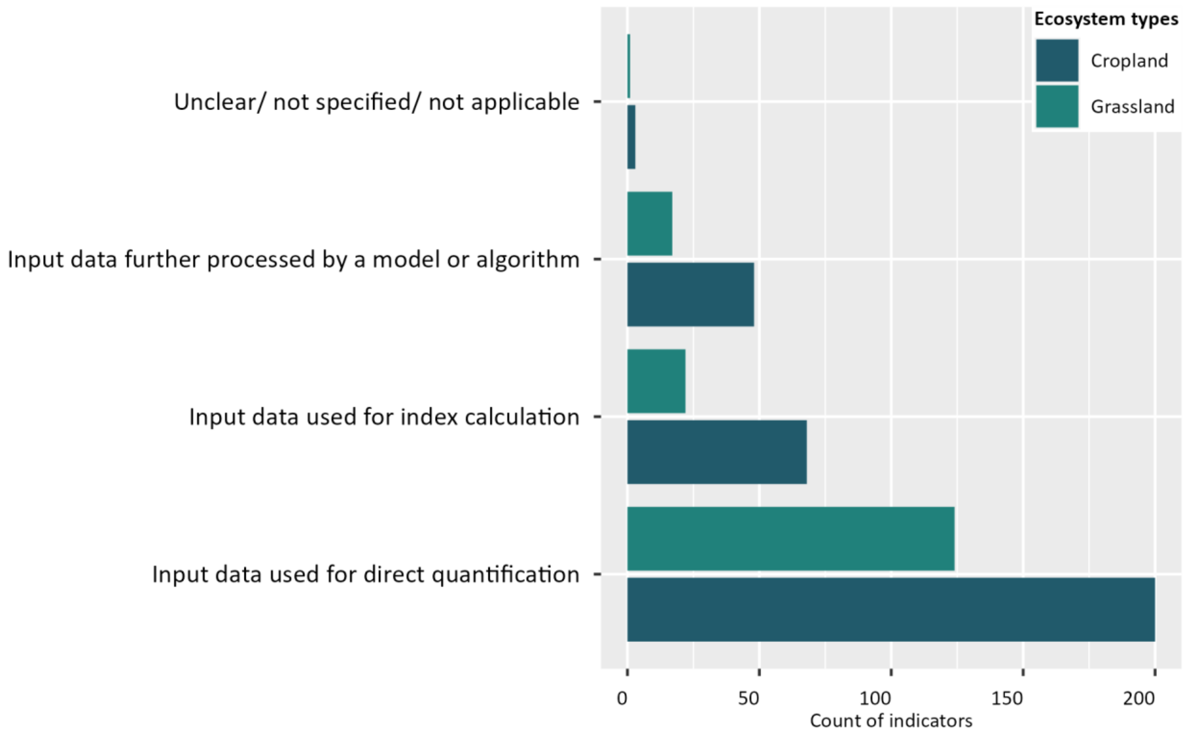

Figure 18: Applied methodologies to assess ecosystem condition of croplands and grasslands. Review aspect allowed for multiple responses.

A diverse range of input data sources was used to assess the condition of cropland and grassland ecosystems. Most of the information was derived directly from the field ($n_{i\text{ for cropland}}$ = 188 and $n_{i\text{ for grassland}}$ = 112) (Fig. 19). Additionally, other processed spatial data ($n_{i\text{ for cropland}}$ = 45 and $n_{i\text{ for grassland}}$ = 23) and remote sensing data ($n_{i\text{ for cropland}}$ = 40 and $n_{i\text{ for grassland}}$ = 25) played an equally important role in capturing the spatial dynamics and features of these ecosystems. Statistical data ($n_{i\text{ for cropland}}$ = 36 and $n_{i\text{ for grassland}}$ = 6) provided quantitative insights into various aspects. Literature, drawing from existing knowledge and research, contributed significantly ($n_{i\text{ for cropland}}$ = 17 and $n_{i\text{ for grassland}}$ = 5). However, in some cases, notably for cropland, the data source was unclear or not explicitly specified. The combination of different sources also played a role in evaluating the condition of these ecosystems.

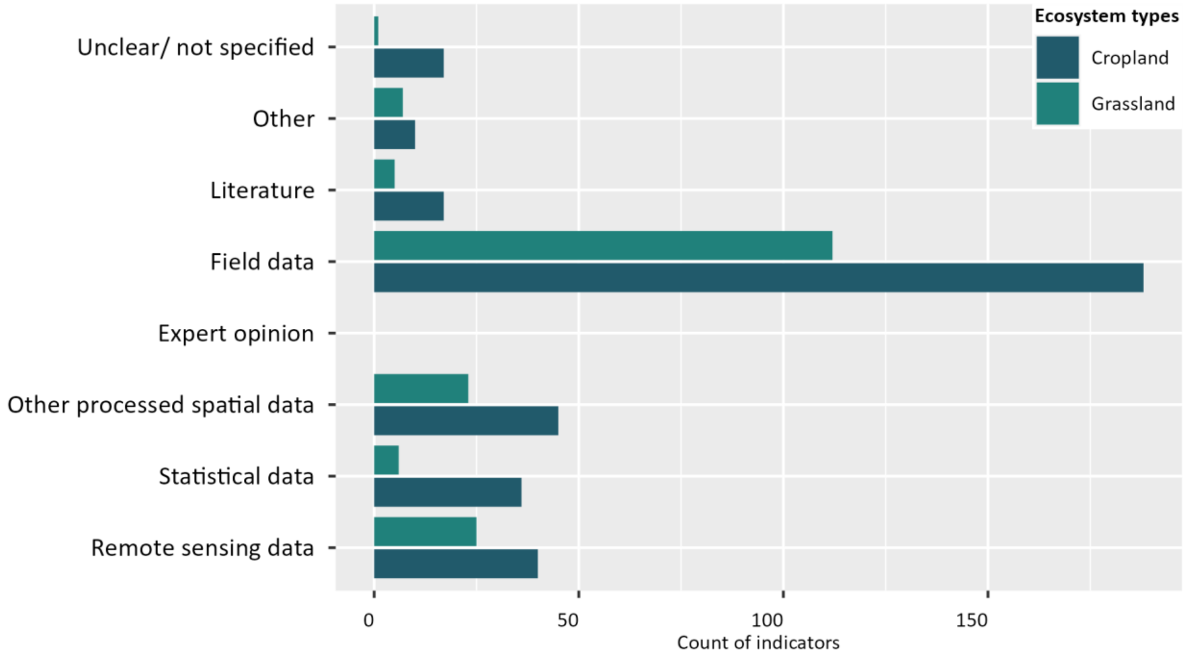

Figure 19: Input data used to assess the condition of croplands and grasslands. Review aspect allowed for multiple responses.

Indicator values were seldom compared to reference levels or reference conditions, with only 5 publications including this in their analysis ($n_{i \text{ for cropland}}$ = 24 and $n_{i \text{ for grassland}}$ = 11). For the indicators where comparison to a reference level or condition was specified, the approach used was either comparison to natural reference conditions, a simple data-driven approach or a fixed year approach.

6.3.2.2. Ecosystem service indicators

The authors identified 249 ES indicators related to cropland ecosystems and 157 ES indicators related to grassland ecosystems in 44 studies. Of these indicators, 135 applied to both agroecosystems. In most cases, the authors assessed ESs in multiple ETs using a single indicator. Only 81 ES indicators for cropland ecosystems and 14 ES indicators for grassland ecosystems were found that were not related to any other ET in the respective study.

ES indicators for agroecosystems were linked to 42 discrete ESs classes. In terms of CICES v5.1 sections, Regulation and Maintenance (Biotic) services were the most represented ESs associated with the indicators (Fig. 20).

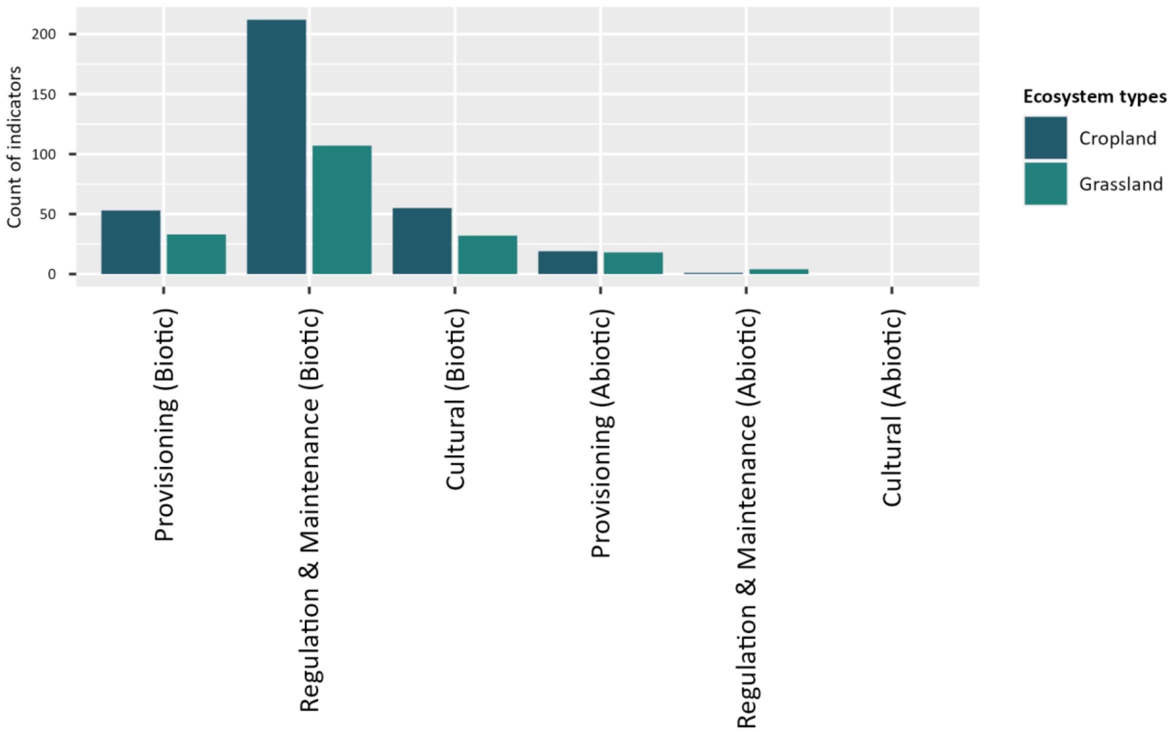

Figure 20: Overview of CICES v5.1 sections related to ecosystem service indicators for agroecosystems. Review aspect allowed for multiple responses.

The distribution of ES indicators across CICES v5.1 sections was similar for both agroecosystems. About 62% of cropland ES indicators were related to services from the Regulation and Maintenance (Biotic) section. On the other hand, grassland ES indicators related to this section only in 55% of cases, and they were more frequently (11%) associated with services provided by abiotic components of ecosystems than cropland ES indicators (6%).

Namely, 41 indicators for cropland ecosystems were related to the ES *2.2.4.2 decomposition and* fixing *processes and their effect on soil quality*, 37 indicators to *2.2.4.1 weathering processes and their effect on soil quality*, followed by 31 indicators for *1.1.1.1 cultivated terrestrial plants grown for nutritional purposes* and 28 indicators for *2.2.1.3 hydrological cycle and water flow regulation*. For grasslands, ES indicators most often focused on *2.2.6.1 regulation of chemical composition of atmosphere and oceans* (n_i = 18), followed by *2.2.4.1 weathering processes and their effect on soil quality* (n_i = 15).

More than three-quarters of the ES indicators for agroecosystems were mapped and assessed using biophysical methods, and economic methods were employed for the ones remaining. The single agroecosystem service indicators were derived using one (n_i = 271) to three (n_i = 25) different ES methods. In the case of cropland ecosystems, the most frequently used methods from the biophysical domain were field observations (n_i = 66), spatial proxy methods (n_i = 63), and the integrated modelling framework (n_i = 28); from the economic domain, they were most often assessed using the value transfer (n_i = 30) and market price methods (n_i = 29). As for grassland ecosystems, they were also most frequently quantified using spatial proxy methods (n_i = 50), integrated modelling framework (n_i = 28), market price (n_i = 28) and value transfer (n_i = 27) methods. Socio-cultural methods were not employed for agroecosystem ES indicators (Fig. 21). Into the group "other method" fell 9 indicators obtained as an interview-based assessment of ES indicators. The overall uncertainty of reviewers about selected ES methods was rather low. Around 89% of the methods were selected with low to medium uncertainty.

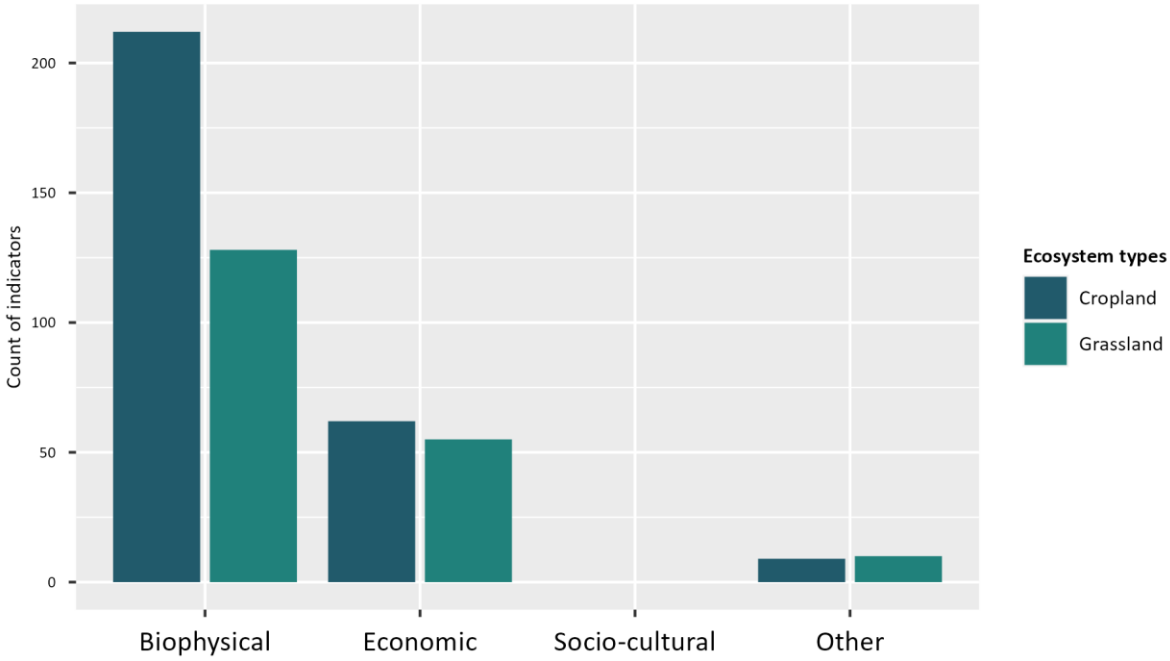

Figure 21: Methods, categorised by method domain, used to map and assess ecosystem service indicators for agroecosystems. Note that a single indicator could be derived by multiple methods. Review aspect allowed for multiple responses.

The input data for ES indicators for agroecosystems aligned with the methods used to map and assess ES indicators. One indicator was derived from one to five data sources. The input data used for cropland ecosystems were mostly field data (n_i = 110), processed spatial data (n_i = 76), and literature sources (n_i = 62); while for grassland ecosystems, the authors commonly used other processed spatial data (n_i = 64) and literature (n_i = 53).

The majority of the ES indicators for agroecosystems were not spatially specific (54%). Almost forty-five percent of the ES indicators for agroecosystems were assessed and mapped as spatially explicit. Such indicators were most commonly aggregated at administrative scales (n_i = 76). The trend differed slightly for cropland and grassland ecosystems (Fig. 22). More specifically, 61% of grassland ES indicators were spatially explicit (96 out of 157 indicators), whereas 57% of the ES indicators were not spatially explicit for cropland ecosystems (142 out of 249 indicators).

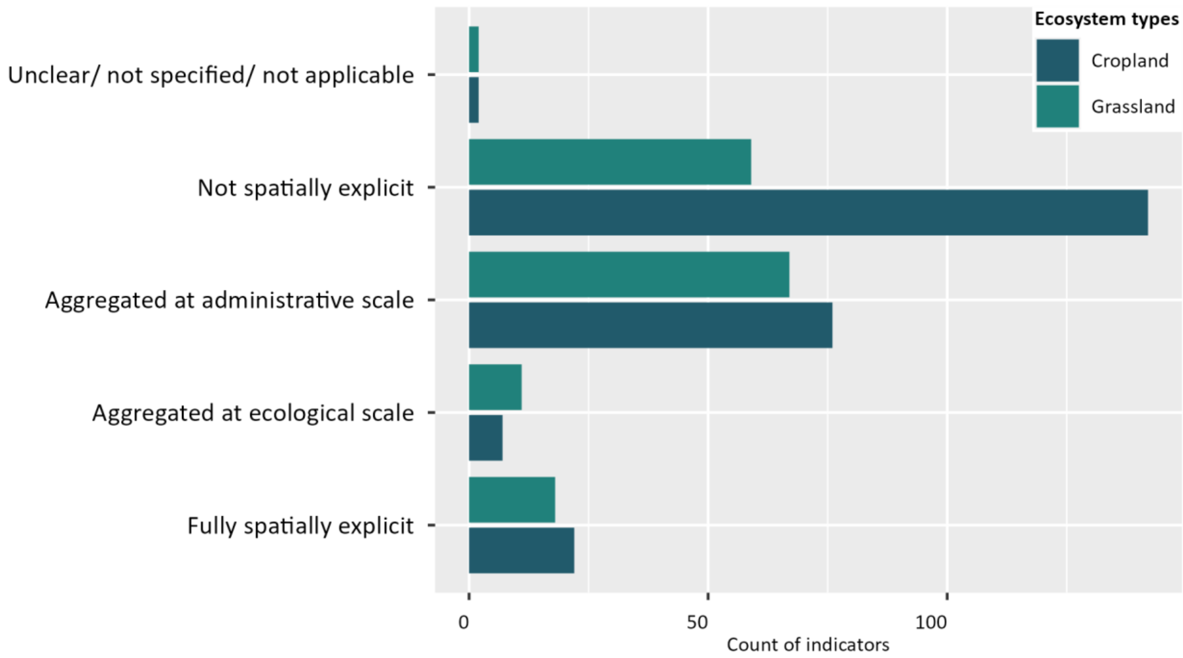

Figure 22: Spatial resolution of output of ecosystem service indicator assessment for agroecosystems. Review aspect allowed for multiple responses.

6.3.2.3. Relation between ecosystem condition and ecosystem service(s)

The majority (around 90%) of EC indicators identified in cropland and grassland ecosystems were linked by the study authors to ESs, with around half of these linked to multiple ESs. One EC indicator was linked to the assessment of one or more ESs; in the most extreme case, up to ten ESs were related to one EC indicator. For example, Guo et al. (2021) used an Aggregation Index on remote sensing images to assess nine different ESs in five ETs to study spatial relationships in a Chinese region of urbanisation.

In general, studies linked the two concepts through integrating indicators of EC into an ES assessment, but a small number of studies limited their consideration of the relation to a quantitative or qualitative comparison of condition and service indicators. For the indicators that were compared, for cropland ecosystems mostly a positive relation was identified, i.e. an increase in the condition variable corresponded to increased supply of ES. For grassland ecosystems an equal proportion of positive and negative relations to ES supply were identified.

Across agroecosystems, EC indicators were mostly linked to ESs of regulation & maintenance, i.e. including 120 indicators related to *2.2.2.3 maintaining nursery populations and habitats (including gene pool protection),* 84 indicators related to *2.2.4.2 decomposition and fixing processes and their effect on soil quality*, 70 related to *2.2.4.1 weathering processes and their effect on soil quality*, and 69 related to *2.2.6.1 regulation of chemical composition of atmosphere and oceans*. Indicators were also frequently related to provisioning ESs, e.g. 81 related to *1.1.1.1 cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes*.

6.3.3. Woodland and forest, heathland and shrub, sparsely vegetated land

Lead Chapter authors: Ioannis P. Kokkoris, Panayotis Dimopoulos and Joana Vincente

The ETs woodland and forest, heathland and shrub, and sparsely vegetated land were jointly analysed within this subchapter. Together, 243 EC indicators and 294 ESs indicators have been recorded in studies addressing among others these ETs.

For woodland and forests, the numbers of indicators, for both EC and ESs, were significantly higher than those for heathland and shrub and sparsely vegetated land. The literature review revealed that more than 220 EC and more than 260 ES indicators included or exclusively dealt with woodland and forest, 20 and 44 with heathland and shrub and 8 and 4 respectively with sparsely vegetated land ETs (Fig. 23). In the reviewed literature corpus, only one study exclusively addressed 8 EC indicators and 17 ES indicators for heathland and shrub (Huerta et al. 2022) and only one single ES indicator "Beach visitation" has been exclusively linked to sparsely vegetated land (Dvarskas et al. 2019). This hinted that woodland and forest were more commonly studied and thus more indicators have been developed and used for assessments of this ET, compared to the other two.

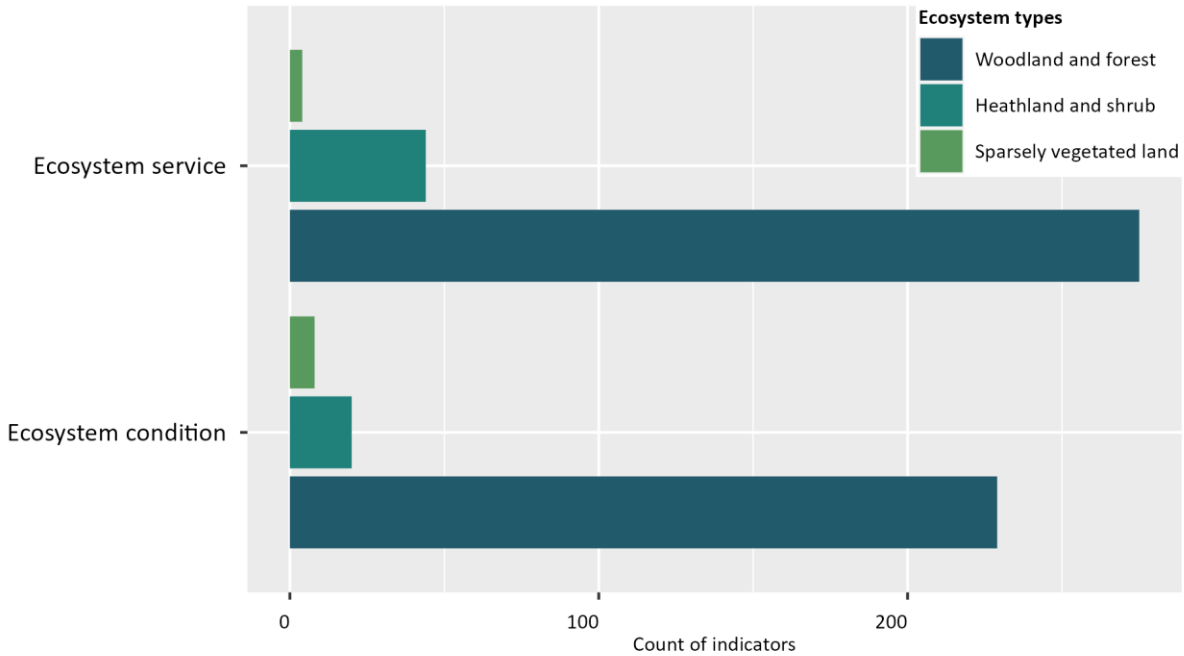

Figure 23: Indicator distribution (number) among the different ecosystem types (i.e., woodland and forest, heathland and shrub, sparsely vegetated land). Review aspect allowed for multiple responses.

6.3.3.1. Ecosystem condition indicators

For these ETs, the 243 EC indicators have been revised and aggregated based on selected general categories that include one or more sub-indicators capturing similar attributes (ecosystem characteristics, functions, state etc.). The aggregated indicators can be associated with various aspects of ecosystem health and functionality, as acknowledged in ecological research (Czúcz et al. 2021, Edens et al. 2022, Hatziiordanou et al. 2019, Vallecillo et al. 2016). Figure 24 presents a chart of the "Top 10" aggregated EC indicator categories, the ones that were most frequently assessed throughout the pool of the reviewed studies. Most EC indicators were classified into the categories EC (including e.g. naturalness and ecosystem vigor), species richness and forest structure (including e.g. canopy cover, basal area and tree density). Furthermore, recorded EC indicators were identified as common ES potential and supply indicators (for more details on this, please refer to Chapter 7.2 and 7.4).

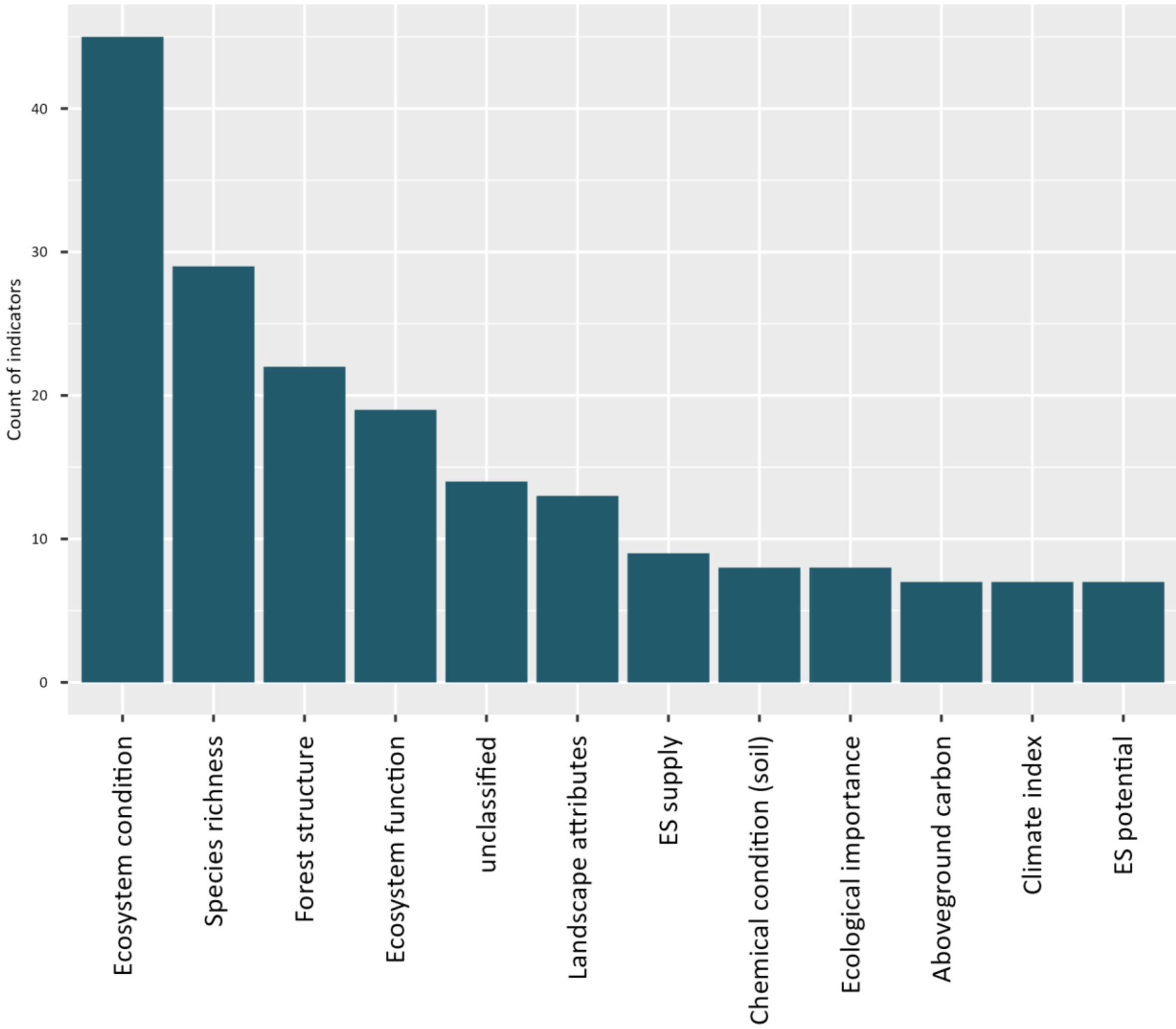

Figure 24: The 10 most frequently assessed aggregated ecosystem condition indicator classes assessed in woodland and forest, heathland and shrub and sparsely vegetated land.

Most of the EC indicators for woodland and forest were directly quantified based upon the input data, whereas for the majority of EC indicators related to heathland and shrub as well as sparsely vegetated land, the input data was used for an index calculation.

For woodland and forest, 47 EC indicators from 12 literature items have been specifically classified in the hierarchical ECT classification (UN 2021). For heathland and shrub as well as sparsely vegetated land, only the publication by Mallick et al. (2021) linked respective indicators to the landscape/seascape characteristics class, while the other indicators have not been linked to this typology framework. The results of this review showed that ECT was not followed or mentioned in the vast majority of the reviewed papers (Fig. 25).

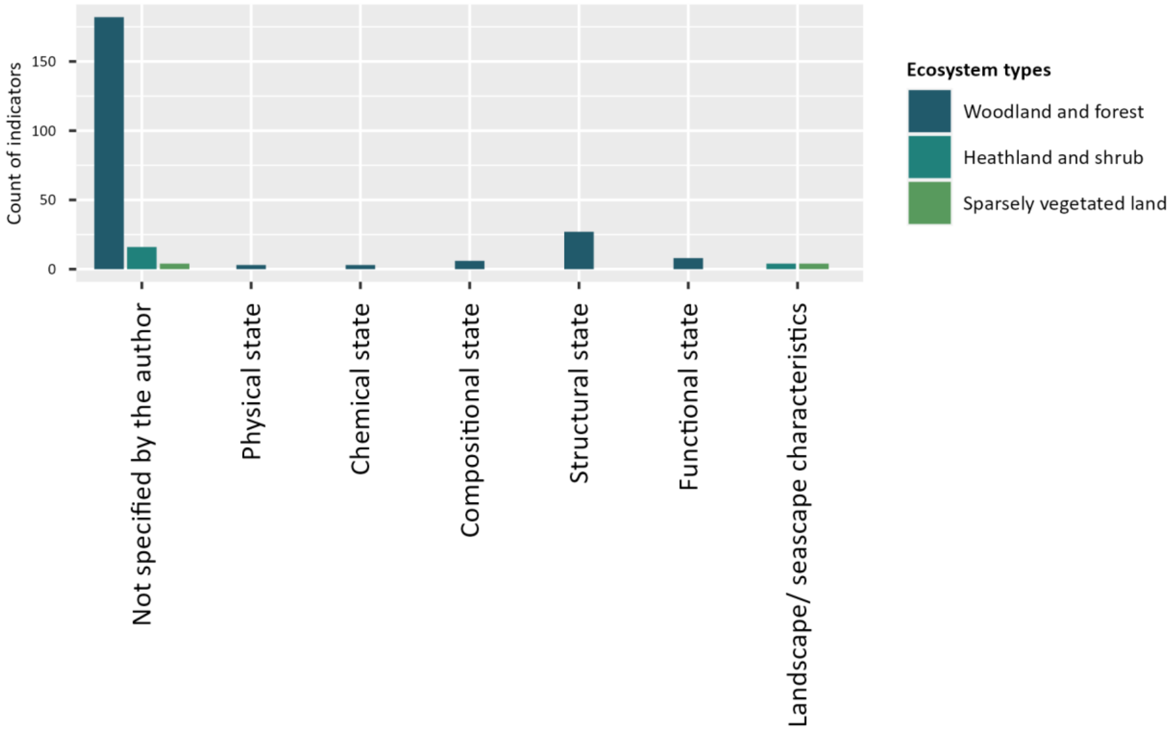

Figure 25: Indicator correspondence to the SEEA EA ecosystem condition typology classes.

When applying EC indicators in an EA, they should be compared to reference levels. The literature review points out that for most indicators (n_i = 224, 92%) reference levels or reference conditions were not considered, while only very few indicators for woodland and forests (n_i = 19) included a reference level, notably a comparison to the natural (n_i = 13, Kobayashi et al. 2002) or semi-natural (n_i = 3, Ling et al. 2020) state or following a fixed year approach (n_i = 2, Liu et al. 2022).

6.3.3.2. Ecosystem service indicators

For the here analysed ETs, 294 ES indicators have been registered. The input data used to assess these different indicators originated from different sources. The analysis revealed that literature and field data were the ones most commonly used, followed by statistical data and remote sensing data and products. This trend slightly differs for the heathland and shrub ecosystems, where remote sensing data were the most commonly used input data.
Regarding the spatial resolution of the different ES indicators used, most indicators were spatially explicit (n_i = 179), however at different resolutions, ranging from fully spatially explicit to aggregated at different scales (i.e., ecological or administrative scales). A significant number of indicators was not spatially explicit (n_i = 97), with the indicators recorded for heathland and shrub assessments, being in their vast majority not spatially explicit (n_i = 25 out of 44) (Fig. 26).

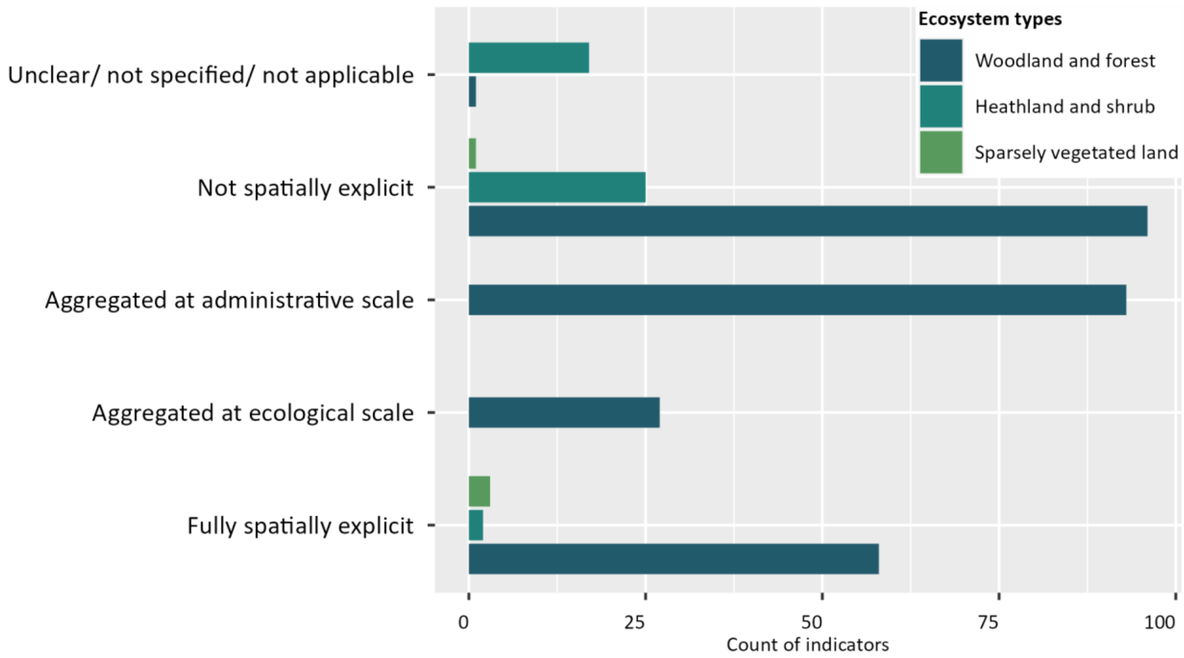

Figure 26: Number of indicators per spatial resolution categories, for woodland and forest, heathland and shrub and sparsely vegetated land ecosystem types.

Figure 27 presents the frequency of different methods and models used for the assessment of the ES indicators on the level of the method domains, i.e. biophysical, economic and socio-cultural. For woodland and forest the indicators were predominantly assessed based upon biophysical methods followed by economic methods, whereas the indicators related to heathland and shrub as well as sparsely vegetated land were rather evenly distributed between those two method domains. For woodland and forest, various methods were recorded, while indicators for heathland and shrubs as well as sparsely vegetated land have only been assessed by 4 or 3 different methods. Spatial biophysical methods were very commonly used across all three ETs, with the highest application in woodland and forests. In contrast, methods like cost-benefit analysis (CBA) and hedonic pricing seem to be less frequently used and are not represented across all ETs.

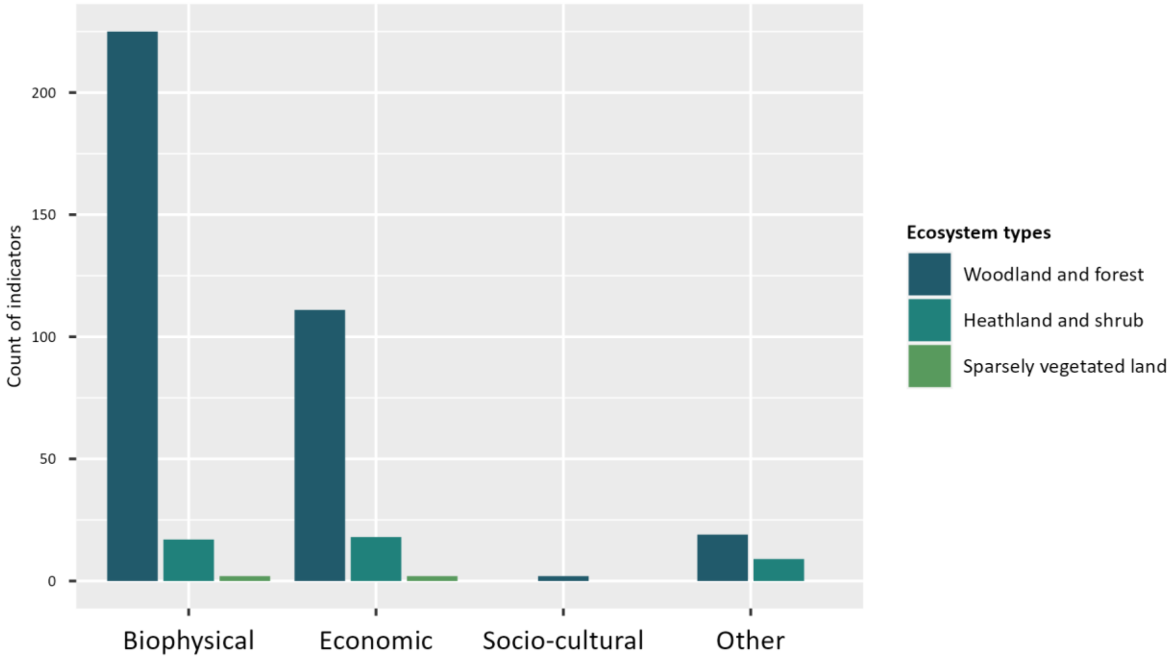

Figure 27: Number of indicators corresponding to the different method domains used for woodland and forest, heathland and shrub and sparsely vegetated land ecosystem types. Review aspect allowed for multiple responses.

Within the review template, the applied ES methods used were not freely recorded but had to be chosen from a predefined list. Therefore, reviewers were asked to indicate their uncertainty with regard to the selected method as well. Many reviewers experienced very low to low (around 42%) levels of uncertainty when classifying the ES methods (e.g. field observations, value transfer and statistical methods). However, there was also a significant number of methods with (especially) medium (around 50%) and higher level (around 7%) of uncertainty (e.g. for production function and integrated modelling).

6.3.3.3. Relation between ecosystem condition and ecosystem service(s)

The key objective of this review deals with the integration of EC and ES assessments. For this ET subgroup, 189 out of 243 EC indicators were linked to ES assessments. More than 75% of the EC indicators related to woodland and forests are directly related to specific ESs (Fig. 28). For heathland and shrubs, about 50% were linked and for sparsely vegetated land 75%.

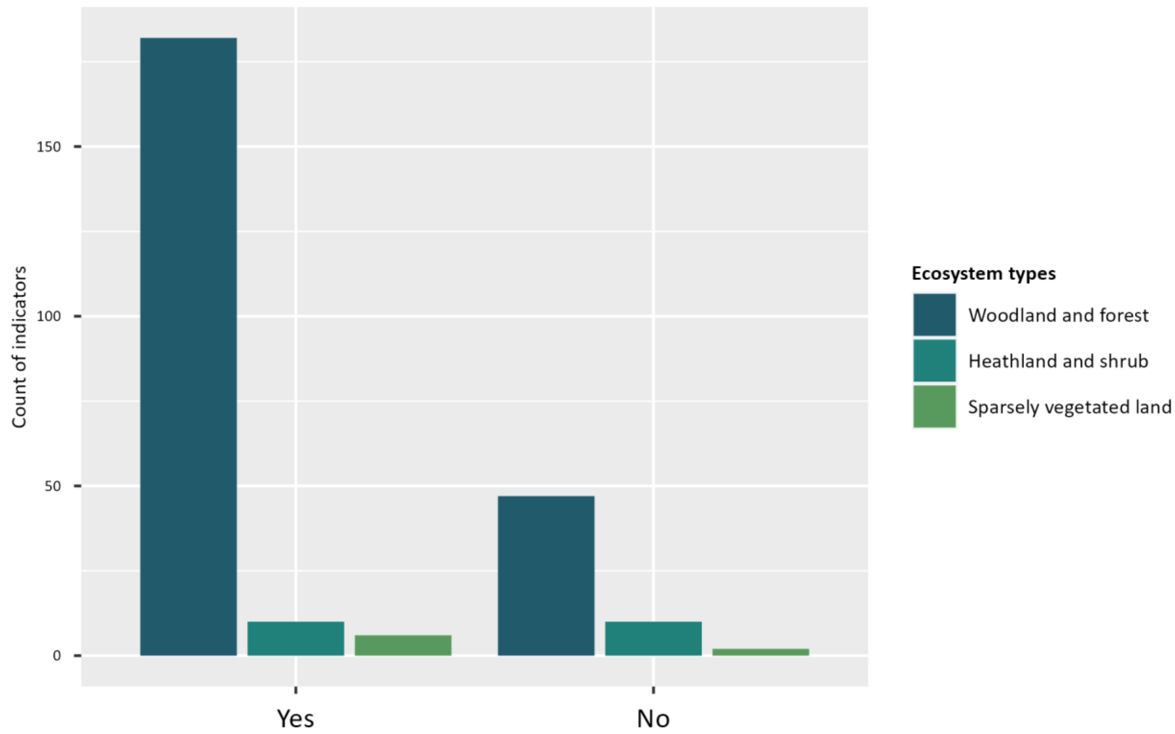

Figure 28: Number of indicators related to specific ecosystem service(s), for woodland and forest, heathland and shrub, and sparsely vegetated land.

For the woodland and forests EC indicators that were related to ES, the nature of the relation was predominantly the integration of EC into the ES assessment, followed by the quantitative comparison of EC and ES assessment results (Fig. 29). For heathland and shrubs and for sparsely vegetated land, the integration of EC and ES for a third purpose corresponded to the most commonly recorded nature of relation.

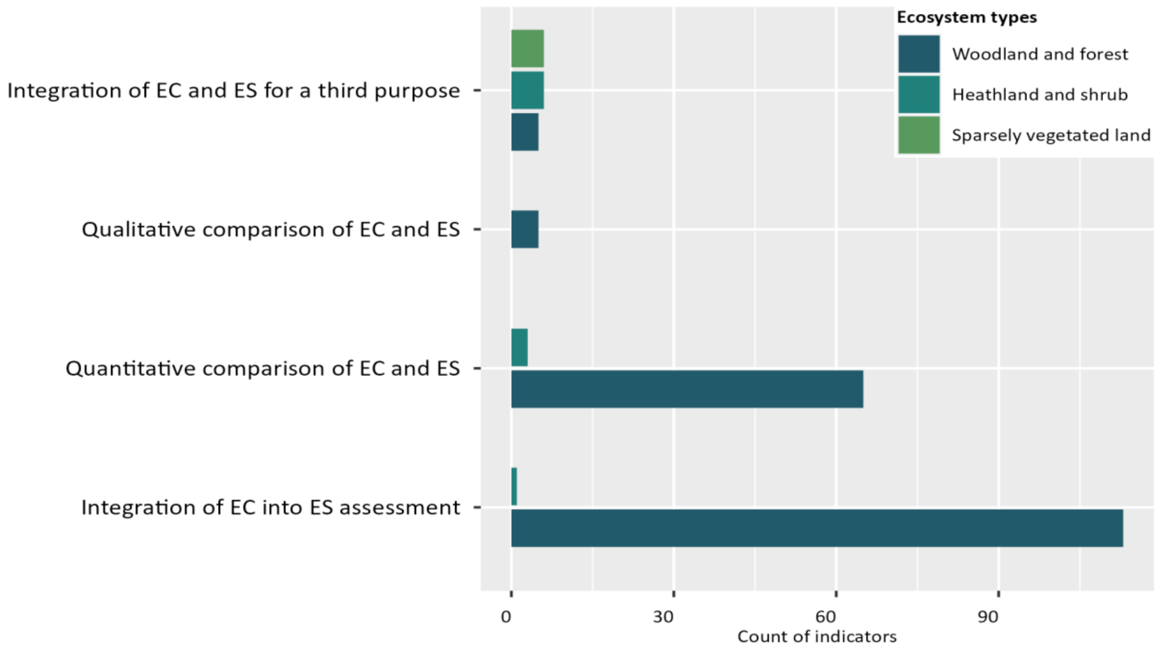

Figure 29: Nature of relation to ecosystem services, for the woodland and forest, heathland and shrub, and sparsely vegetated land. Review aspect allowed for multiple responses.

The analysis revealed that woodland and forests EC indicators showed by far the highest interlinkage to Regulation and Maintenance (Biotic) ESs, while Provisioning (Biotic) and Cultural (Biotic) ESs were linked with nearly the same number of indicators (Fig. 30). Only very few indicators linked to Provisioning (Abiotic), more precisely to the CICES v5.1 classes *4.2.1.1 surface water for drinking* and *4.2.2.1 ground (and subsurface) water for drinking*. Heathland and shrubs contributed to most of the identified ES classes in this ET subgroup, however with significantly fewer indicators, compared to those recorded for woodland and forest. The pattern for heathland and shrubs was different, with most interlinkages to Provisioning (Biotic), closely followed by Regulation and Maintenance (Biotic) and very few for the Cultural (Biotic) ES section. Finally, EC indicators for sparsely vegetated land with a link to ES (n_i = 6) have not been assigned to any ES. For 6 EC indicators reviewed in Mallick et al. (2021), falling in both ET categories heathland and shrubs and sparsely vegetated land, the assessed ESs in the study could not be linked to a specific CICES v5.1 class as the total ES value was quantified. Predominant regulating ESs that were identified were *2.1.1.2 filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals, 2.2.6.1 regulation of chemical composition of atmosphere and oceans, 2.2.3.1 pest control, and 2.2.2.3 maintaining nursery populations and habitats.* For provisioning services, predominant ESs that were identified are *1.1.1.1 cultivated terrestrial plants grown for nutritional purposes,* and *1.1.5.2 fibres and other materials from wild plants for direct use or processing dominated*.

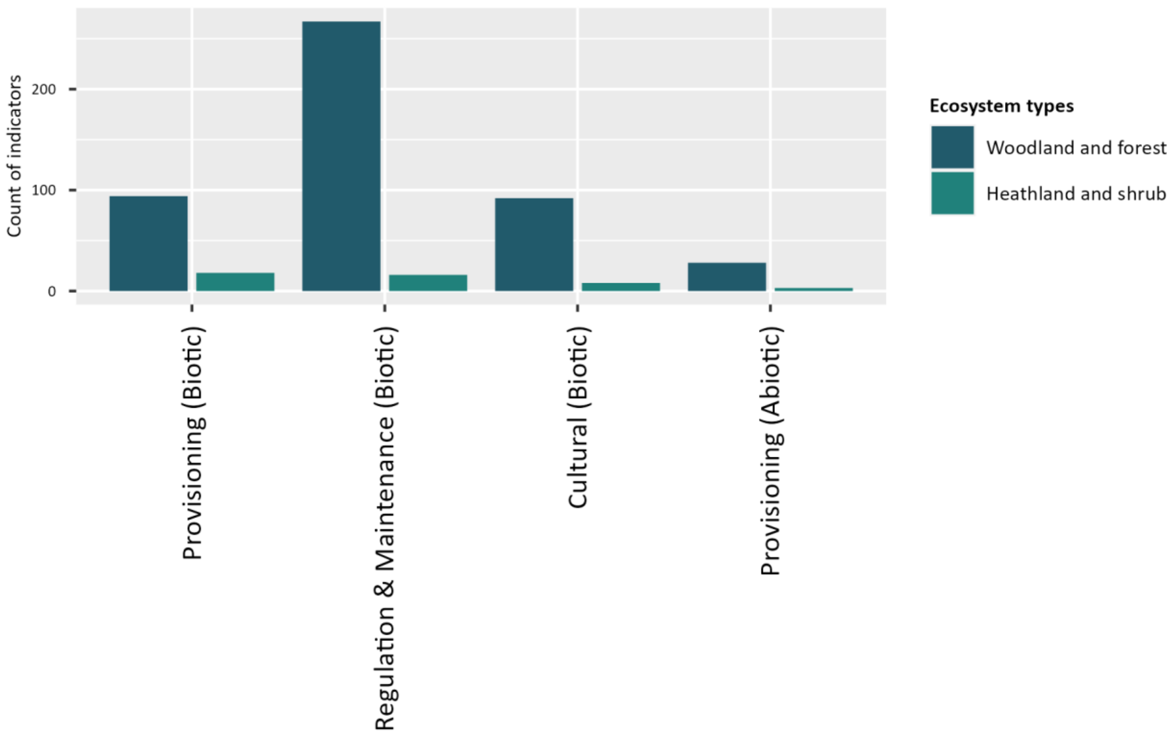

Figure 30: Ecosystem services, according to CICES v5.1 sections, to which EC indicators were linked in woodland and forest, heathland and shrub and sparsely vegetated land. Review aspect allowed for multiple responses.

6.3.4. Rivers and lakes, wetlands

Lead Chapter authors: Hristina Prodanova, Małgorzata Stępniewska and Stoyan Nedkov

Publications dealing with rivers and lakes, and wetlands ecosystems included 265 EC indicators and 204 ES indicators altogether. EC indicators for rivers and lakes ecosystems were 223 and for wetlands 52 (Fig. 31). EC indicators used only for rivers and lakes ecosystems were 144, and those used only for wetlands 37. The rest of the indicators were used in various combinations with other ecosystems. For instance, 33 EC indicators were applied for the combination of woodland and forest – rivers and lakes, 11 EC indicators for the combination of urban – rivers and lakes, and 68 indicators were used in combinations containing more than two ecosystems. While 112 ES indicators have been recorded with regard to rivers and lakes ecosystems, only 53 of those have been applied solely onto rivers and lakes ecosystems. The ES indicators recorded with regard to wetlands were 116, most of them used in combination with other ecosystems predominantly urban and cropland.

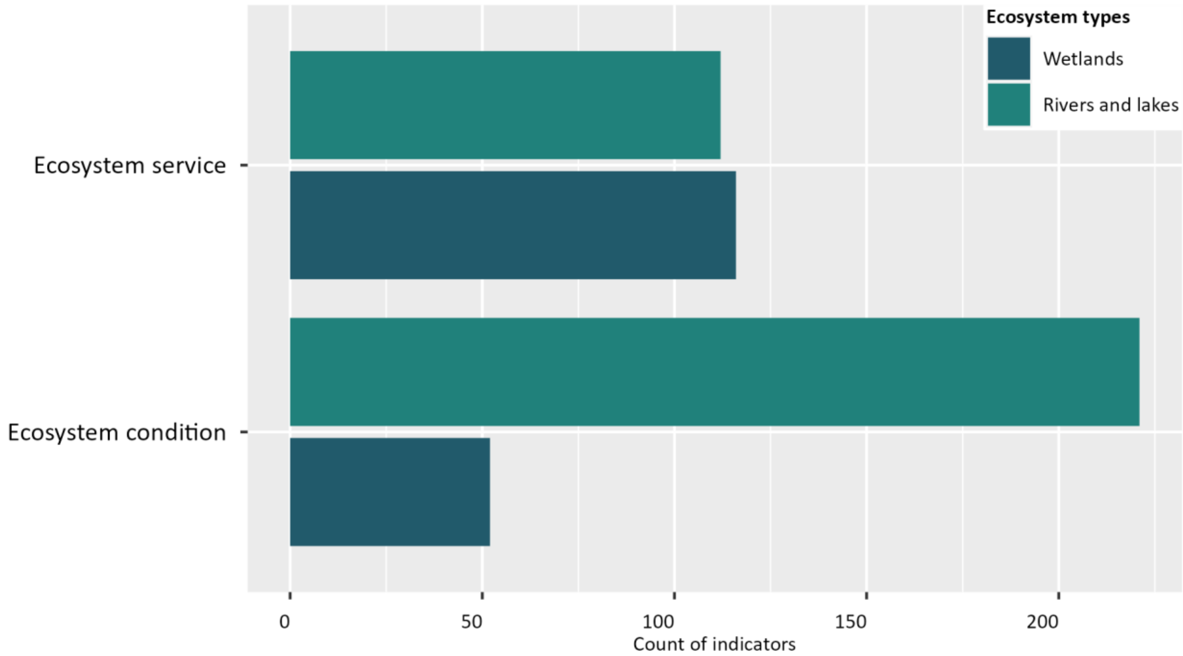

Figure 31: Applied indicators for rivers and lakes, and wetlands. Review aspect allowed for multiple responses.

6.3.4.1. Ecosystem condition indicators

The relation to the EC typology classes (Czúcz et al. 2021) was generally unclear as in most publications this was not specified by the authors. Only for 36 (14%) EC indicators an ECT was recorded, 31 of them were for rivers and lakes ecosystems and only 5 for wetlands. The latter were related to landscape/seascape characteristics while the rivers and lakes indicators were distributed to all 5 categories with a predominance of the chemical and structural state. Through the aggregation of the recorded EC indicators, it was found that most applied EC indicators were related to either biodiversity or considered as a metric with regard to water quality (Fig. 32).

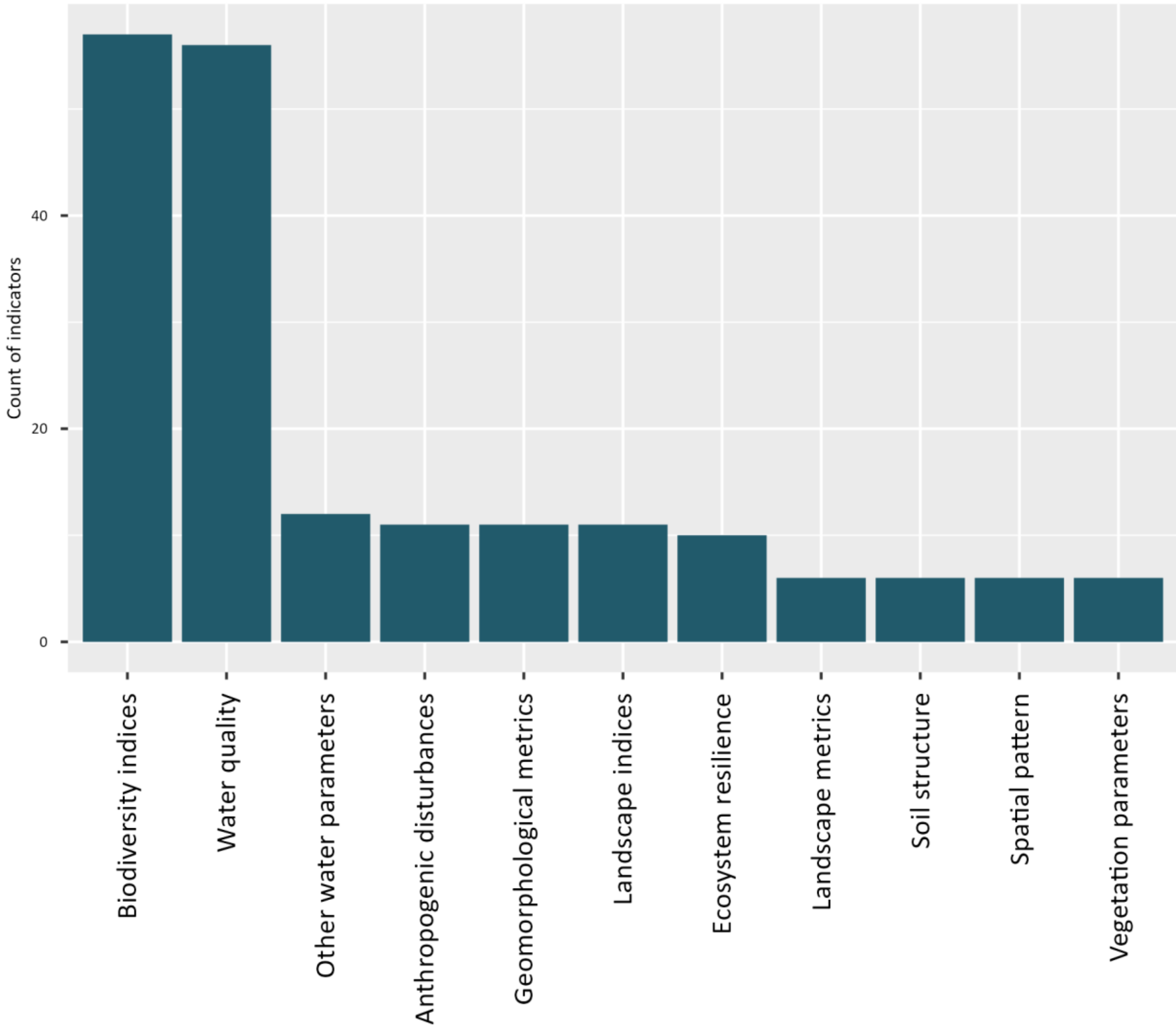

Figure 32: The 10 most frequently assessed aggregated ecosystem condition indicator classes assessed in rivers and lakes, and wetlands.

More than half of the rivers and lakes EC indicators and about 80% of the wetlands EC indicators were part of a composite indicator. A limited number of the indicators were actual composite indicators themselves, while about 20% to 30% are individual indicators (not part of composite indicators) for wetland and rivers and lake ETs, respectively. The remaining indicators were recorded as unclear or not specified. The most commonly applied methodology to assess rivers and lakes' EC was by index calculation, while direct quantification and modelling methods were less applied. However, also the share of EC indicators where the reviewers recorded an unclear or not specified methodology was relatively high. The wetlands ecosystems by contrast were assessed predominantly by direct quantification and modelling while index calculation was less popular. The number of unclear or not specified methods in wetlands studies was very low.

The most common input data type for the assessment of indicators for rivers and lakes EC were by far - field data, followed by remote sensing data, statistical data, and literature sources (Fig. 33). Expert opinions were not commonly applied. Besides, for a significant number of EC indicators unclear or not specified data sources were recorded. Even though field data were also the leading input data type for the indicators related to wetland ecosystems, the leadership was less pronounced and the other processed spatial data, remote sensing, and statistical data were in close position.

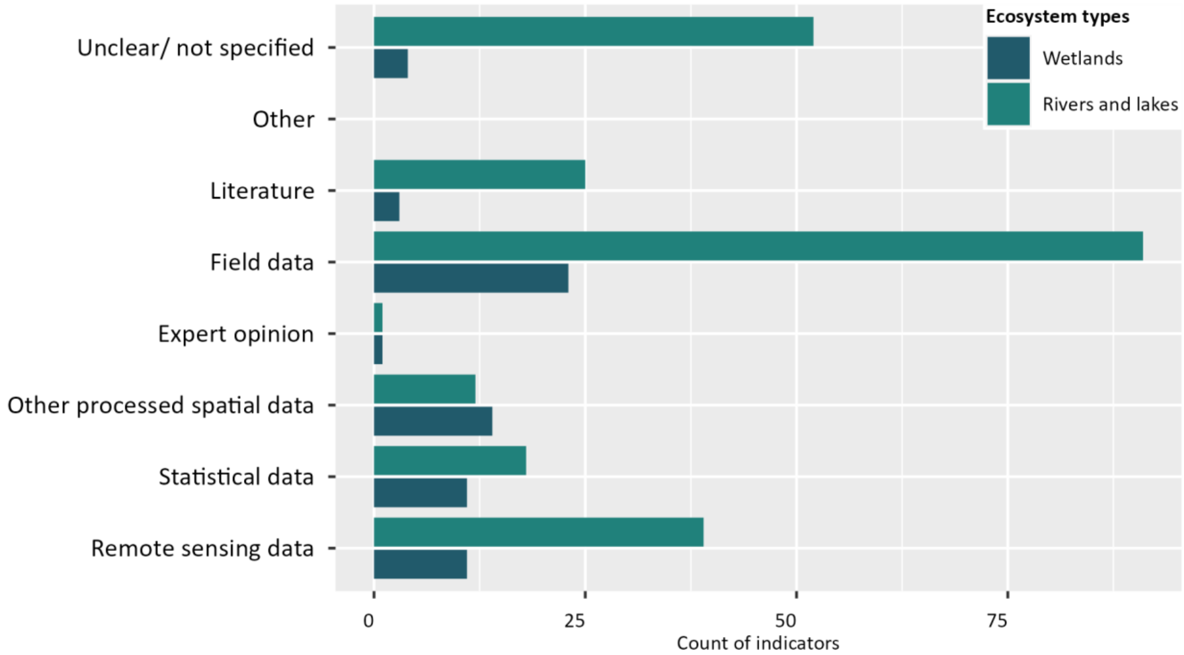

Figure 33: Input data types for the assessment of ecosystem condition indicators for rivers and lakes, and wetlands. Review aspect allowed for multiple responses.

The input data and methods predefined the usage of predominantly spatially explicit ecosystem indicators for rivers and lakes ecosystems and in contrast not spatially explicit for wetlands ecosystems (Fig. 34). The aggregation of both river and lakes and wetlands ecosystems was more often at an ecological scale than at an administrative level. Studies with unclear or not specified spatial resolution were recorded only for rivers and lake ecosystems while no such cases were recorded for wetlands ecosystems.

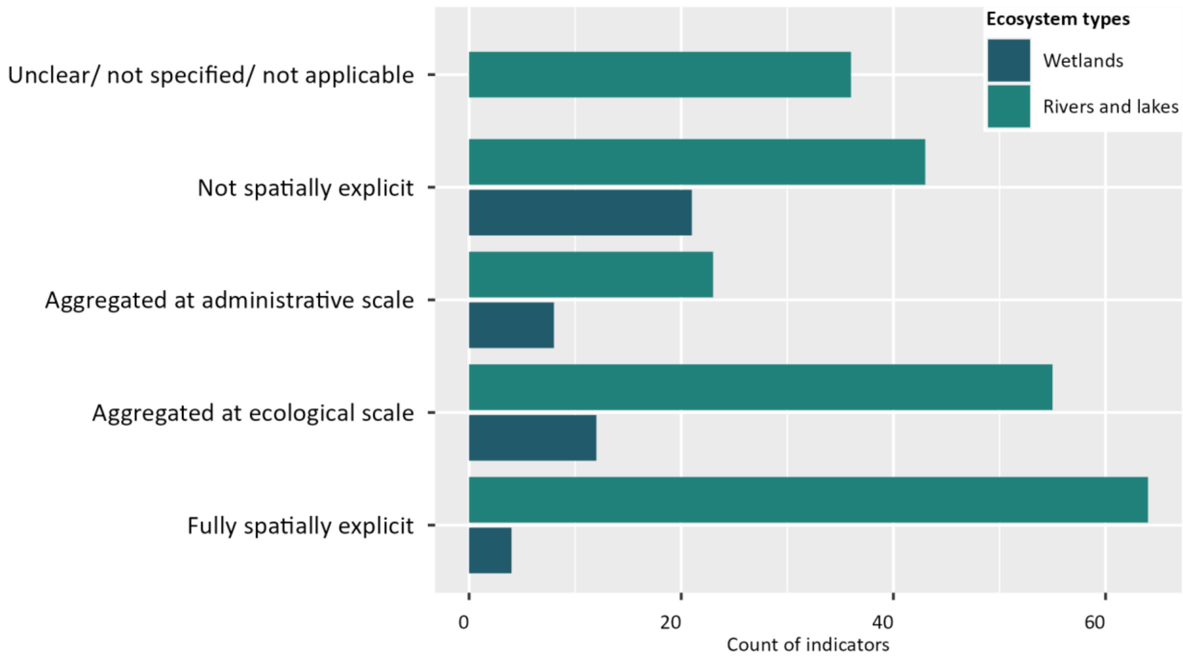

Figure 34: Spatial resolution of ecosystem condition indicators for rivers and lakes, and wetlands. Review aspect allowed for multiple responses.

About two-thirds of the EC indicators related to river and lakes ecosystems were not associated with any reference level or reference condition. For wetlands ecosystems, the share of such indicators was much higher, almost 80%. In case reference levels or condition were considered (n_i = 84), the nature of the reference level was predominantly unclear or not specified for both ET. The indicators related to wetland EC with specified reference level had a policy target as reference level or considered a re-naturalisation reference condition, while for the rivers and lakes ecosystem, they were distributed between policy target, fixed year approach, and safety health. A limited number of indicators had expert-based, socio-economic, and natural reference levels. For both ETs, no indicators have been recorded to consider semi-natural, and simple data-driven approaches.

6.3.4.2. Ecosystem service indicators

In total, 190 out of 204 ES indicators assessed for rivers and lakes as well as wetlands were specifically linked to biotic as well as abiotic ESs. ESs from the regulation & maintenance (Biotic) section were predominantly assessed for both ETs followed by cultural (Biotic) (Fig. 35). For wetlands, provisioning services of biotic and abiotic origin were assessed almost on a par, while rivers and lakes had a significantly larger share in provisioning services (abiotic), even exceeding the cultural (Biotic) section. This was naturally related to the provision of water for diverse purposes.

Among the indicators of provisioning services for rivers and lakes, the services describing water supply, notably *4.2.1.1 surface water for drinking* and *4.2.1.2 surface water used as a material (non-drinking purposes)* were the most commonly recorded. For regulation & maintenance services, indicators most often described *2.2.1.3 hydrological cycle and water flow regulation*, and *2.1.1.2 filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals*. When considering cultural services, the indicators addressed in particular *3.1.1.1 characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions*. Concerning wetland studies, the most common indicators were those related to *2.2.6.1 regulation of chemical composition of atmosphere and oceans*, and *2.2.1.3 hydrological cycle and water flow regulation* (both representing regulation & maintenance services). In the case of wetland provisioning services, the largest number of indicators covered the abiotic supply of *4.2.1.2 surface water for non-drinking purposes* and on for the biotic section *1.1.1.1 cultivated terrestrial plants grown for nutritional purposes* was most commonly assessed. Cultural services indicators for wetlands primarily concerned the *3.1.1.1 and 3.1.12 characteristics of living systems that enable active or passive interactions* and *3.1.2.4 characteristics of living systems that enable aesthetic experiences*.

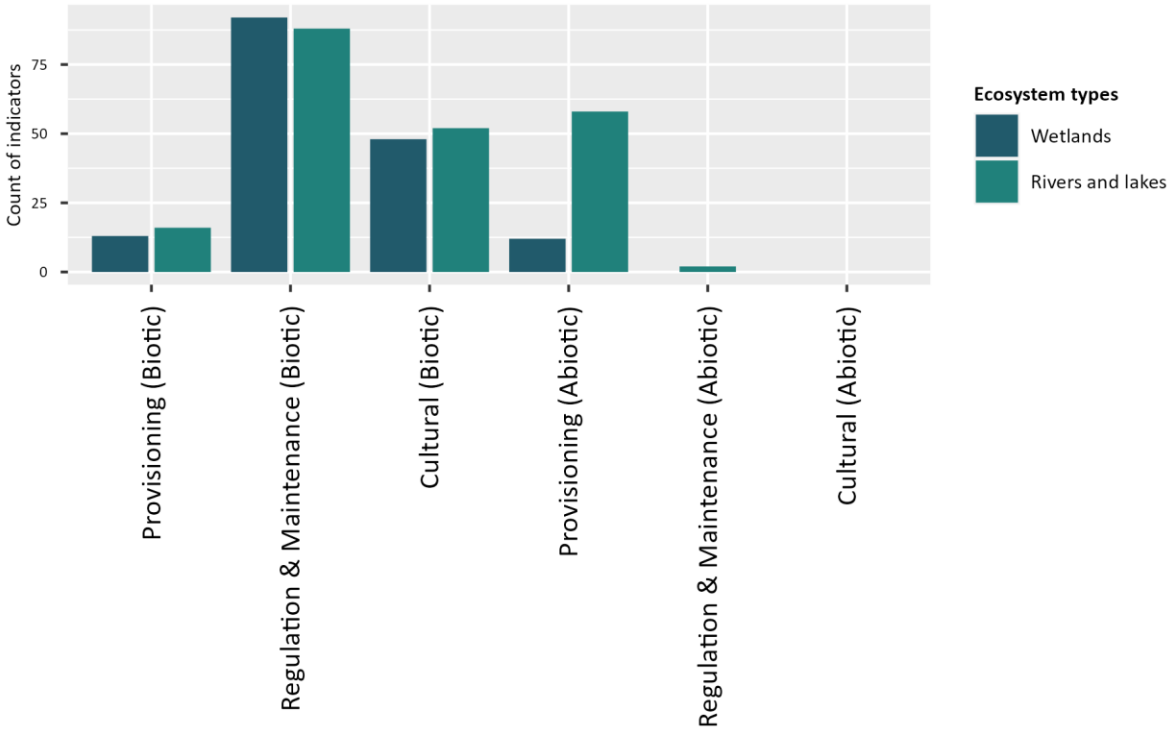

Figure 35: Ecosystem services (CICES v5.1) assessed for rivers and lakes, and wetlands. Review aspect allowed for multiple responses.

Generally, the recorded ES indicators with regard to wetlands as well as rivers and lake were most commonly assessed based upon ES methods from the biophysical method domain, followed by the economic method domain (Fig. 36). Socio-cultural methods were rarely applied for ES indicators with regard to rivers and lakes and not at all for wetlands.

More specifically, spatial proxy methods were the most common ES methods recorded for rivers and lakes as well as wetlands ($n_{i \text{ for rivers and lakes}} = 37$, $n_{i \text{ for wetlands}} = 55$). In the case of rivers and lakes, the next most frequently used method was the use of statistical and socio-economic data (21% of ES indicators). In turn, for studies on wetlands ESs, these were market price (24% of ES indicators) and value transfer (18%) methods.

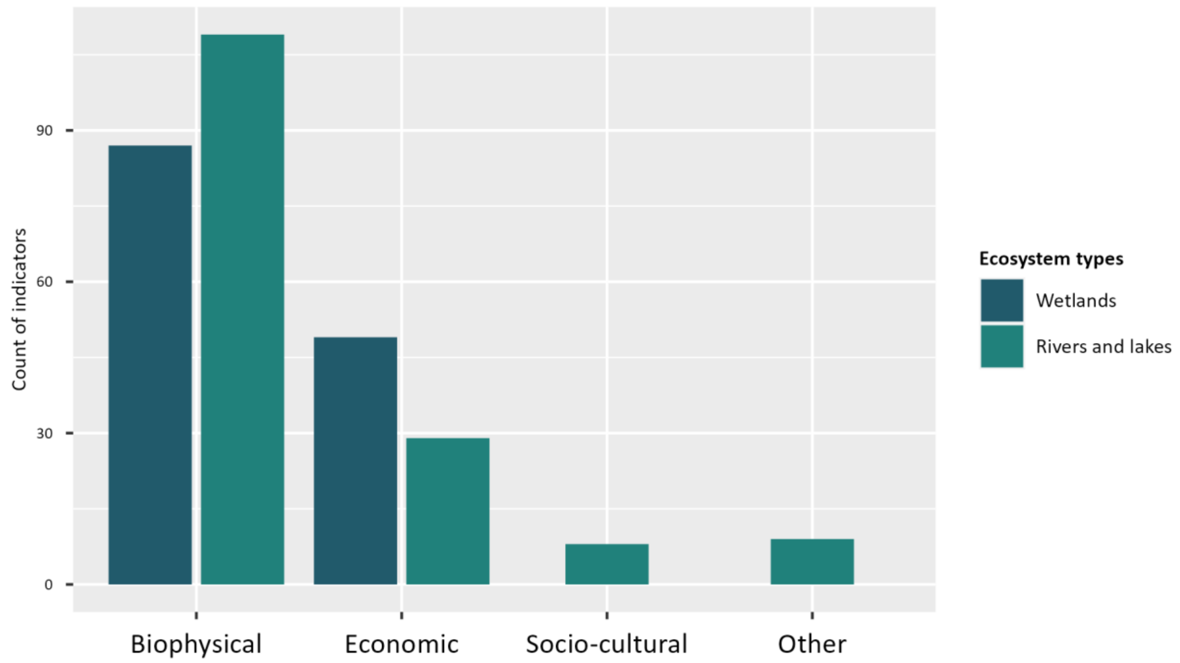

Figure 36: Number of indicators corresponding to the different method domains assessed for rivers and lakes and wetlands. Review aspects allowed for multiple responses.

Input data types (Fig. 37) for assessing ESs of rivers and lakes consisted mainly of statistical data (for 40% of the indicators), followed by other processed spatial data (27%) and literature (26%). To a lesser extent, also field data, remote sensing data and expert opinion were used. The most common input data types for wetlands ESs were other processed spatial data (for 46% indicators), followed by statistical data (33%) and literature (17%). Additional input data played a much smaller role than in the case of rivers and lakes.

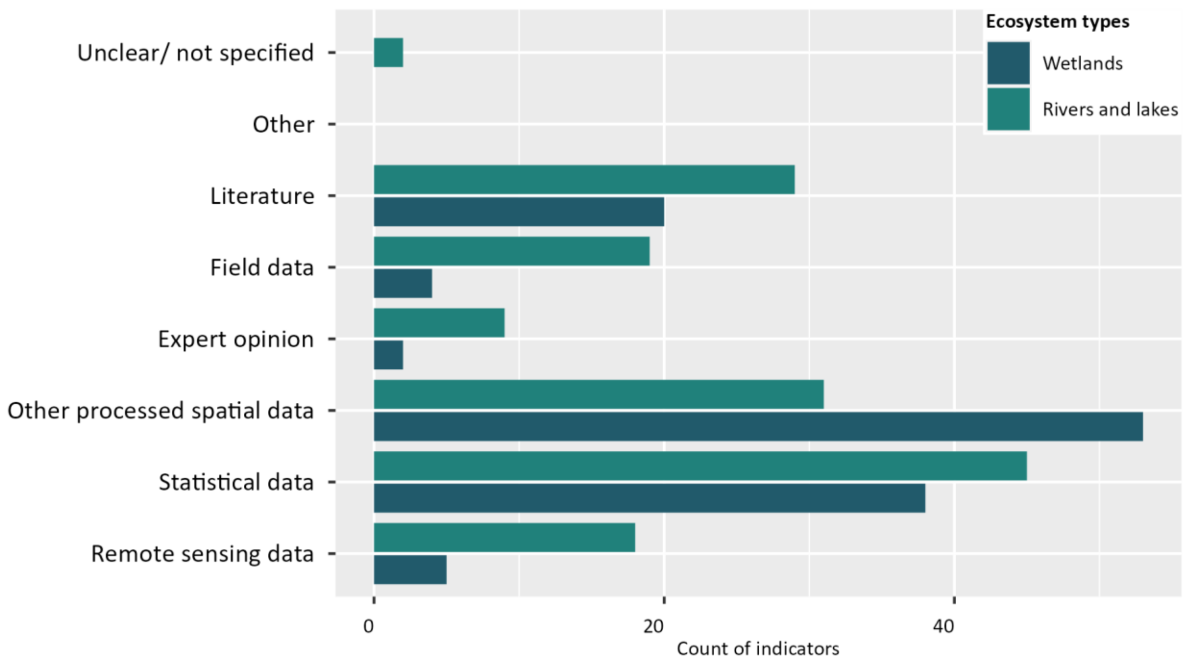

Figure 37: Input data types to assess ecosystem services indicators for rivers and lakes and wetlands. Review aspect allowed for multiple responses.

The largest group of indicators for ESs of rivers and lakes were not spatially explicit (49%) (Fig. 38). Less common were fully spatially explicit indicators (14%) and indicators aggregated at ecological (17%) and administrative (13%) scales. The recorded indicators on wetland ESs were dominated by an aggregation at an administrative scale (65%), followed by indicators that weren't spatially explicit (21%). Only around 9% of the wetland ES indicators were recorded to be fully spatially explicit.

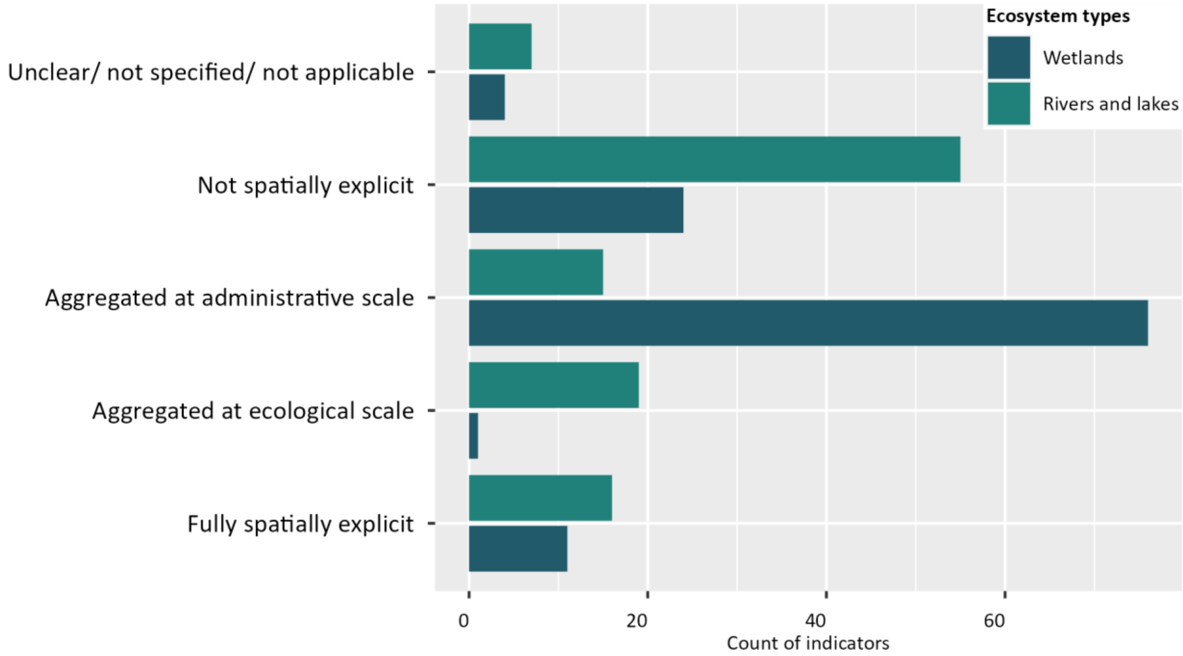

Figure 38: Spatial resolution of ecosystem services indicators for rivers and lakes and wetlands. Review aspect allowed for multiple responses.

6.3.4.3. Relation between ecosystem condition and ecosystem service(s)

Various relations between EC and ES have been analysed for both ETs - rivers and lakes, and wetlands. The results indicate that the majority of the EC indicators is related to specific ES ($n_{i\text{ for rivers and lakes}}$ = 113, $n_{i\text{ for wetlands}}$ = 38). EC indicators with regard to rivers and lakes were predominantly related to specific ES through the integration of EC into ES assessments (n_i = 57) and secondly through the quantitative comparison of EC and ES (n_i = 47). During the latter, positive as well as negative relations were discovered. For wetland ecosystems, the EC indicators and ES indicators were predominantly integrated for a third purpose (n_i = 19). Besides, 10 wetland EC indicators were integrated into ES assessments. Also, wetland EC indicators were quantitatively compared to ES (n_i = 10). During the latter mostly positive relations were found. For rivers and lakes as well as wetlands, EC indicators were mostly related to ES from the CICES v5.1 section cultural (biotic) followed by regulation & maintenance (biotic).

6.3.5. Marine and coastal

Lead Chapter authors: Miguel Inácio and Paulo Pereira

Marine and coastal ecosystems supply an array of ES, essential for human well-being (Barbier 2017). Despite their importance, they are among the most affected by direct and indirect anthropogenic impacts. Consequently, many of these ecosystems experience a decrease in ecological status and condition, affecting the quality and quantity of ES supplied (Buonocore et al., 2021). Despite the need for a better understanding, research on coastal and marine ES is generally lacking compared to terrestrial ecosystems. This is normally attributed to the need for more data and a better understanding of the mechanisms responsible for generating ES in these ETs (Townsend et al., 2018). EC has been integrated into coastal and marine research as a consequence of the establishment of several environmental policies and directives (e.g. Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD)). Several status indices (HELCOM Benthic) were developed to represent the status/condition of coastal and marine ecosystems. Although some research was conducted on EC and ES, few studies address their relation with each other. Therefore, it is critical to develop practical approaches linking EC and ES.

6.3.5.1. Ecosystem condition indicators

Around 32, 23 and 24 EC indicators were related to marine (incl. shelf and open ocean), marine inlets and transitional waters and coastal, respectively. Hereafter, the ET marine (incl. shelf and open ocean) is referred to as "marine" only for the sake of readability. It is important to remember the distinction from marine inlets and transitional waters. For most of the indicators assessed with regard to coastal and marine ecosystems the authors did not specify the type of EC indicator, according to the SEEA EA ECT. Only for very few EC indicators (n_i = 19), such a classification was provided. Those mostly fell into the compositional state class. The EC indicators related to marine inlets and transitional waters were most commonly assessed based upon direct quantification of the input data (Fig. 39). In marine waters, for most of the indicators input data was used for index calculation (n_i = 20). Contrary to that, for indicators related to coastal areas no prevailing method was recorded but the review revealed a rather balanced distribution.

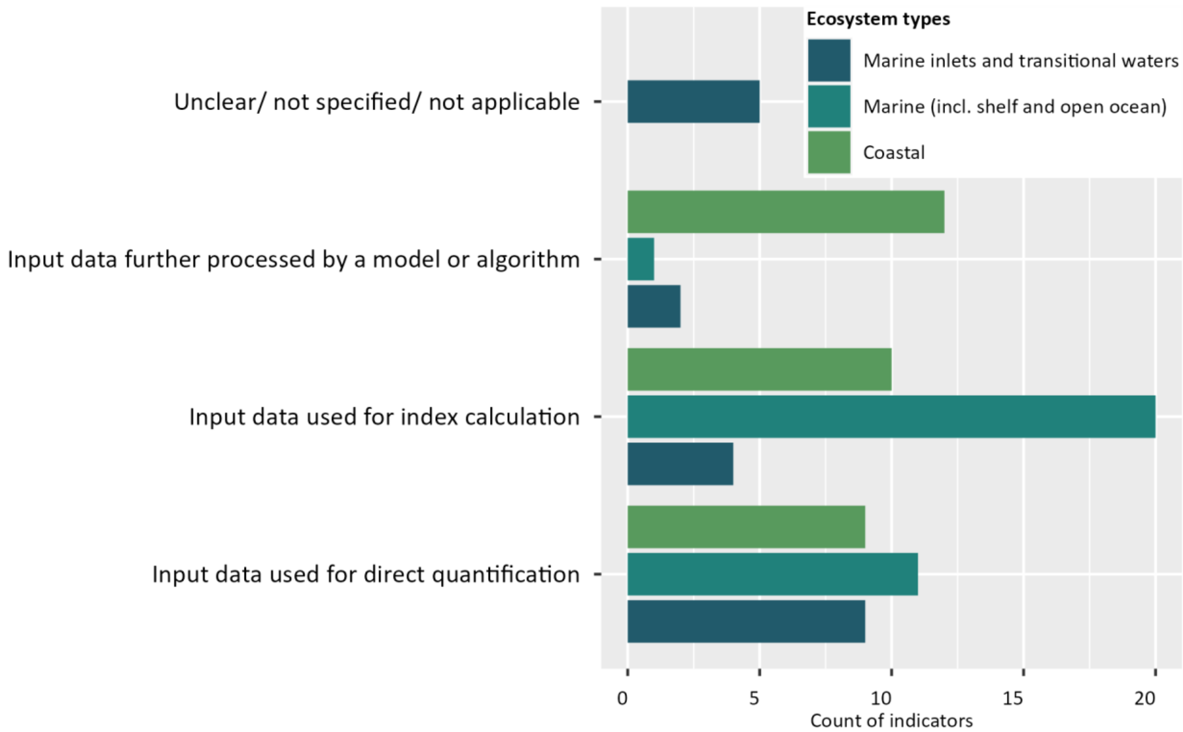

Figure 39: Nature of input data for ecosystem services indicators for rivers and lakes and wetlands. Review aspect allowed for multiple responses.

For marine and coastal ecosystem related EC indicators, mostly no reference level or condition was considered. Contrary to that, for more than 50% of the EC indicators related to marine inlets and transitional waters reference levels or reference condition were considered. Those were predominantly related to semi-natural reference condition, followed by policy target reference level. The respective EC indicators related to the marine and coastal areas solely considered policy target reference level. None of the recorded EC indicators was fully spatially explicit. While the coastal EC indicators were predominantly not spatially explicit, EC indicators related to marine as well as marine inlets and transitional ecosystems were aggregated at ecological and administrative scales (Fig. 40).

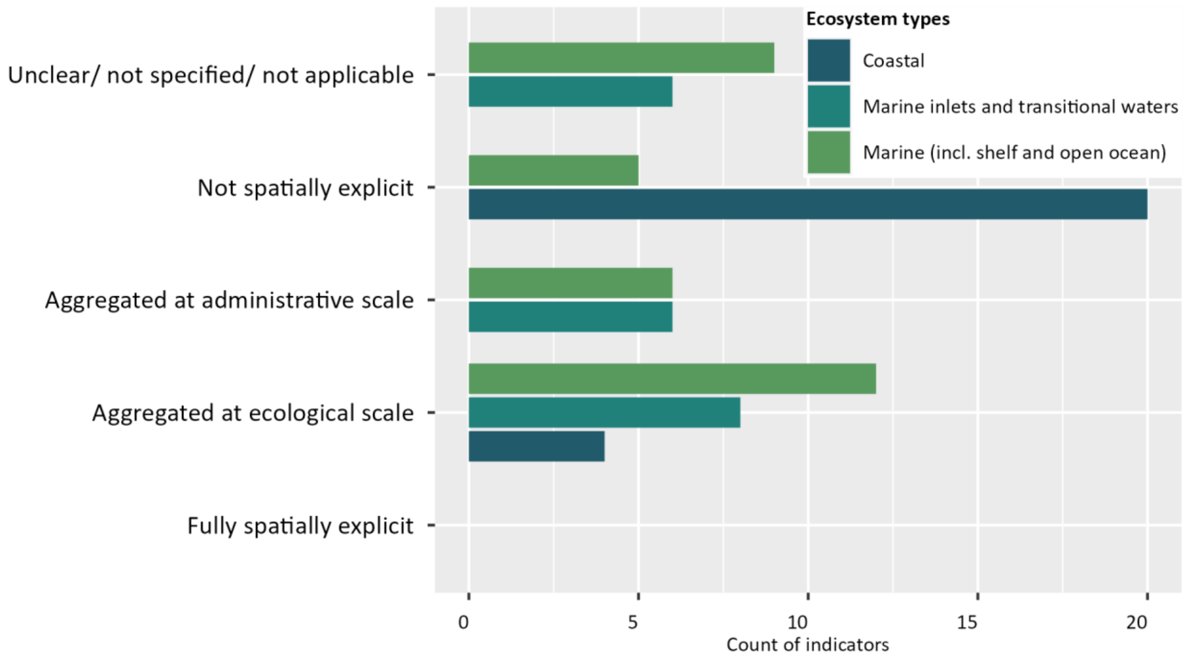

Figure 40: Spatial resolution of ecosystem services indicators for rivers and lakes and wetlands. Review aspect allowed for multiple responses.

For all three ETs, the EC indicators were mostly based on field data. For indicators related to marine ecosystems, in addition to field data, also literature was commonly recorded as input data type. For marine as well as coastal ecosystems, related EC indicators were commonly classified as being part of a composite indicator, composite indicators as well as not being (part of) a composite indicator, whereby for marine ecosystems a dominance towards part of a composite indicator prevailed. Even though for marine inlets and transitional waters the indicator classification roughly followed the trend of coastal areas, very few EC indicators were recorded as composite indicators, leading to a relatively high part of composite indicator/ composite indicator ratio. Through the aggregation of EC indicators, it was possible to aggregate all allocated EC indicators into 28 categories. The 10 most common categories are presented in Figure 41. Most indicators fell into the categories related to the concentration of chemicals in the water (e.g. nitrogen concentration), related to an overarching/ holistic condition indicator (composite indicator e.g. conservation status), and related to the spatial extent of specific habitats (e.g. % cover of corals).

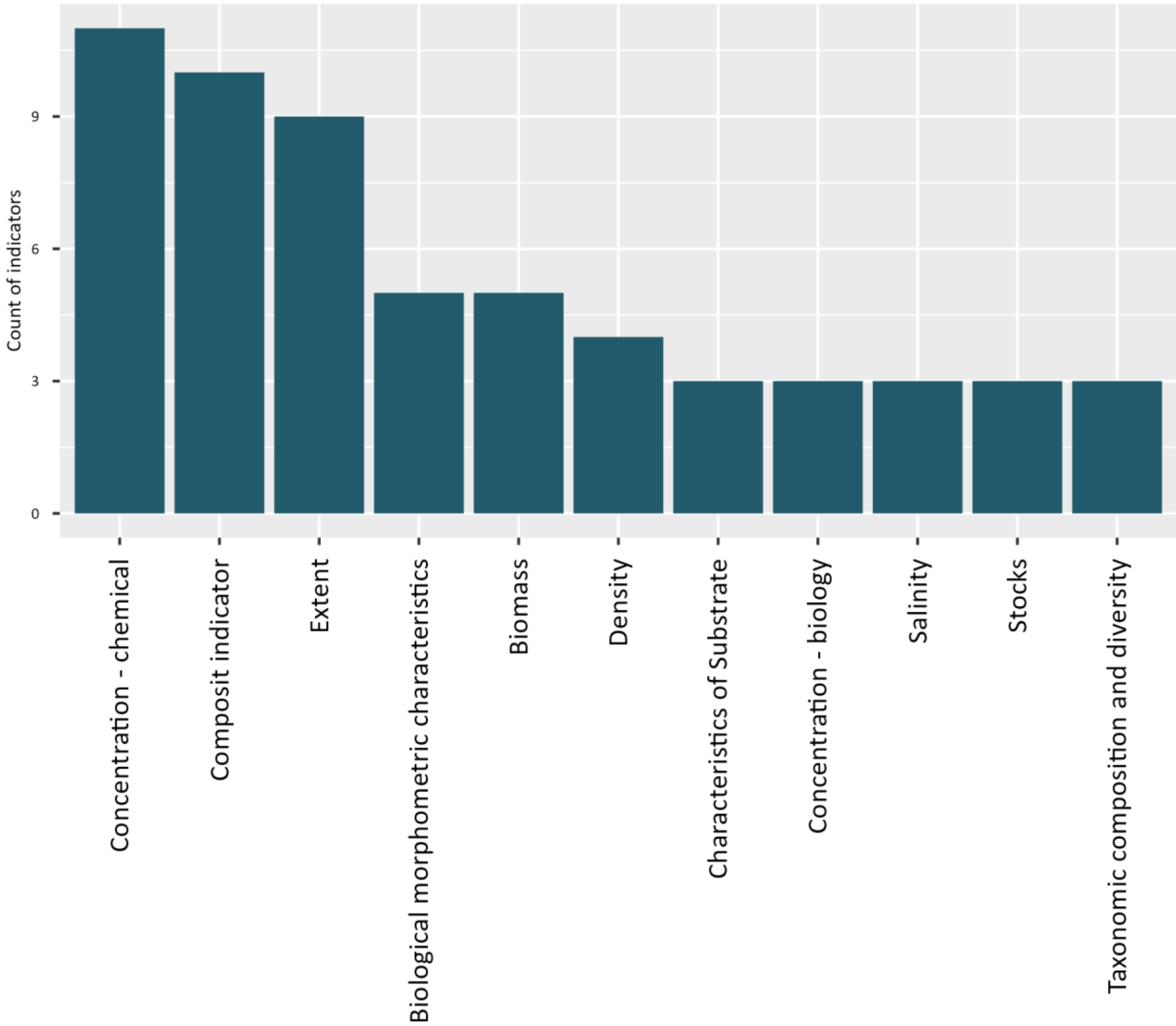

Figure 41: The 10 most frequently assessed aggregated ecosystem condition indicator classes assessed in rivers and lakes and wetlands.

6.3.5.2. Ecosystem service indicators

A total of 67 ES indicators were identified and used to represent 38 different ES. For marine inlets and transitional waters, the indicators identified were related to almost all 38 ES, however mostly related to the two ES CICES v5.1 classes *2.2.6.1 regulation of the chemical composition of the atmosphere and oceans* and *2.2.2.3 maintaining nursery populations and habitats (including gene pool protection)*. Regarding marine ecosystems, the indicators identified represented 7 ES, mostly represented were *2.2.1.1 control of erosion rates* and *2.2.5.1 regulation of chemical conditions of freshwaters by living processes*. The indicators related to marine ecosystems did not correspond to any cultural ES. For coastal ecosystems, the indicators identified represented 13 ES. Six indicators were associated with *2.1.1.2 filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants and animals* as well as *2.2.6.1 regulation of chemical composition of atmosphere and oceans*. For all three ETs, the ES are assessed based upon methods from the biophysical and economic domain. Whereas, for marine inlets and transitional waters, as well as marine ecosystems the distribution was rather evenly between those two method domains, the ES indicators assessed with regard to coastal ET showed a clear tendency towards economic methods.

In line with the spatial resolution of the EC indicators, also for the ES indicators no fully spatial explicit indicator was recorded. The ES indicators were commonly aggregated at the ecological scale (marine inlets and transitional waters as well as marine ETs) or the administrative level (coastal). Several ES indicators in coastal ecosystems were not spatially explicit. The ES Indicator input data for marine inlets and transitional waters was mainly based upon expert opinion (n_i = 30). Input data was mostly derived from literature or field data for coastal and marine ecosystems.

6.3.5.3. Relation between ecosystem condition and ecosystem service(s)

The majority of EC indicators related to coastal and marine ecosystems were recorded to feature relations to specific ES. On the contrary, only a very limited amount (n_i =2) of EC indicators related to marine inlets and transitional waters was recorded to be related to a specific ES. For coastal ecosystems, the EC indicators related to ES were mostly integrated into the ES assessment and to a lesser extent quantitatively compared to the ES (Fig. 42). For those that were compared, a positive relation was found. Most of the identified ES for coastal ecosystems were related to *1.1.6.1 wild animals (terrestrial and aquatic) used for nutritional purposes* and *2.2.1.1 control of erosion rates*. The EC indicators related to marine ecosystems were mostly qualitatively compared, followed by their integration with ES for a third purpose. Again, a positive relation was found for the majority of those indicators that were compared. In marine ecosystems, the most related ES belonged to regulating (e.g. *2.2.5.2 regulation of chemical conditions of salt waters by living processes*, *2.2.6.1 regulation of chemical composition of atmosphere and oceans*, *2.2.2.3 maintaining nursery populations and habitats (including gene pool protection)*) and cultural services (e.g. *3.1.1.1 characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions*). Similarly, to coastal ecosystems, the EC indicators related to marine inlets and transitional waters were either integrated in ES assessment or quantitatively compared to ES assessment results (Fig. 42). Here no relation was found.

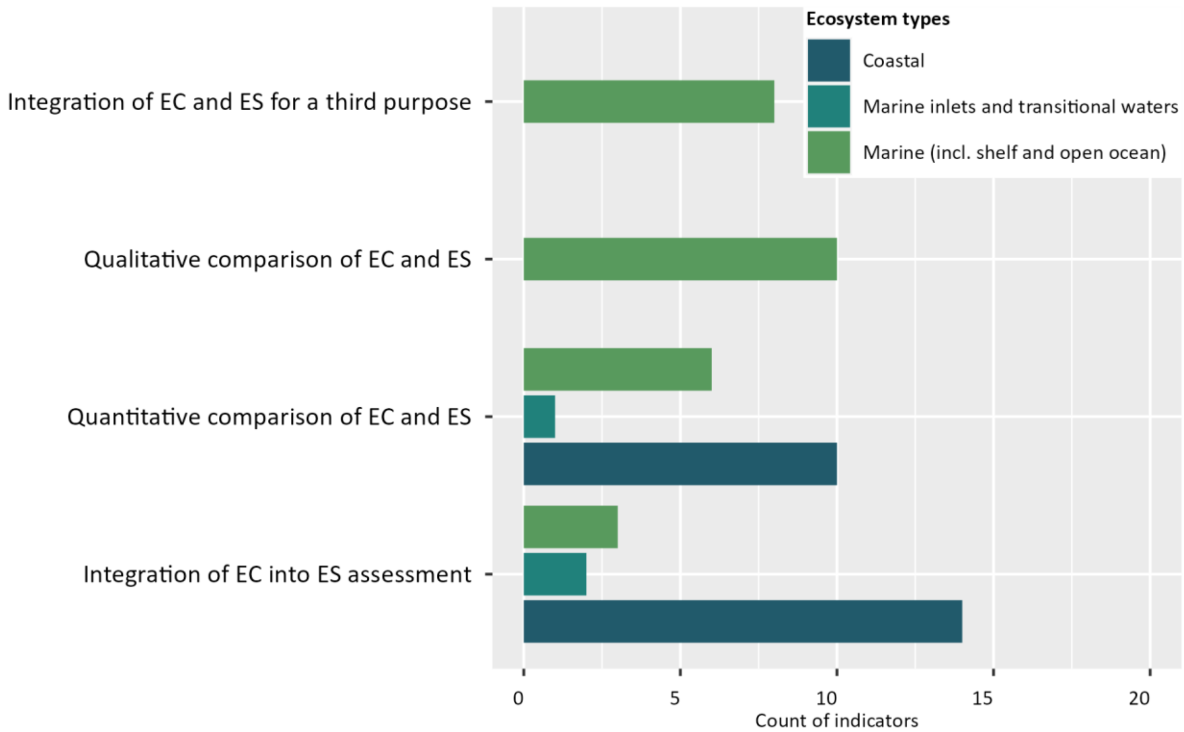

Figure 42: Relation of ecosystem condition and ecosystem services for rivers and lakes and wetlands. Review aspect allowed for multiple responses.

6.3.6. Various, other, unspecified

Lead Chapter authors: Chiara Cortinovis, Jarumi Kato Huerta, Mark Mansoldo and Helena Duchková

The EC indicators and ES recorded in the review, which did not specifically refer to one of the described ETs, are included in this subchapter. This encompasses indicators which were related to more than five ETs, referred to here as "various", as well as indicators that were related to other ETs not described in the main subchapters. Additionally, there were recorded indicators where the authors haven't clearly specified any particular ET.

6.3.6.1. Ecosystem condition indicators

EC indicators related to various ETs (i.e., multiple) were mostly fully spatially explicit, or aggregated at the ecological or administrative scales. Most of the data was sourced from remote sensing, other processed spatial data or statistical data. Additionally, most indicators utilised input data to calculate an index, followed by many which required processing by a model or algorithm. A few of the indicators did not undergo any further data processing and were therefore used for direct quantification (Fig. 43). The majority of the EC indicators assessing multiple ETs were either not incorporated into a composite indicator or were part of a composite indicator. The majority of EC indicators employed in evaluating multiple ETs did not compare to a reference level or condition. Where a reference level or condition was considered, most of the reference levels considered were sourced from a simple data-driven approach, followed by a fixed-year approach, with very few utilising expert-based reference levels or natural reference conditions (Fig. 44).

For the other ETs, the majority of EC indicators were not spatially explicit, yet, almost all indicators were obtained from field data and some from other processed spatial data. More than 80 EC indicators involved the input of data for direct quantification, with some indicators being based upon the calculation of an index (Fig. 43). Around 75% of these EC indicators were part of a composite indicator, whereas only a limited number of composite indicators was recorded.

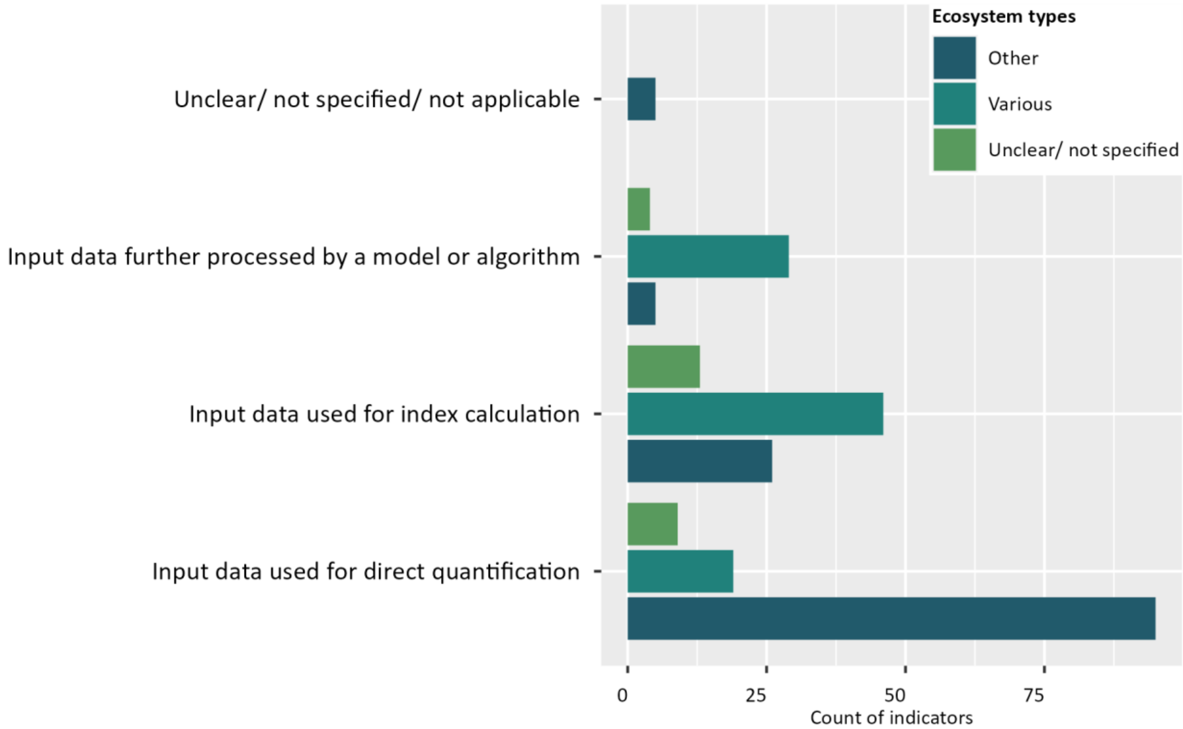

Figure 43: The methodology applied to the input data for the ecosystem condition indicators of multiple and other ecosystem categories. Review aspect allowed for multiple responses.

The vast majority (n_i = 117) of these EC indicators did not consider a baseline reference level or condition. For those that did consider a specific reference level, it was based on a fixed-year approach, policy targets or expert based. Where the ET was unclear or not specified, most EC indicators were assessed through a fixed-year approach or a natural reference condition (Fig. 44).

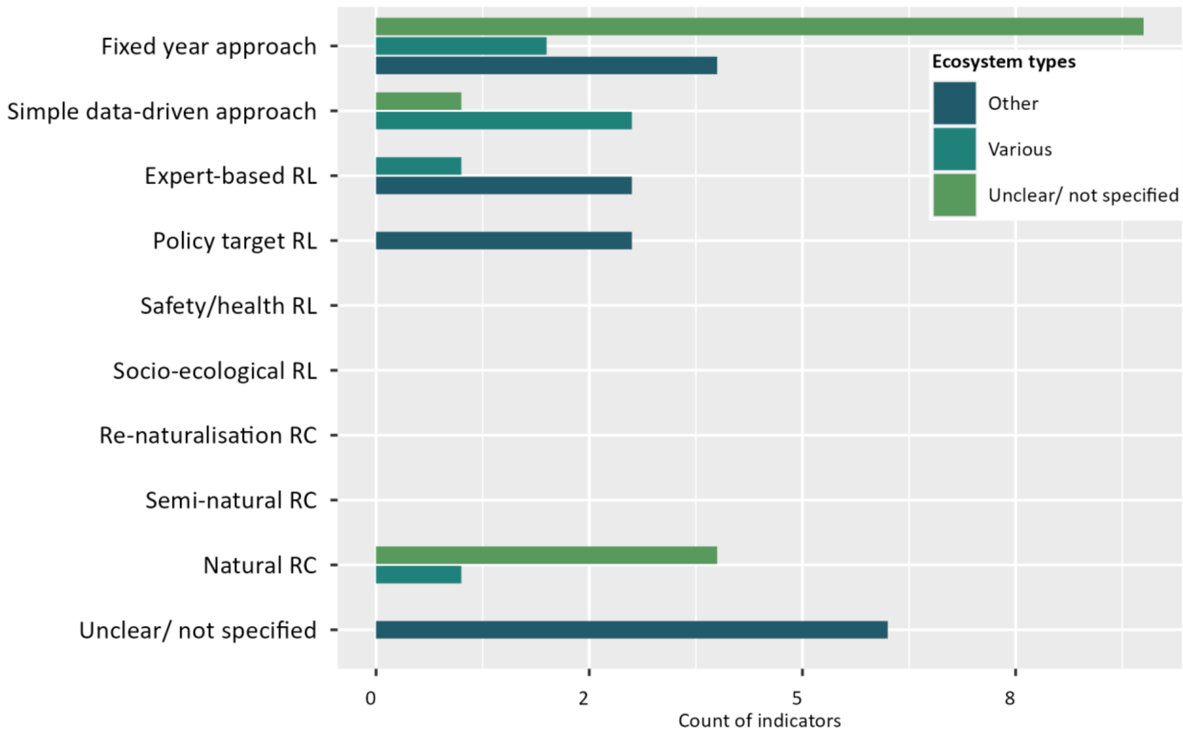

Figure 44: The nature of the reference level or condition where utilised for ecosystem condition indicators across ecosystem types classified as multiple/various, other or unclear. Review aspect allowed for multiple responses.

For the majority of all indicators that were related to multiple, other and unclear ETs, authors did not specify the EC typology class, with very few exceptions where EC indicators were categorised as physical state, functional state or characteristics of the landscape/seascape. Following the aggregation of the EC indicators, the highest number of indicators were related to the landscape and habitat distribution pattern, the concentration of elements and compounds found in the air, soil or water and species richness (Fig. 45).

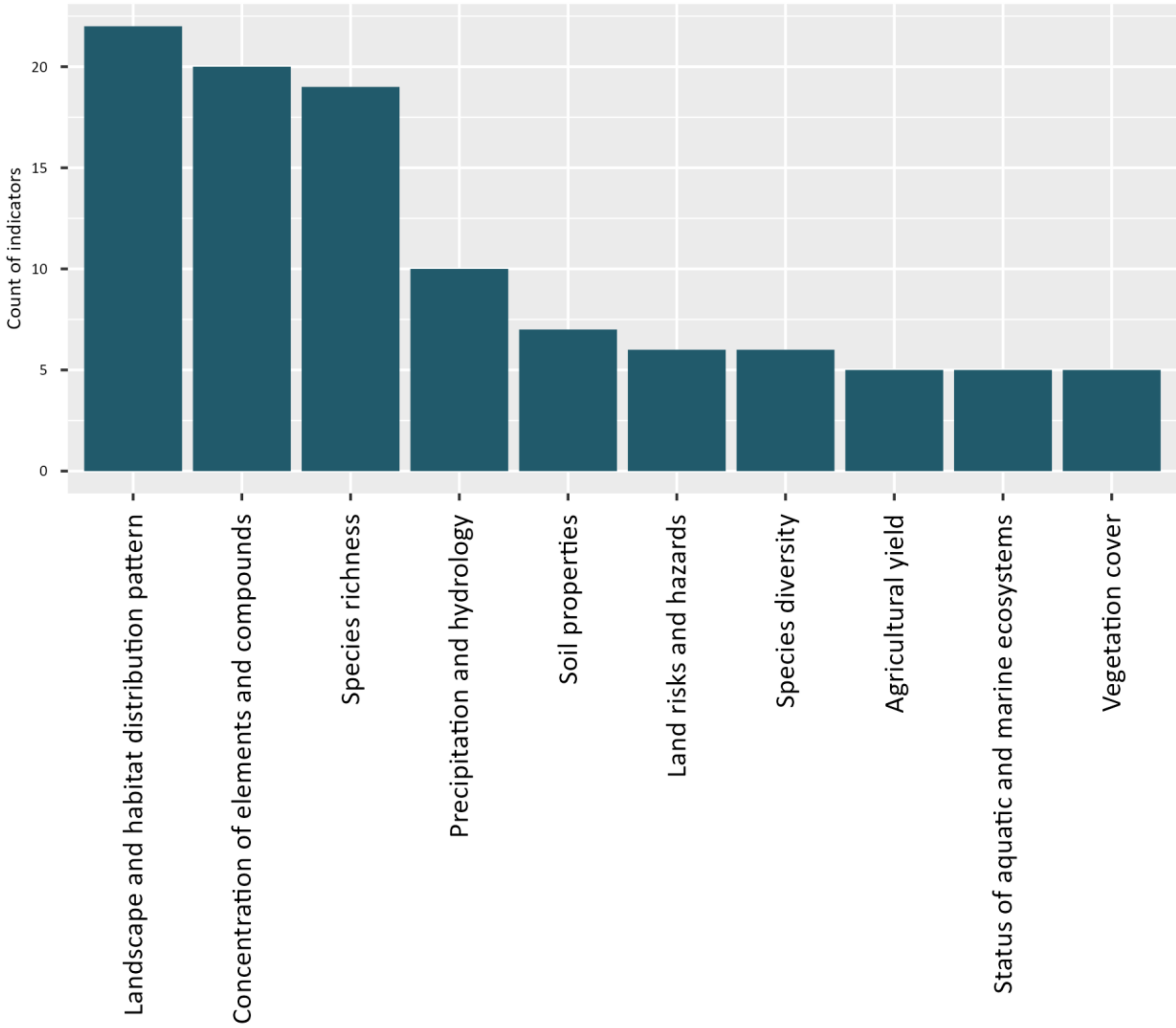

Figure 45: The 10 most frequently assessed aggregated ecosystem condition indicator classes assessed in ecosystem types classified as multiple/various, other or unclear.

6.3.6.2. Ecosystem service indicators

Spatial proxy methods were most commonly used to quantify ES indicators related to various ETs, followed by the use of benefit value transfer and ES assessments. The spatial resolution of the ES indicators was recorded to be rather diverse (distributed evenly between fully spatially explicit, aggregated at ecological scale and not spatially explicit). Most of the input data was sourced from literature, based upon expert opinion and remote sensing. The ES indicators were related to many different ES classes, however, the highest number of indicators were related to *2.2.1.3 hydrological cycle and water flow regulation (including flood control and coastal protection)*, *2.2.6.1 regulation of the chemical composition of atmosphere and oceans* and *3.1.1.1 characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions.*

Spatial proxy methods were also mostly employed in the assessment of ES indicators across the other ETs (n_i = 42), followed by more than 25 ES indicators involving a market price analysis. The ES indicators were mainly aggregated at the administrative scale, drawing on data collected through other forms of processed spatial data and statistical data. For the assessment of other ETs, most of the indicators referred to the ES *2.2.6.1 regulation of chemical composition of atmosphere and oceans*, *2.2.6.2 regulation of temperature and humidity, including ventilation and transpiration* and *4.2.1.2 surface water as a material (non-drinking purposes).*

6.3.6.3. Relation between ecosystem condition and service(s)

The number of indicators applied to assess ES equals almost double the number applied to assess EC in the context of various ETs. Conversely, for other ETs, over 125 indicators have been applied to assess EC, whereas less than 85 indicators have been applied to assess ES (Fig. 46).

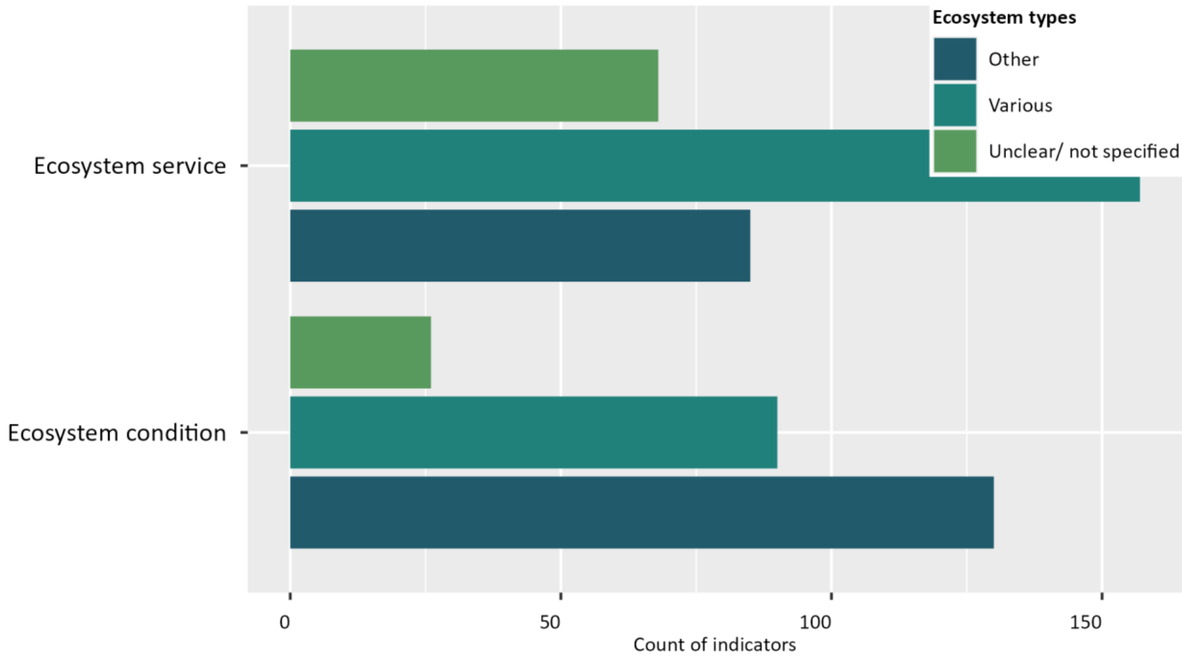

Figure 46: The number of indicators applied to ecosystem condition and services across ecosystem types classified as various, other or unclear.

More than 50% of the indicators related to multiple ETs were evaluated in relation to specific ES. Most of these indicators were related through a qualitative comparison. When EC and ES indicators were compared, mostly no clear relation was found. The highest number of EC indicators used to analyse multiple/various ETs, specifically referred to *1.1.1.1 cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes*, *2.2.1.3 hydrological cycle and water flow regulation (including flood control and coastal protection)* and *2.2.6.1 regulation of chemical composition of atmosphere and oceans*.

The vast majority (n_i = 118) of the EC indicators pertaining to other ETs were related to specific ES. Thereof, the majority was related through the integration of EC into an assessment of ES. The highest number of EC indicators, used to analyse other ETs, specifically referred to *1.1.5.1 wild plants* (terrestrial *and aquatic, including fungi, algae) used for nutrition*, *2.2.2.3 maintaining nursery populations and habitats (including gene pool protection)*, *2.2.4.2* *decomposition and fixing processes and their effect on soil quality* and *3.1.1.1 characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions*.

6.4. Focus on ecosystem accounting

Lead Chapter authors: Nicolas Grondard, Solen Le Clec'h, Vince van 't Hoff and Victoria Guisado Goñi

As the number of papers related to EA was small (n_p = 12), we could not analyse the results of EA papers by ET. We analysed results on EA papers for all ETs together and compared them with the results of non-EA papers (also for all ETs). Hereunder, we present results on a selection of review criteria.

6.4.1. Ecosystem condition indicators

Around 75% of EC indicators in the EA papers were spatially explicit, either fully spatially explicit (n_i = 1) or aggregated at ecological/administrative scale (n_i = 32), but for around 25% of the EC indicators the spatial resolution was not spatially explicit or unclear (Fig. 47). Differences have been observed between the EC indicators that were represented in an EC accounting table and those not represented in an EC accounting table. All EC indicators applied in an EC accounting table were spatially explicit and were mainly aggregated at an ecological scale (63%). EC indicators that were not applied in an EC table were mainly aggregated at an administrative scale (53%).

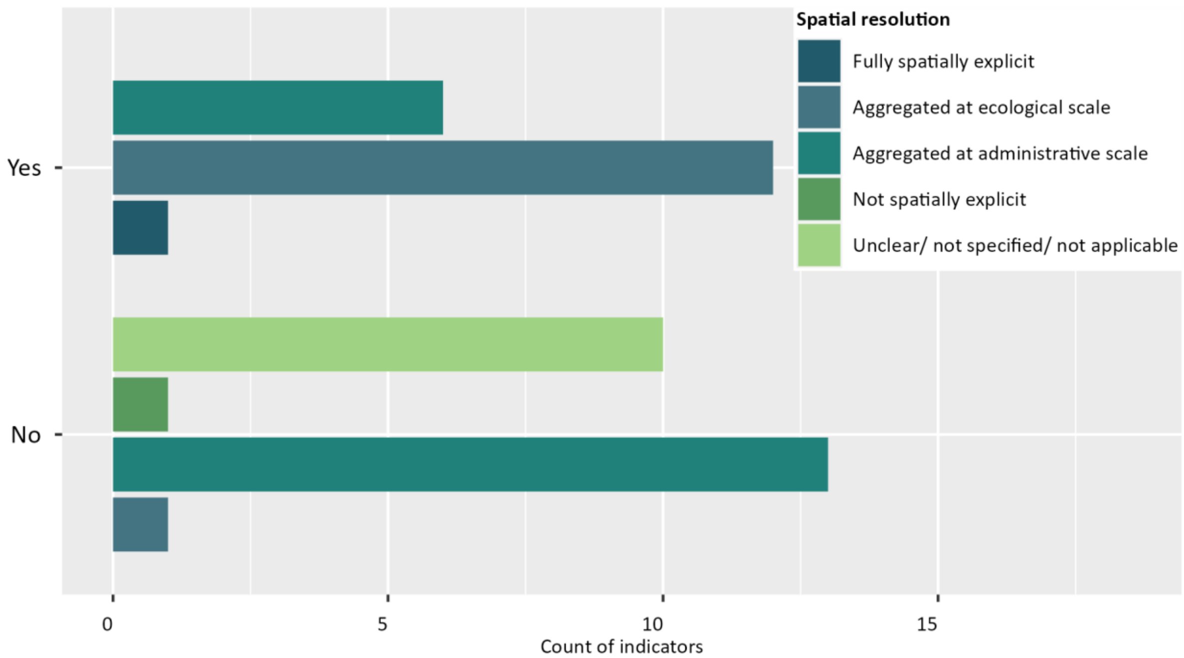

Figure 47: Spatial resolution of ecosystem condition indicators in ecosystem accounting papers (review aspect allowed for multiple responses); yes: Indicators represented in an accounting table, no: Indicators not represented in an accounting table.

In the reviewed EA papers, most indicators of EC were not considered against a reference level. Note that almost all papers considering reference levels were published in 2021, the year from which the new SEEA EA standards required reference levels (Fig. 48).

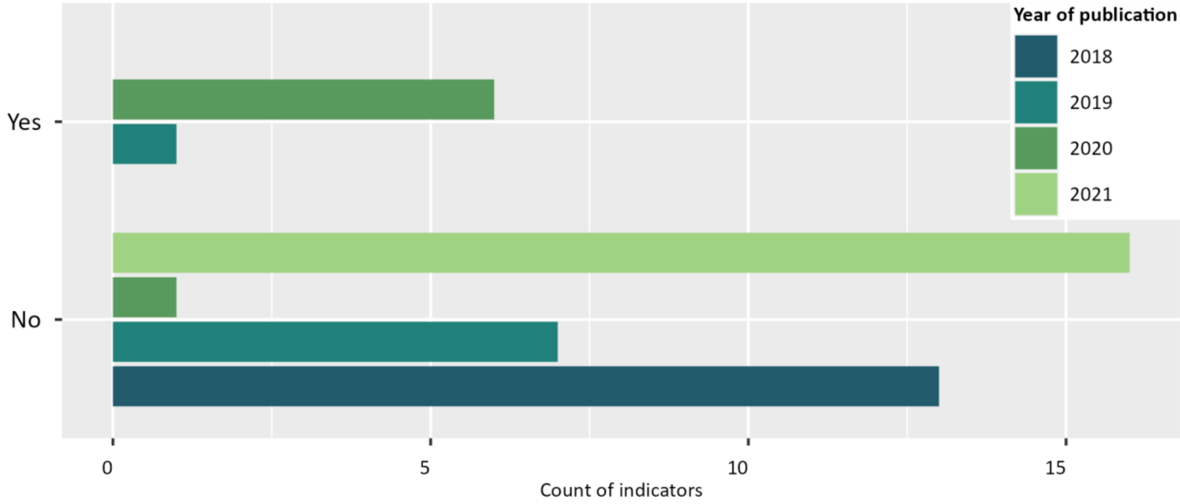

Figure 48: Consideration of reference level in ecosystem condition indicators in ecosystem accounting papers and their respective year of publication.

6.4.2. Ecosystem service indicators

In the EA papers no ES indicator was assessed based upon a method from the socio-cultural domain. In both EA and non-EA papers, the most used biophysical methods were spatial proxies, whereas the second and third most used methods differ between the indicators in the EA and non-EA publications: surveys and questionnaires, statistical and socio-economic data for EA papers; field observations and statistical models for non-EA papers (Fig. 49). Economic methods mostly applied by EA papers were production function, market price and contingent valuation, whereas non-EA papers used mostly value transfer, ecosystem service assessment and market price (Fig. 50).

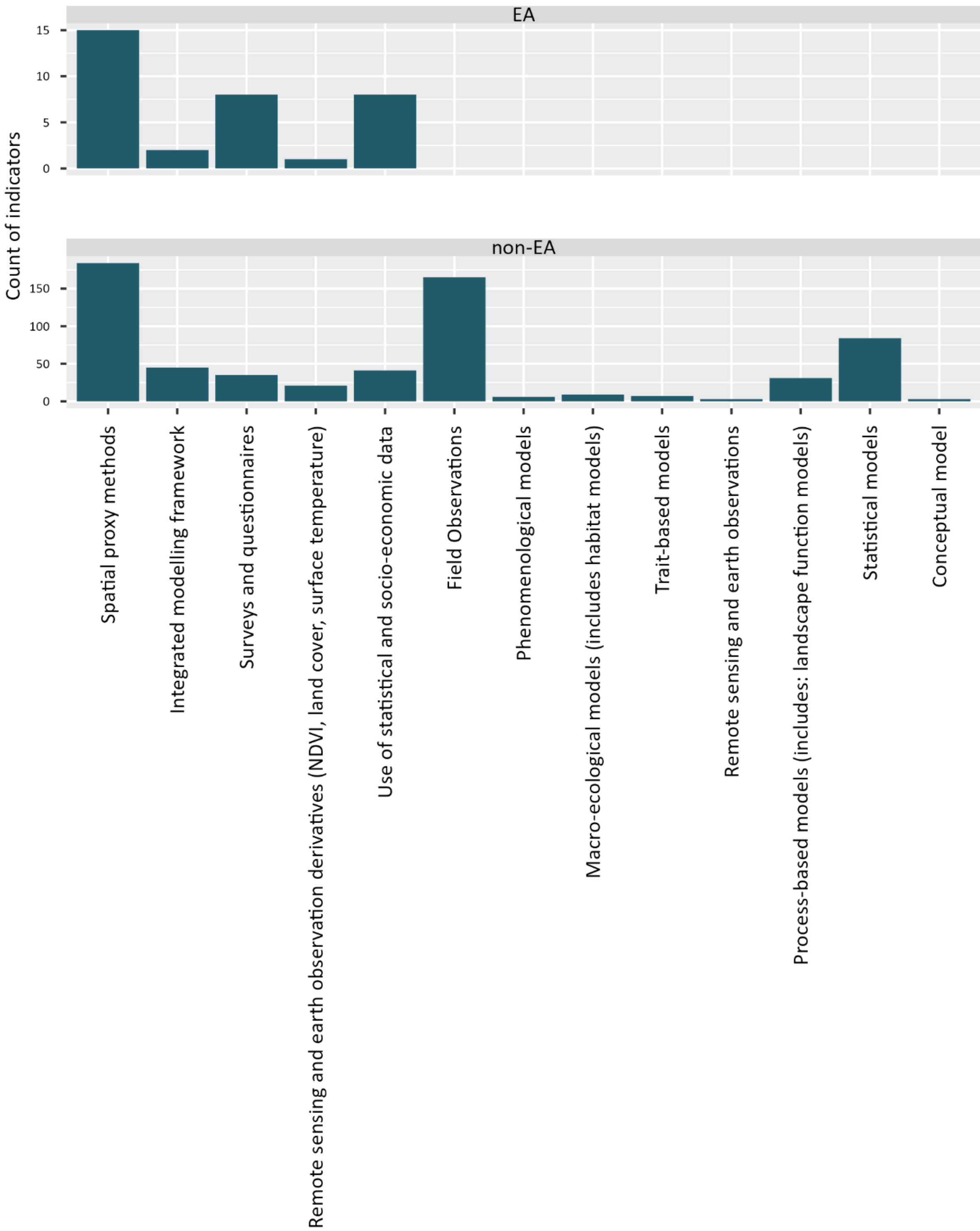

Figure 49: Biophysical methods used to compile ecosystem service indicators in ecosystem accounting papers (top) and non-ecosystem accounting papers (bottom). Review aspect allowed for multiple responses.

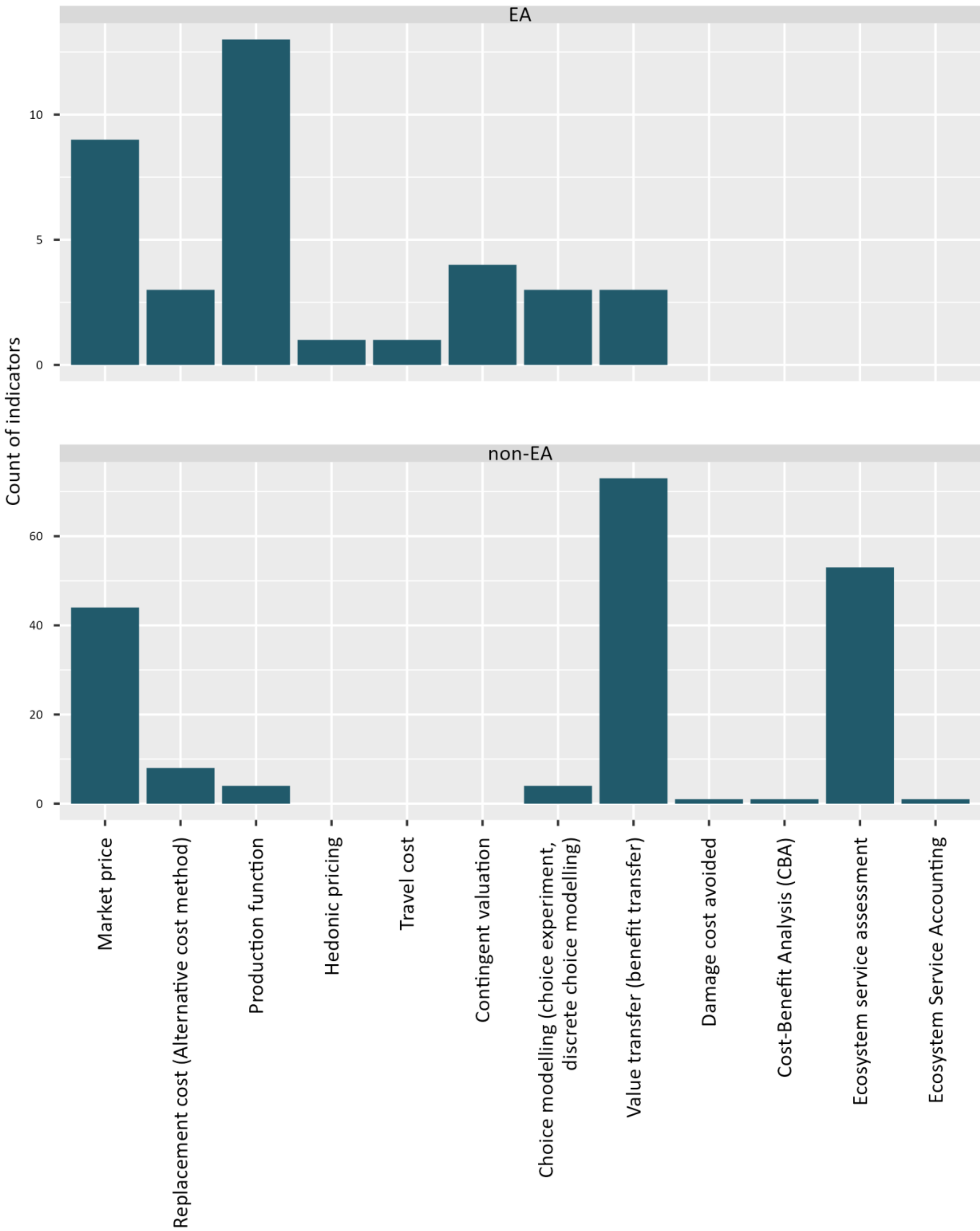

Figure 50: Economic methods used to compile ecosystem service indicators in ecosystem accounting papers (top) and non-ecosystem accounting papers (bottom). Review aspect allowed for multiple responses.

In EA papers, indicators were mostly used to assess (biotic) cultural ES (n_i = 54), then regulation and maintenance ES (n_i = 39), and provisioning ES in similar proportions (n_i = 35). This pattern contrasted with the trend seen in non-EA papers, where indicators were utilised three times as much for evaluating regulation and maintenance ES compared to the other two categories (Fig. 51).

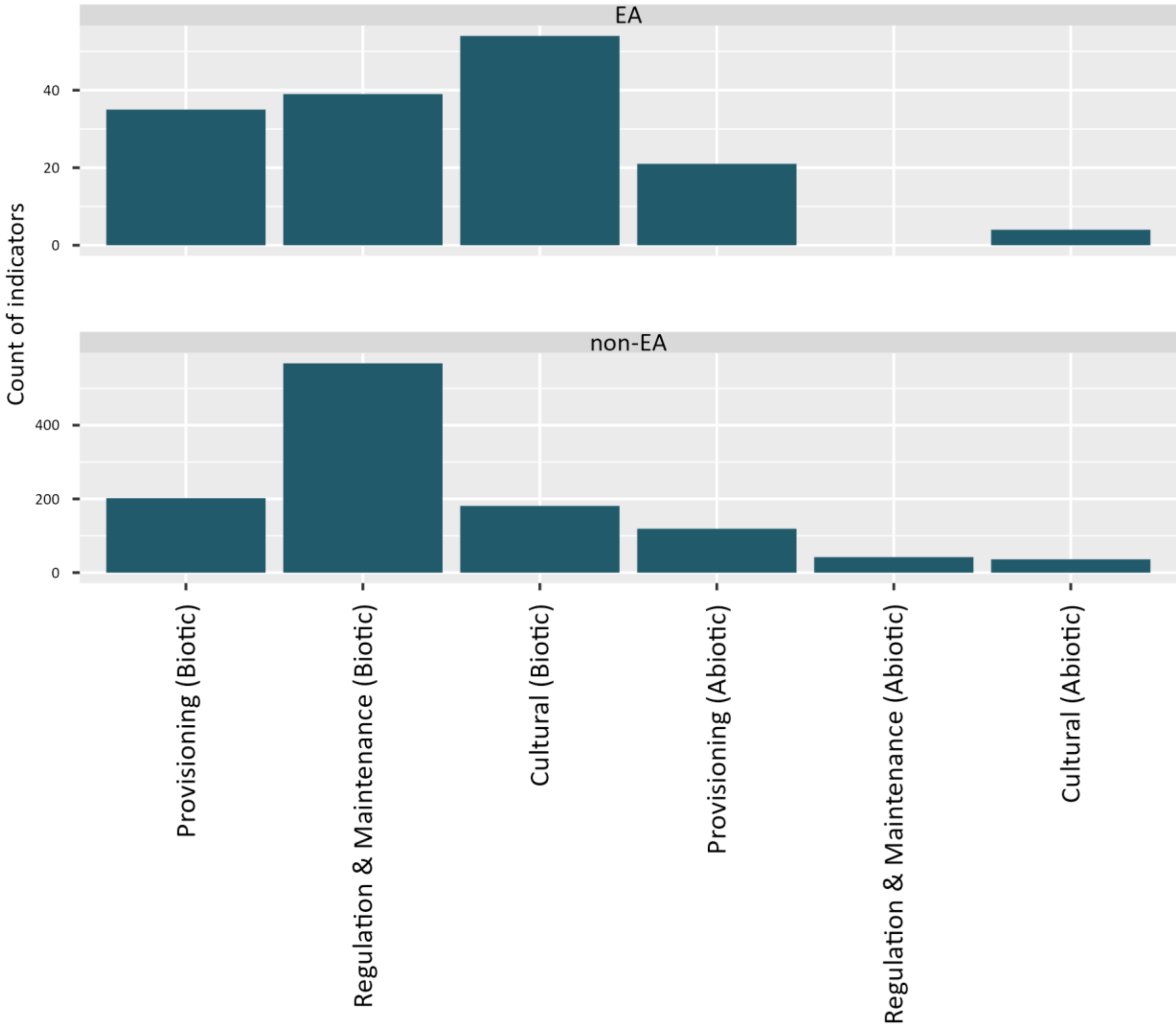

Figure 51: CICES v5.1 Ecosystem service sections in ecosystem accounting papers (top) and non-ecosystem accounting papers (bottom). Review aspect allowed for multiple responses.

About two third of ES indicators in the EA papers were spatially explicit, either fully spatially explicit (n_i = 32) or aggregated at ecological/administrative scale (n_i = 10). The remaining indicators were not spatially explicit (n_i = 22). Proportions of spatially and not spatially explicit indicators were comparable in non-EA papers, but aggregation at ecological/administrative scale was more frequent than full spatial explicitness (Fig. 52).

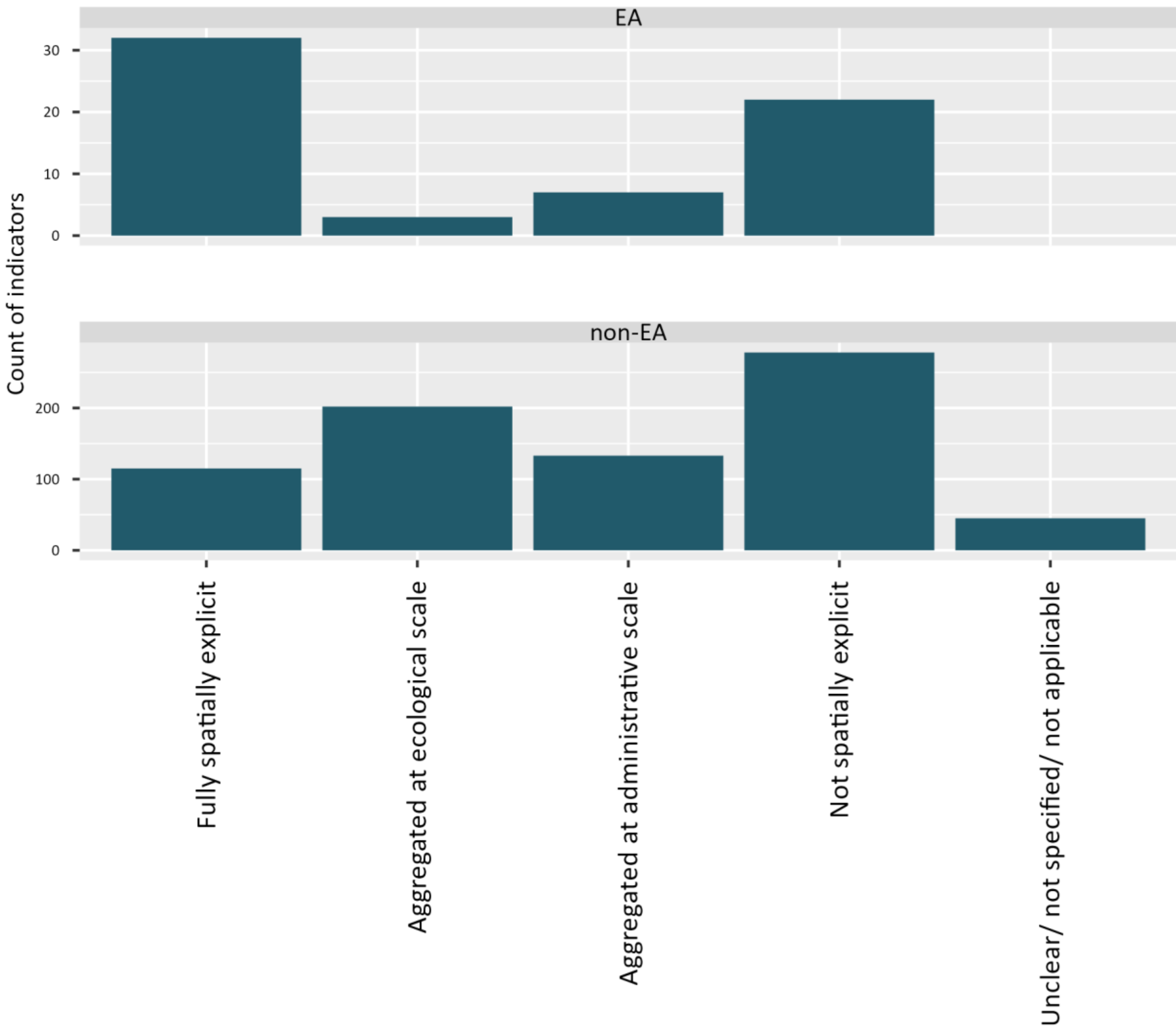

Figure 52: Spatial resolution of ecosystem service indicators in ecosystem accounting papers (top) and non-ecosystem accounting papers (bottom). Review aspect allowed for multiple responses.

7. Discussion

The discussion is structured in multiple sub-chapters. In the following section, notable findings regarding striking aspects or diverging trends between the overall results and results with regard to individual ETs are discussed. This is followed by a more specific exploration of ET related findings and a focused analysis on EA aspects. Eventually, the review's strengths and limitations are discussed.

7.1 General discussion

The evaluation of the indicator specific review results on the level of ETs is in line with the common and most recent international standards and guidelines (UN 2021, European Commission 2022), in which e.g. comprehensive lists of indicators (more specifically: variables) are proposed to assess EC for different ETs. Reference levels, encompassing concrete values of variables indicative of EC, provide a crucial benchmark against which the measured values can be meaningfully compared. Generally, throughout the review and across ETs, a lack of association between EC indicators and reference conditions or reference levels has been identified. This trend is in line with the findings of the "EU-wide methodology to map and assess ecosystem condition" (European Commission 2022) which acknowledges difficulties in setting (uniform) reference levels and thresholds for good EC. Thus, the absence of considered reference conditions or levels may indicate a general gap in understanding or consensus regarding specific reference values (i.e. levels). Yet, with the release of the SEEA EA in 2021 (UN), it is anticipated that more studies will emerge concentrating on establishing and applying reference conditions and values. The EC indicators related to marine inlets and transitional water as well as rivers and lakes were identified to have the greatest share of considered reference levels or conditions, aligning well with the fact that for these ETs the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) are of great relevance and already in place for some years. In the context of these directives, indicators play a crucial role in assessing the status and quality of water bodies and marine environments. These indicators are linked to reference levels or target values, as specific goals or benchmarks for the indicators.

The results revealed that the SEEA EA ECT was hardly ever followed or mentioned in the vast majority of the reviewed papers. Nevertheless, the low numbers may well be explained by the fact that (i) the SEEA EA guidance, including the ECT, was only published in 2021 (UN 2021) and (ii) the time range of the review only included the years 2018 to 2022. Most of the EC indicators in the review were recorded to be part of a composite indicator, relatively closely followed by the option not part of a composite indicator. For the ETs marine, coastal and multiple, a relatively high share of composite indicators was identified, reducing the average number of indicators (i.e., part of composite indicators) feeding into composite indicators.
In their review, Harrison et al. (2014) state that "'ecosystem services' is a relatively new term and, hence, only using this term in a literature search is likely to miss relevant papers" on the interlinkage between biodiversity and ESs. Almost a decade later, we decided to specifically search for papers addressing the ES or NCP concepts and enrich the search query with ecosystem-specific terms.

Looking into the CICES v5.1 sections related to the assessed ES indicators, most ETs followed the general trend identified for the whole review, which was a predominance of regulation & maintenance (biotic) ES and a fairly balanced amount of ES indicators for provisioning (biotic) and cultural (biotic) ES. The ETs urban, wetlands, rivers and lakes as well as marine inlets and transitional water showed a higher tendency towards cultural ES than provisioning ES.

Spatial proxy methods were found to be applied in ES assessments very commonly throughout the identified indicators and across most ETs. Strikingly, the marine and coastal ETs were found to be an exemption from this rule which aligns well with the identified corresponding spatial resolution, where no fully spatially explicit ES indicators were identified. Compared to the input data types used for the assessment of the EC indicators, for the ES indicators the distribution was more balanced. With regard to the ET specific recorded input data types, it is striking that a large share of the ES indicators related to marine inlets and transitional waters were based on expert opinion. It must be taken into consideration that all of these recorded indicators originated from the same publication (Inácio et al. 2018) in which the Marine Ecosystem Services Assessment Tool was developed and applied in two

Baltic lagoons. Moreover, the variation in ES method application across different ETs could be indicative of the suitability and effectiveness of certain methods for assessing specific ESs. For example, woodlands and forests may provide a broader range of quantifiable services that are amenable to spatial biophysical methods, whereas sparsely vegetated lands may provide ES that are more challenging to quantify (and assess). The findings of the review process might indicate that the general prevalence of biophysical methods across the different ETs relates to their robustness and ability to provide tangible, spatially explicit data that can be critical for land management and policy decisions. However, the lesser frequency of methods like CBA and hedonic pricing might reflect the complex, often contentious nature of assigning monetary values to ESs, which can be fraught with ethical, methodological, and practical challenges.

When it comes to the identified relation between EC and ES assessments, mostly a relation was found between an EC indicator and ESs from the CICES v5.1 section regulation and maintenance. This distribution was to be expected, as it is commonly claimed that this relation is more direct and therefore more easily assessable compared to the other ES classes (Grizzetti et al. 2019, Kandziora et al. 2013). In general, most EC indicators were integrated into ES assessments. Nevertheless, several ETs deviate from this trend (e.g. rivers and lakes, wetlands, marine and multiple ETs). For those ETs a lack of integration of EC indicators in ES assessments was identified. Also, the dominant positive relation (direction) that has been identified through the comparison of EC and ES indicators is not followed by all ETs. For grasslands as well as rivers and lakes, the identification of positive and negative relations was recorded to be at a similar magnitude. For grasslands, the review results suggested that some of this was due to the use of EC indicators that in some landscapes would naturally lead to opposing relationships (i.e., Edge density is linked to a positive relation, mean patch size is linked to a negative relation). However, there were other indicators where this was more complex (i.e., the relation of the EC indicator soil organic carbon to ES was reported as both a positive and negative relation, in different publications). No relation was commonly identified for marine inlets, whereas the ETs heathland and shrubs as well as multiple ETs mostly recorded a negative and unclear relation, respectively. Interestingly, here the two arable land ETs cropland and grassland did not follow the same trend. Another interesting point of discussion arose with regard to the identified negative relation between EC and ES indicators. The relative proportion of negative relations identified through qualitative comparisons was rather low (compared to all other method and relation combinations), potentially suggesting that authors might not have initially expected to discover this relation.

The highly diverse distributions of the spatial resolution of EC indicators with regard to the ETs, led to a fairly balanced ratio of spatial resolutions found for all EC indicators. It needs to be noted, that for the marine ETS, a lack of fully spatially explicit indicators (EC and ES) was identified, which aligns with the data scarcity for our planet's ocean that has been highlighted by Townsend et al. (2018). With regard to the input data types that have been recorded in the review for the assessment of the EC indicators, most ETs follow the general trend which indicates that field data was the most commonly used data type. The only exceptions to this rule were the ETs sparsely vegetated land and multiple. For both of these ETs, the majority of the indicators were based upon remote sensing as input data type. For sparsely vegetated land, we considered this an over-representation of remote sensing data from one study in Saudi Arabia (Mallick et al., 2021) which accounted for 5 out of 8 EC indicators for this ET. For the ET multiple, this particularity reflected the potential universality and broad applicability of these indicators (cf. Chapter 7.2, Section on ET multiple).

To summarise, it can be stated that the following key gaps have been identified:

- ★ Lack of understanding regarding the interrelations between EC and the provision of specific ES;
- ★ ET specific lack of integration of EC indicators in ES assessments, in particular in marine ecosystems and wetlands;
- ★ ET specific lack of fully spatially explicit EC and ES indicators, in particular in marine and coastal ETs, and to a lesser extent in heathland and shrubs, wetlands and agroecosystems ETs;
- ★ Lack of association between EC indicators and reference conditions or reference levels;
- ★ Lack of relation between EC indicators and provisioning and cultural ES and
- ★ Lack of prevailing clear differentiation between EC and ES indicators (and other indicators, e.g. those associated with the extent of ecosystems).

7.2 Ecosystem type specific discussion

The assessment of EC in publications focusing on **urban ecosystems** was marked by the use of spatially explicit information and reliance on field data. Indeed, spatially-explicit EC indicators were more frequent than spatially-explicit ES indicators, which was somehow surprising considering the availability and wide application of several spatially-explicit methods for ES assessments in urban areas (Veerkamp et al. 2023, Baró et al. 2016, Gómez-Baggethun et al. 2013). Also, the number of ES linked to EC indicators was high, especially among ES in the "regulation and maintenance" CICES v5.1 section. Furthermore, when assessed, the relationship between EC and ES was often very clear, with authors reporting on either a positive or negative relation. However, a notable limitation emerges in the scarcity of studies that directly assessed and quantified such a relation. Another identified discussion point is the discrepancy between the ES most frequently assessed and those associated with EC. While the CICES v5.1 section of "regulation and maintenance ES" always prevailed, the specific ES most frequently assessed through ES indicators were not the same and were more frequently linked to EC indicators. For example, *2.2.1.3 hydrological cycle and water flow regulation* was by far the most assessed ES, but only seventh in the ranking of the ES most commonly linked to EC indicators. This might suggest issues in comprehending the interrelations between EC and the provision of specific ES or gaps related to existing EC enabled assessment methodologies. This difference highlights the need for more comprehensive studies bridging the gap between EC assessments and the broader understanding of ES provision. Finally, there was a lack of association between EC indicators and reference levels. The absence of these limits the understanding of what constitutes a healthy or desired state for urban ecosystems. Moreover, the lack of explicit reference levels restricts the ability to evaluate whether the current EC state aligns with desired or sustainable conditions, hindering effective management strategies and more comprehensive assessments of EC linked to ES.

For **crop- and grassland** related indicators, in some cases, it was difficult to distinguish between the indicators recorded in the review as EC and actual ES indicators. The underlying concepts were applied with liberal interpretation by some authors, with some indicators presented as characterising condition which might be more appropriately applied as representations of ecosystem extent or services (e.g. Liu et al. 2022). For example, the review identified several 'condition' indicators related to agricultural yield, cultural heritage and aesthetics. Furthermore, it needs to be highlighted that the majority of the studies assessing the condition of cropland and grassland ecosystems did not consider a reference condition or reference levels (more than 92%). The lack of integration of reference levels in most studies hinders the establishment of a standardised framework for assessing and interpreting EC, potentially limiting the depth and accuracy of the evaluations conducted in these agricultural landscapes.

For **woodland and forest, heathland and shrub, and sparsely vegetated land**, large variations in the number of indicators were discovered. Heathland and shrub, and sparsely vegetated land were only exclusively addressed in one publication each (Huerta et al. 2022, Dvarskas 2019). This suggests a potential gap in research on interlinkages of EC and ES indicators for these ETs. This discrepancy also indicates areas where additional research efforts may be reasonable to ensure a more balanced approach to EC and ES assessments and subsequent management actions. Moreover, this imbalance in indicator application across different ETs emphasises the need to tailor research and conservation efforts to the unique conditions and services provided by each ET.

Under the ten most frequently assessed aggregated EC indicator categories, "ES supply" and "ES potential" were listed. Similar to the findings discussed for agroecosystems, it seems surprising that ES indicators are used for an EC assessment. One hypothesis would be that higher (potential) ES supply can be interpreted as reflecting EC. This also reflects the heterogeneous understanding with regard to EC.

Results from the analysis of the indicators review with regard to **rivers, lakes and wetlands** showed various gaps that can be considered for future studies and improvement. In general, wetlands are less studied compared to rivers and lakes. Also, no ES indicators were recorded that only applied to wetland ecosystems. Generally, there were disproportional differences between the numbers of indicators applied to assess EC and ES of the ETs Rivers and lakes, and wetlands which might be linked to the regulations and corresponding availability of monitoring systems and data for freshwater ecosystems that arise from the WFD. Those differences appeared in both ETs – indicators for EC, ES, and relationships between them. As expected, most authors did not relate the assessed EC indicators to the newly established SEEA EA ECT.

The analysis of the indicator review results with regard to **coastal and marine ecosystems** revealed interesting aspects to be considered in future research. The fact that most studies conducted on coastal and marine ecosystems relate EC condition to ES is a positive step towards a better understanding of the interrelationships between both. Assessments that include both, EC and ES, allow to derive an understanding of the magnitude, quantity, and quality of ES provision to some extent. For coastal and marine ecosystems, most studies found a positive relation between EC and ES. This information is essential in decision-making and planning (e.g. Maritime Spatial Planning). However, it is important to note that assessments relating to EC and ES were lacking for marine inlets and transitional waters. Thus, more respective studies should be conducted integrating EC and ES. This is of relevance, for example, in the context of the WFD and the MSFD, by showing the benefits in terms of ES for achieving a good ecological status. This is especially true in the context of the results obtained in this review since most studies on marine inlets and transitional waters considered and compared results to reference conditions when assessing EC indicators. A great share of the indicators identified for EC are related to coastal and marine policies and directives (e.g. WFD, MSFD). For example, in the WFD, the ecological status of water bodies is assessed based on several elements, including chemical conditions (e.g. nutrients) and the extent of habitats (e.g. macroalgae). This suggests the importance of enforcing environmental policies in generating information related to EC. Diving more specifically into the individual findings, regarding EC, most of the studies that applied indicators failed to categorise them according to the SEEA EA ECT. This aspect limits comparing results among studies since indicators can be used in multiple EC categories. Also, there was a general lack of studies defining reference conditions for coastal and marine ecosystems. As mentioned, the consideration of reference condition in future studies was of great importance in order to derive meaningful information on EC, ES, and their relation. Besides, there was a lack of spatially explicit information on EC assessments. Future studies should develop indicators with a spatial perspective, which is highly important and applicable in the context of coastal and marine management and planning. With regard to ES, several studies assessed indicators based on qualitative data (expert knowledge). Future coastal, marine, and transitional water ecosystem studies should assess ES based on quantitative and scientifically robust data. Most studies did not provide spatial, fully explicit information in their ES assessment but aggregate information at the ecological or administrative level. The results were still provided at an interesting and useful scale for decision-making and planning. However, aggregating information means losing spatial explicitness, which is essential to assess better and further understand ES provision. Thus, future studies should apply indicators which can provide fully explicit information, further supporting coastal and marine planning and management.

The classification of indicators spanning **various** (i.e., multiple) ETs holds a profound significance, rooted in the potential universality and broad applicability of these indicators. When an indicator correlates with more than five distinct ETs, it enters this expansive category, hinting at its possible universality. This classification suggests that certain indicators might possess a pervasive influence and relevance that wield across diverse ETs. Understanding the shared relevance of these indicators across multiple ecosystems becomes crucial. Indicators that capture the condition of multiple ETs offer a promising avenue for a comprehensive, simple, and unified approach to integrated ecosystem assessments. However, employing a joined approach introduces complexities in data collection, analysis, and interpretation due to the diverse nature of ETs involved. Harmonising methodologies and approaches for the unique characteristics of each ET poses significant challenges that must not be forgotten. The applicability of such indicators across different ETs may require tailored adaptations. On the contrary, indicators falling under the **other** and **unclear** categories present challenges in interpretation and relevance within ecosystem assessments. Entries designated as "other" often represent ETs not explicitly listed within predefined categories. Their ambiguity can hinder comprehensive analyses and comparisons across established ecosystems, posing difficulties in drawing concrete conclusions or identifying specific strategies. Similarly, indicators categorised as "unclear" lack clarity in defining their associated ETs, making it difficult to attribute their significance or impacts accurately. As a result, these categories present limitations in the meaningful interpretation of their allocated indicators.

7.3 Ecosystem accounting specific discussion

Only 12 papers revolving around ecosystem or natural capital accounts have been selected, a surprisingly low number considering the results of recent reviews on EA implementation in the EU and globally (Hein et al. 2020; Comte et al. 2022; Lange et al. 2022). The small number of selected papers can most likely be explained mainly due to the exclusion of grey literature from the review. As noted by Lange et al. (2022), applied ecosystem accounts are often implemented by governmental institutions (e.g. national statistical offices) or in joint efforts between scientific and governmental institutions, and tend to be published in the grey literature (institutions' websites or reports) rather than in scientific journals. Two recent publications reviewed the scientific and grey literature on EA compiled globally (Hein et al., 2020) and in the EU, UK, and Norway (Lange et al. 2022). A comparison of our results with these two reviews indicates that a significant part of EA applications was missed here. For instance, our selection of EA papers includes accounts compiled in five countries only, whereas reviews by Maes et al. (2020), Hein et al. (2020) and Lange et al. (2022) found accounts compiled in a much larger number of countries. Discrepancies between temporal windows of the studies probably played a role in these differences: Hein et al. (2020) give a state of play for the year 2019, and Lange et al. (2022) include all publications from 1990 to 2021, whereas our review is limited to the period 2018 to 2022. Nevertheless, we think that the exclusion of grey literature from our review is by far the main explanation for the small number of EA applications that we found.

Moreover, it seems our review missed significant scientific publications with EA applications on EC and ESs. In their review of scientific literature on EA, Comte et al. (2022) found 253 articles with EA applications in the period 1990 to 2021. Our review was focused on a narrower time period (2018-2022) than the one by Comte et al. (2022) and it concentrated on EC and ES accounts, which partly explains this difference. However, the number of publications with applications of EA has steadily increased in recent years, reflecting a move from conceptual works towards implementation in case studies (Comte et al. 2022). Around 16 publications related to the practical application of EC and ES accounts, published within our temporal window from the Comte et al. (2022) review, were not included in our final review literature database. This gap might be explained by the specific search terms used in the search query and the interpretation of the inclusion criteria by reviewers. Given the nature of EA, it is unlikely that scientific publications of EC or ES accounts applications did not include indicators of conditions or services. However, the words indicator, variable or proxy may not have been used in the text of some publications and hence led to their exclusion. Moreover, the inclusion criteria “application” of our review may have been interpreted in a different way by Comte et al. (2022).

Given the limited number of EA papers in our review, our results should be interpreted carefully and will need to be confirmed by an extended review including the recent grey literature on EA applications. The lack of reference level consideration in EC indicators may highlight a lack of knowledge or of consensus of reference values and levels. However, following the publication of the new SEEA standard published in 2021 (UN 2021), one can expect that an increasing number of studies will focus on developing and applying such reference levels. The lack of socio-cultural methods to measure ES indicators in EA papers is consistent with the focus of EA on biophysical and monetary quantification of ESs. The higher use of statistical and socio-economic data in EA papers than non-EA papers was also expected, given the links between EA and national statistical offices. It could also explain the relatively higher proportions of ES indicators for provisioning and cultural ES in EA papers compared to non-EA papers, as these two categories of ESs are relatively more straightforward to assess using statistical and socio-economic data than regulation and maintenance ES. Some results were rather surprising. We expected that models (process-based, integrated modelling frameworks) and remote sensing and earth observation would be among the most used biophysical methods, because these methods allow spatially explicit assessments at national scale, an important consideration for EA. Regarding economic methods, most indicators were assessed with EA-aligned methods (e.g. market price, replacement cost, production function), but some papers used welfare-based valuation methods (e.g. contingent valuation, choice modelling, benefit transfer). Moreover, about one-third of ES indicators in EA papers were evaluated as not spatially explicit. Given that spatial explicitness is a core feature of EA, this is a very surprising outcome that should be further checked and analysed.

7.4 Strengths and limitations

The **search strategy** employed in this literature review might have led to the omission of relevant studies due to the limitation to scientific English publications, the application of the specific inclusion/exclusion criteria, the choice of database, and the search terms used (see Chapter 7.3 for specific details on this matter with regard to EA). In particular through the heterogeneous terminology that is used with regard to e.g. the concept of EC, there might be additional relevant synonyms that have not been included. This could influence the comprehensiveness of the review and potentially introduce selection bias. Besides, scientific literature reviews are time-sensitive and dependent on the available literature in the selected considered time period. As new studies are constantly being published, the review might lack the most recent developments, impacting the comprehensiveness and currency of the analysis. The exclusive emphasis on scientific literature in the review process resulted in the omission of potentially valuable findings or insights available within grey literature sources. This has been found to be relevant in particular with regard to publications on ecosystem accounts, as those are often implemented by governmental institutions (e.g. national statistical offices) or in joint efforts between scientific and governmental institutions, and tend to be published in the grey literature (see Chapter 7.3) (Lange et al. 2022).

The development of precise **inclusion criteria** was crucial during this literature review. In the developmental phase, the elaboration of clear and well-defined inclusion criteria helped the T6.1 task force establish meaningful boundaries of the review, ensuring that the selected literature aligns with the specific focus and objectives. Additionally, the development of precise inclusion criteria contributed to the overall quality and rigour of the literature review. By clearly outlining the characteristics that articles or studies must possess to be included, the task force minimised ambiguity and subjectivity in the selection process. This enhanced the reliability and replicability of the review, as all reviewers followed the same criteria to achieve consistent results. Also, it encouraged a more systematic and organised approach to literature review execution. Moreover, having precise inclusion criteria facilitated the efficient identification and retrieval of relevant literature. Researchers streamlined their search process by excluding irrelevant studies based on the established criteria, saving time and resources in the review process.

In addition to the elaborated inclusion criteria, further detailed materials, including the elaborated review template, and guidance materials were compiled as well as training sessions conducted to ensure maximum consistency among individual reviewers along all of the individual screening and reviewing steps. In that context the compilation of our review template (cf. Chapter 5.3) can be regarded as a methodological achievement in structuring and streamlining the literature review process. Nevertheless, it is important to acknowledge that despite all of these efforts, a certain level of bias persisted. This bias potentially arose from a.o., inherent subjectivity in interpretation, diverse perspectives among reviewers, and potential nuances in understanding or assessing certain criteria. Even though the Fleiss' Kappa assessment results proved the validity and robustness of the screening process, these results need to be cautiously interpreted as the sample size for the calculation was rather small. It needs to be noted that a limitation arises from the fact that some reviewers received assistance from colleagues in screening and reviewing their allocated literature items. Consequently, in these instances, papers relevant for calculating Fleiss' Kappa were considered only once per team, impacting the analysis. Thus, the review process certainly involved **subjective judgement** to some degree. This subjectivity might have led to interpretation biases or inconsistencies in the process, impacting the overall quality of the review and the respective conclusions drawn. We experienced that in particular when it came to the identification of publications and indicators related to ecosystem accounts, a bias persisted in favouring the faulty identification of ecosystem accounts. To address this issue, all relevant publications were double-checked and the review template entries adapted by the sub-group with expertise on EA. Also, identifying the ES aspect proved challenging for reviewers, particularly in distinguishing between ES potential/capacity and ES flow/actual use/supply and use. As a result, we handled these specific findings with consideration.

Particularly in the past year, with the introduction of ChatGPT version 3.5[8] to the general public (Mahuli et al. 2023), the use of **artificial intelligence (AI)** and large language models has increased drastically. There are already first attempts to use the benefits of AI for systematic literature reviews (Atkinson 2023, Mahuli et al. 2023, Khalil et al. 2022, van Dinter et al. 2021). As Task 6.1 and the procedures for the systematic review were conceptualised before the release of ChatGPT, the use of AI was not foreseen and thus was not leveraged here. However, once the review was completed, its results were fed into ResearchRabbit, an AI-based tool to support literature search, to get an idea about the potential applications and usefulness of such tools. For the future, it may be beneficial to use AI-tools notably to facilitate labour-intensive tasks, though the results on the author and paper connections gathered here were not satisfying for a systematic approach (yet).

Challenges arise from the heterogeneity and inconsistency in used terminology (Pinto et al. 2022, Inácio et al. 2022, Gomes et al. 2021). Therefore, throughout the literature review, we

[8] https://openai.com/blog/chatgpt

prioritised standardised methodologies and referenced and integrated **common classifications and definitions**, amongst which CICES v5.1 and the SEEA EA ECT (UN 2021). This approach strengthened the review by ensuring consistency, facilitating a clearer understanding for readers and researchers, and enabling better connections with existing research, thereby enhancing the review's credibility, consistency, relevance, and contribution to the field. However, as potential shortcoming in this context, it should be acknowledged that for the classification of the ES methods in the review template predefined answering options were provided, leading to occasional challenges in classification, especially considering that the list originated from the (ESMERALDA) MAES Methods Explorer[9] and was not updated since 2018 and, possibly, new methods or advancements have emerged since then. Nevertheless, to counter this, the option "other" was also made available to list a different method, and reviewers had to indicate their own uncertainty regarding the method selection. When applicable, many reviewers experienced very low to low (around 42%) levels of uncertainty when classifying the ES methods (e.g. field observations, ES assessment and statistical methods). However, there was also a significant number of methods with (especially) medium (around 46%) and higher level (around 11%) of uncertainty (e.g. for value transfer: n_i = 20, and spatial proxy methods: n_i = 18). Besides, during the review process, it was found that the methods applied to assess ES that were predefined in the review template can belong to multiple method categories simultaneously. For example, statistical data, recorded as a biophysical method in the considered method classification might also encompass aspects belonging to the social and economic domains.

Furthermore, the initial quality of the scientific publications included in the review varied significantly. Heterogeneity in study designs, methodologies, and sample sizes across different studies affected the synthesis of findings and the ability to draw overarching conclusions. More specifically, several publications included in the review lack **comprehensive reporting** of methods, results, or key indicators, leading to incomplete information. Missing data or selective reporting within the publications hindered a thorough analysis. In this context the heterogeneity of concepts, definitions and understandings encountered in the reviewed literature items needs to be highlighted. These aspects impact scientific literature reviews negatively by introducing significant challenges with regard to consistent data retrieval, potentially leading to ambiguity, inconsistencies, and issues in synthesising or comparing findings. In addition, the decision to collect the reviewed information on an indicator basis, may have additionally caused a study bias in the form of an over-representation or over-estimation of methodological procedures from studies that assessed numerous indicators, e.g. dominant remote sensing data as input for the assessment of sparsely vegetated land based on one publication (cf. Chapter 7.1). In addition, the decision to collect the reviewed information on an indicator basis, may have additionally caused a study bias in the form of an over-representation or over-estimation of methodological procedures from studies that assessed numerous indicators, e.g. dominant remote sensing data as input for the assessment of sparsely vegetated land based on one publication (cf. Chapter 7.1).

During the review process, for most fields, the reviewers were asked to adhere to the **wording and statements applied by the original authors**, without any interpretation, inference, or

[9] https://database.esmeralda-project.eu/

subjective evaluation of information, and the few review questions where the reviewers were expected to make an interpretation were clearly highlighted in the review template. Consequently, most of the errors made by the original authors would be incorporated into the review database without alteration or correction. In particular, the authors often displayed a high degree of flexibility in linking the different indicators to the diverse elements of the framework being addressed, presenting a metrics characterising the extent of an ecosystem or an ES as an "ecosystem condition indicator". For instance, the review revealed EC indicators associated with agricultural yield, cultural heritage, and aesthetics. Based upon that, further challenges emerged with regard to the reclassification and aggregation of EC indicators. Another shortcoming arose from the fact that the limitations mentioned in the publications reviewed were not considered, potentially introducing an additional bias into the existing results.

Another challenge arising from the review template design was caused by the fact that several fields allowed for multiple selection of response options. This was beneficial to keep the review template more concise, but on the downside, it made the evaluation of the results more challenging as the use of relative numbers and comparisons between ETs were less intuitive.

Some publications included multiple EC and ES indicators but only on a subset of these EC and ES indicators was related. It is important to note that in the results section all EC and ES indicators included in the relevant publications have been described, thus, **not every result is specifically tailored** to the EC and ES indicators that were directly linked or included within an ecosystem account. Generally, the **reclassification and aggregation of EC indicators** was based on a bottom-up approach with no predefined categories; hence inconsistencies between the different ET teams were to be expected. Also, the process may have been influenced by the dominant expertise and research fields of the researchers involved in the ET related task.

8. Synthesis

In conclusion, the systematic literature review undertaken in this Deliverable 6.1 serves as a foundational stepping stone in identifying the current knowledge base on the relation between EC and ES indicators, and their application in EA. Based upon the findings of the review, the two research questions posed in the introduction are addressed.

RQ1: Which ecosystem condition indicators are deduced to assess which ecosystem services in recent scientific publications (pre-SELINA)?

The review revealed a diverse and complex landscape of relations between EC and ES indicators. While a predominantly recorded relation was observed between certain EC indicators and regulation and maintenance ES, disparities and complexities emerged across different ETs. Marine ecosystems and wetlands, notably, demonstrated a lack of integration between EC and ES indicators, indicating specific gaps in understanding and alignment within these contexts. Further, a lack of clarity and common understanding with regard to the concept of EC and EC indicators was identified, e.g. no clear differentiation between EC and ES indicators.

RQ2: Which indicators are integrated into ecosystem condition and service(s) accounts in recent scientific publications (pre-SELINA)?

In recent scientific publications, the indicator-focused integration of EC and ES into ecosystem accounts appeared limited, with only 12 papers selected for review. This low number can primarily be attributed to the exclusion of grey literature, the specific search query focusing on indicators and the narrow timeframe. All of these shortcomings need to be considered when evaluating the findings with regard to this research question: The majority of the EC indicators that were integrated into ecosystem accounts lack a consideration of reference conditions or reference levels. Also, there was a scarcity of socio-cultural methods in EA papers aligning with the EA's emphasis on biophysical and monetary quantification of ESs. The ES indicators related to EA studies were commonly quantified based upon statistical and socio-economic data. Surprisingly, around one-third of ES indicators in EA papers lacked spatial explicitness, a notable deviation from EA's fundamental principles that requires further investigation.

Furthermore, beyond the formulated research questions, relevant findings have been revealed. For example, the information assessed on the application of ES methods are useful to understand which methods are most commonly applied and perhaps to infer which might be considered the most reliable or standard for specific assessments among the different ETs. Moreover, these results could also indicate fields where more methodological development or application is needed.

In addition to the content related findings, there are some practical recommendations that we would like to put forward to guide future research on the discussed topics. Numerous publications considered in this review lack comprehensive reporting. We have learned that this poses challenges for consistent data retrieval, potentially causing inconsistencies, and difficulties in synthesising or comparing findings. Therefore, we highly recommend transparent and explicit reporting. In this context, also the variation in concepts and definitions across the research domain, in particular with regard to EC, poses additional challenges and limits the collaborative development of a holistic understanding of EC in general and with regard to ES. Also, the uptake of research results is hindered. Therefore, we argue for streamlining future research with international efforts and established classifications. In this context, future research would, e.g. benefit from assigning any applied EC indicators to the corresponding SEEA EA ECT in order to contribute to streamlining EC efforts by establishing a more coherent terminology and enhancing the structure and organisation of individual indicators. At the same time, this would lay the foundation for the efficient incorporation of this information for future developments of ecosystem accounts.

Generally, the findings and limitations identified provide a solid foundation for the upcoming SELINA Tasks to seamlessly integrate and build upon, navigating the connections between EC indicators and ESs, while addressing the specified gaps.

As the review was designed to target the needs of various user groups, the different pieces of information will be further processed, reported and disseminated e.g. in the form of a scientific publication directed towards the academic community as well in practice-oriented guidance material for practitioners and decision-makers, starting from the DPs in WP8 and

WP9. The various forms of anticipated dissemination and relations to other SELINA efforts, are outlined in the following section.
Conceptually and practically, Task 6.1 is related to Task 3.2 ("derive a minimum set of key ecosystem condition indicators per ecosystem type") as both tasks execute a scientific literature review including aspects of EC on the indicator level. The current communication will be maintained and the results on the EC indicators will be shared.
The review results also relate very directly to the Task 6.6 ("Operational database development") as the indicator specific information will be fed into the developed database. Alongside providing the data, the lessons learned from the review regarding specific fields and predefined options will be shared. For instance, based upon the challenges that arose from the initial ES method classification, recommendations will be shared, i.e. slight modifications in the classification system to allow for recent method developments.
The main gaps identified in the review on ecosystem accounts originate from excluding grey literature, the review's narrow temporal window and specific focus on indicators (also in the search query) resulting in a limited number of identified publications. In Task 6.3 ("Integration through standardisation with ecosystem accounting"), these shortcomings can be addressed, by integrating grey literature, refining search terms, and harmonising inclusion criteria to comprehensively capture recent trends and implementations in EA, ensuring a more exhaustive review of its applications.
Further, the review results with regard to the topic of integration, will be shared with the Task 6.4 ("Integrated ecosystem assessment"), where they will support the development of a uniform integrated ecosystem assessment framework.
Based upon the findings of this review we will develop guidance material for the public and private DPs that are hosted in the SELINA WP8 and WP9. The guidance material will allow them to harness the available information they need, select useful EC and ES indicators, and access existing databases. To ensure the meaningfulness of the guidance material, the DPs' interests will be collected beforehand and integrated into the development process. In addition to that, the findings will also be integrated into the Task 10.4 ("Guidance for the decision-making for different sectors") where the final and overarching guidance from the SELINA project will be collected and harmonised to feed into the Compendium of Guidance (CoG).
The outlook for compiling a scientific paper based on the findings described in this Deliverable involves a comprehensive approach. This includes updating the database using the Deliverable's insights, addressing inconsistencies and data gaps, and delving deeper into the concrete relationship between EC and ES indicators. There is a potential for evaluating EC indicators based on SEEA EA criteria and aiming for cross-ET homogenization of indicator aggregation, ensuring a more robust and standardised analysis across various ecological landscapes.

The progress with regard to the scientific understanding of EC (indicators) and in particular the relation between EC (indicators) and ESs is crucial for improving credibility, the establishment of a solid foundation to support policies, decision-making (in both the public and private sector) and legal instruments. Only through informed decisions, we will be able to set meaningful targets for restoration (European Commission 2022). Hence, despite the acknowledged limitations, the outcomes of this review can be regarded as a significant contribution, not only within the scope of the SELINA project but also beyond, paving the way towards a holistic understanding of our ecosystems and towards informed decision-making.

9. References

Andreasen, J. K., O'Neill, R. V., Noss, R., & Slosser, N. C. (2001). Considerations for the development of a terrestrial index of ecological integrity. Ecological Indicators.

Atkinson, C. F. (2023). Cheap, Quick, and Rigorous: Artificial Intelligence and the Systematic Literature Review. Social Science Computer Review, 08944393231196281. https://doi.org/10.1177/08944393231196281

Bae, J., Sohn, W., Newman, G., Gu, D., Woodruff, S., Van Zandt, S., Ndubisi, F., Wilkins, C., Lee, J., & Tran, T. (2021). A longitudinal analysis of green infrastructure conditions in Coastal Texan cities. Urban Forestry & Urban Greening, 65, 127315. https://doi.org/10.1016/j.ufug.2021.127315

Balvanera, P., Quijas, S., Martín-López, B., Barrios, E., Dee, L., Isbell, F., Durance, I., White, P., Blanchard, R., & Groot, R. D. (2016). The Links Between Biodiversity and Ecosystem Services. In M. Potschin, R. Haines-Young, R. Fish, & R. K. Turner (Eds.), Routledge Handbook of Ecosystem Services (1st ed., pp. 45–61). Routledge. https://doi.org/10.4324/9781315775302-5

Barbier, E. B. (2017). Marine ecosystem services. Current Biology, 27(11), R507–R510. https://doi.org/10.1016/j.cub.2017.03.020

Baró, F., Palomo, I., Zulian, G., Vizcaino, P., Haase, D., & Gómez-Baggethun, E. (2016). Mapping ecosystem service capacity, flow and demand for landscape and urban planning: A case study in the Barcelona metropolitan region. Land Use Policy, 57, 405–417. https://doi.org/10.1016/j.landusepol.2016.06.006

Batjes, N. H. (1996). Total carbon and nitrogen in the soils of the world. European Journal of Soil Science, 47(2), 151–163. https://doi.org/10.1111/j.1365-2389.1996.tb01386.x

Boerema, A., Rebelo, A. J., Bodi, M. B., Esler, K. J., & Meire, P. (2017). Are ecosystem services adequately quantified? Journal of Applied Ecology, 54(2), 358–370. https://doi.org/10.1111/1365-2664.12696

Brady, N. C., & Weil, R. R. (2008). The nature and properties of soils (14th ed). Pearson Prentice Hall.

Bruzón, A. G., Arrogante-Funes, P., & Santos-Martín, F. (2023). Modelling and testing forest ecosystems condition account. Journal of Environmental Management, 345, 118676. https://doi.org/10.1016/j.jenvman.2023.118676

Buchhorn, M., Smets, B., Danckaert, T., Van Loo, M., Broekx, S., & Peelaerts, W. (2022). Establishing a reference tool for ecosystem accounting in Europe, based on the INCA methodology. One Ecosystem, 7, e85389. https://doi.org/10.3897/oneeco.7.e85389

Buonocore, E., Grande, U., Franzese, P. P., & Russo, G. F. (2021). Trends and Evolution in the Concept of Marine Ecosystem Services: An Overview. Water, 13(15), 2060. https://doi.org/10.3390/w13152060

Burkhard, B., Lange, S., Seguin, J., Czúcz, B., Geneletti, D., Immerzeel, B., Liekens, I., & Nedkov, S. (2023). Development of the SELINA Internal Glossary v1.0 (Internal Report 01; SELINA).

Burkhard, B., & Maes, J. (Eds.). (2017). Mapping Ecosystem Services. Pensoft Publishers. https://doi.org/10.3897/ab.e12837

Burkhard, B., Maes, J., Potschin-Young, M., Santos-Martín, F., Geneletti, D., Stoev, P., Kopperoinen, L., Adamescu, C., Adem Esmail, B., Arany, I., Arnell, A., Balzan, M., Barton, D. N., Van Beukering, P., Bicking, S., Borges, P., Borisova, B., Braat, L., M Brander, L., … Zulian, G. (2018a). Mapping and assessing ecosystem services in the EU - Lessons learned from the ESMERALDA approach of integration. One Ecosystem, 3, e29153. https://doi.org/10.3897/oneeco.3.e29153

Burkhard, B., Santos-Martin, F., Nedkov, S., & Maes, J. (2018b). An operational framework for integrated Mapping and Assessment of Ecosystems and their Services (MAES). One Ecosystem, 3, e22831. https://doi.org/10.3897/oneeco.3.e22831

Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P. W., Trisos, C., Romero, J., Aldunce, P., Barrett, K., Blanco, G., Cheung, W. W. L., Connors, S., Denton, F., Diongue-Niang, A., Dodman, D., Garschagen, M., Geden, O., Hayward, B., Jones, C., … Péan, C. (2023). IPCC, 2023: Climate

Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. (First). Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.59327/IPCC/AR6-9789291691647

Cole, V., & Boutet, M. (2023). ResearchRabbit (product review). Journal of the Canadian Health Libraries Association / Journal de l'Association Des Bibliothèques de La Santé Du Canada, 44(2), 43–47. https://doi.org/10.29173/jchla29699

Comte, A., Campagne, C. S., Lange, S., Bruzón, A. G., Hein, L., Santos-Martín, F., & Levrel, H. (2022). Ecosystem accounting: Past scientific developments and future challenges. Ecosystem Services, 58, 101486. https://doi.org/10.1016/j.ecoser.2022.101486

Czúcz, B., & Arany, I. (2016). Indicators for ecosystem services. OpenNess Project.

Czúcz, B., Götzl, M., Schwaiger, E., Sonderegger, G., & Condé, S. (2018). Fact sheets on ecosystem condition: A synthesis (ETC/BD Report to the EEA). https://www.eionet.europa.eu/etcs/etc-bd/products/etc-bd-reports/etc-bd-report-12-2018-fact-sheets-on-ecosystem-condition

Czúcz, B., Keith, H., Maes, J., Driver, A., Jackson, B., Nicholson, E., Kiss, M., & Obst, C. (2021). Selection criteria for ecosystem condition indicators. Ecological Indicators, 133, 108376. https://doi.org/10.1016/j.ecolind.2021.108376

Ding, R., Yu, K., Fan, Z., & Liu, J. (2022). Study and Application of Urban Aquatic Ecosystem Health Evaluation Index System in River Network Plain Area. International Journal of Environmental Research and Public Health, 19(24), 16545. https://doi.org/10.3390/ijerph192416545

Dragulescu, A., & Arendt, C. (2020). xlsx: Read, Write, Format Excel 2007 and Excel 97/2000/XP/2003 Files. https://CRAN.R-project.org/package=xlsx

Dvarskas, A. (2019). Experimental ecosystem accounting for coastal and marine areas: A pilot application of the SEEA-EEA in Long Island coastal bays. Marine Policy, 100, 141–151. https://doi.org/10.1016/j.marpol.2018.11.017

Edens, B., Maes, J., Hein, L., Obst, C., Siikamaki, J., Schenau, S., Javorsek, M., Chow, J., Chan, J. Y., Steurer, A., & Alfieri, A. (2022). Establishing the SEEA Ecosystem Accounting as a global standard. Ecosystem Services, 54, 101413. https://doi.org/10.1016/j.ecoser.2022.101413

Edrisi, S. A., El-Keblawy, A., & Abhilash, P. C. (2020). Sustainability Analysis of Prosopis juliflora (Sw.) DC Based Restoration of Degraded Land in North India. Land, 9(2), 59. https://doi.org/10.3390/land9020059

European Commission. (n.d.-a). Biodiversity strategy for 2030. Retrieved December 29, 2023, from https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

European Commission. (n.d.-b). Nature Restoration Law. Retrieved December 29, 2023, from https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en

European Commission. (2013). Mapping and assessment of ecosystems and their services: An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020. Publications Office of the European Union. https://data.europa.eu/doi/10.2779/22870

European Commission, & Directorate-General for Environment. (2014). Mapping and assessment of ecosystems and their services: Indicators for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020. Publications Office of the European Union. https://data.europa.eu/doi/10.2779/75203

Fang, X.-S., Liu, S., Chen, W.-Z., & Wu, R.-Z. (2021). An Effective Method for Wetland Park Health Assessment: A Case Study of the Guangdong Xinhui National Wetland Park in the Pearl River Delta, China. Wetlands, 41(4), 44. https://doi.org/10.1007/s13157-021-01418-5

Farrell, C., Coleman, L., Norton, D., Kelly-Quinn, M., Obst, C., Eigenraam, M., O'Donoghue, C., Kinsella, S., Smith, F., Sheehy, I., & Stout, J. (2021). Developing peatland ecosystem accounts to guide targets for restoration. One Ecosystem, 6, e76838. https://doi.org/10.3897/oneeco.6.e76838

Feng, S., Liu, X., Zhao, W., Yao, Y., Zhou, A., Liu, X., & Pereira, P. (2022). Key Areas of Ecological Restoration in Inner Mongolia Based on Ecosystem Vulnerability and Ecosystem Service. Remote Sensing, 14(12), 2729. https://doi.org/10.3390/rs14122729

Field, C. B., Behrenfeld, M. J., Randerson, J. T., & Falkowski, P. (1998). Primary Production of the Biosphere: Integrating Terrestrial and Oceanic Components. Science, 281(5374), 237–240. https://doi.org/10.1126/science.281.5374.237

Fleiss, J. L. (1971). Measuring nominal scale agreement among many raters. Psychological Bulletin, 76(5), 378–382. https://doi.org/10.1037/h0031619

Fleiss, J. L., Levin, B., & Paik, M. C. (2003). Statistical Methods for Rates and Proportions (1st ed.). Wiley. https://doi.org/10.1002/0471445428

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., … Zaks, D. P. M. (2011). Solutions for a cultivated planet. Nature, 478(7369), 337–342. https://doi.org/10.1038/nature10452

Franklin, J. F., Spies, T. A., Pelt, R. V., Carey, A. B., Thornburgh, D. A., Berg, D. R., Lindenmayer, D. B., Harmon, M. E., Keeton, W. S., Shaw, D. C., Bible, K., & Chen, J. (2002). Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest Ecology and Management, 155(1–3), 399–423. https://doi.org/10.1016/S0378-1127(01)00575-8

Geijzendorffer, I. R., Martín-López, B., & Roche, P. K. (2015). Improving the identification of mismatches in ecosystem services assessments. Ecological Indicators, 52, 320–331. https://doi.org/10.1016/j.ecolind.2014.12.016

Geijzendorffer, I. R., Regan, E. C., Pereira, H. M., Brotons, L., Brummitt, N., Gavish, Y., Haase, P., Martin, C. S., Mihoub, J., Secades, C., Schmeller, D. S., Stoll, S., Wetzel, F. T., & Walters, M. (2016). Bridging the gap between biodiversity data and policy reporting needs: An Essential Biodiversity Variables perspective. Journal of Applied Ecology, 53(5), 1341–1350. https://doi.org/10.1111/1365-2664.12417

Geneletti, D., Adem Esmail, B., Cortinovis, C., Arany, I., Balzan, M., Van Beukering, P., Bicking, S., Borges, P., Borisova, B., Broekx, S., Burkhard, B., Gil, A., Inghe, O., Kopperoinen, L., Kruse, M., Liekens, I., Lowicki, D., Mizgajski, A., Mulder, S., … Veidemane, K. (2020). Ecosystem services mapping and assessment for policy- and decision-making: Lessons learned from a comparative analysis of European case studies. One Ecosystem, 5, e53111. https://doi.org/10.3897/oneeco.5.e53111

Glenn, J. K., & Goldman, J. (1976). Task delegation to physician extenders—Some comparisons. American Journal of Public Health, 66(1), 64–66. https://doi.org/10.2105/ajph.66.1.64

Gomes, E., Inácio, M., Bogdzevič, K., Kalinauskas, M., Karnauskaitė, D., & Pereira, P. (2021). Future land-use changes and its impacts on terrestrial ecosystem services: A review. Science of The Total Environment, 781, 146716. https://doi.org/10.1016/j.scitotenv.2021.146716

Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. Ecological Economics, 86, 235–245. https://doi.org/10.1016/j.ecolecon.2012.08.019

Grizzetti, B., Liquete, C., Pistocchi, A., Vigiak, O., Zulian, G., Bouraoui, F., De Roo, A., & Cardoso, A. C. (2019). Relationship between ecological condition and ecosystem services in European rivers, lakes and coastal waters. Science of The Total Environment, 671, 452–465. https://doi.org/10.1016/j.scitotenv.2019.03.155

Guerry, A. D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G. C., Griffin, R., Ruckelshaus, M., Bateman, I. J., Duraiappah, A., Elmqvist, T., Feldman, M. W., Folke, C., Hoekstra, J., Kareiva, P. M., Keeler, B. L., Li, S., McKenzie, E., Ouyang, Z., Reyers, B., … Vira, B. (2015). Natural capital and ecosystem services informing decisions: From promise to practice. Proceedings of the

National Academy of Sciences, 112(24), 7348–7355. https://doi.org/10.1073/pnas.1503751112
Guo, M., Shu, S., Ma, S., & Wang, L.-J. (2021). Using high-resolution remote sensing images to explore the spatial relationship between landscape patterns and ecosystem service values in regions of urbanization. Environmental Science and Pollution Research, 28(40), 56139–56151. https://doi.org/10.1007/s11356-021-14596-w
Haines-Young, R., & Potschin, M. (2018). Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure. https://cices.eu/content/uploads/sites/8/2018/01/Guidance-V51-01012018.pdf
Harrison, P. A., Berry, P. M., Simpson, G., Haslett, J. R., Blicharska, M., Bucur, M., Dunford, R., Egoh, B., Garcia-Llorente, M., Geamănă, N., Geertsema, W., Lommelen, E., Meiresonne, L., & Turkelboom, F. (2014). Linkages between biodiversity attributes and ecosystem services: A systematic review. Ecosystem Services, 9, 191–203. https://doi.org/10.1016/j.ecoser.2014.05.006
Hatziiordanou, L., Fitoka, E., Hadjicharalampous, E., Votsi, N., Palaskas, D., & Malak, D. (2019). Indicators for mapping and assessment of ecosystem condition and of the ecosystem service habitat maintenance in support of the EU Biodiversity Strategy to 2020. One Ecosystem, 4, e32704. https://doi.org/10.3897/oneeco.4.e32704
Hein, L., Bagstad, K. J., Obst, C., Edens, B., Schenau, S., Castillo, G., Soulard, F., Brown, C., Driver, A., Bordt, M., Steurer, A., Harris, R., & Caparrós, A. (2020). Progress in natural capital accounting for ecosystems. Science, 367(6477), 514–515. https://doi.org/10.1126/science.aaz8901
Heink, U., & Jax, K. (2019). Going Upstream—How the Purpose of a Conceptual Framework for Ecosystem Services Determines Its Structure. Ecological Economics, 156, 264–271. https://doi.org/10.1016/j.ecolecon.2018.10.009
Hooper, D. U., Chapin, F. S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J. H., Lodge, D. M., Loreau, M., Naeem, S., Schmid, B., Setälä, H., Symstad, A. J., Vandermeer, J., & Wardle, D. A. (2005). Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. Ecological Monographs, 75(1), 3–35. https://doi.org/10.1890/04-0922
Huang, X., Rippy, M. A., Mehring, A. S., Winfrey, B. K., Jiang, S. C., & Grant, S. B. (2018). Shifts in dissolved organic matter and microbial community composition are associated with enhanced removal of fecal pollutants in urban stormwater wetlands. Water Research, 137, 310–323. https://doi.org/10.1016/j.watres.2018.03.020
Huerta, S., Marcos, E., Fernández-García, V., & Calvo, L. (2022). Short-term effects of burn severity on ecosystem multifunctionality in the northwest Iberian Peninsula. Science of The Total Environment, 844, 157193. https://doi.org/10.1016/j.scitotenv.2022.157193
Inácio, M., Barceló, D., Zhao, W., & Pereira, P. (2022). Mapping lake ecosystem services: A systematic review. Science of The Total Environment, 847, 157561. https://doi.org/10.1016/j.scitotenv.2022.157561
Kandziora, M., Burkhard, B., & Müller, F. (2013a). Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators—A theoretical matrix exercise. Ecological Indicators, 28, 54–78. https://doi.org/10.1016/j.ecolind.2012.09.006
Kandziora, M., Burkhard, B., & Müller, F. (2013b). Mapping provisioning ecosystem services at the local scale using data of varying spatial and temporal resolution. Ecosystem Services, 4, 47–59. https://doi.org/10.1016/j.ecoser.2013.04.001
Kassambara, A. (2019). Inter-Rater Reliability Essentials: Practical Guide In R. independently published.
Keith, D. A., Ferrer-Paris, J. R., Nicholson, E., Bishop, M. J., Polidoro, B. A., Ramirez-Llodra, E., Tozer, M. G., Nel, J. L., Mac Nally, R., Gregr, E. J., Watermeyer, K. E., Essl, F., Faber-Langendoen, D., Franklin, J., Lehmann, C. E. R., Etter, A., Roux, D. J., Stark, J. S., Rowland, J. A., … Kingsford, R. T. (2022). A function-based typology for Earth's ecosystems. Nature, 610(7932), 513–518. https://doi.org/10.1038/s41586-022-05318-4

Khalil, H., Ameen, D., & Zarnegar, A. (2022). Tools to support the automation of systematic reviews: A scoping review. Journal of Clinical Epidemiology, 144, 22–42. https://doi.org/10.1016/j.jclinepi.2021.12.005

Kobayashi, Y., Seidl, R., Rammer, W., Suzuki, K. F., & Mori, A. S. (2023). Identifying effective tree planting schemes to restore forest carbon and biodiversity in Shiretoko National Park, Japan. Restoration Ecology, 31(1). https://doi.org/10.1111/rec.13681

Korpilo, S., Jalkanen, J., Virtanen, T., & Lehvävirta, S. (2018). Where are the hotspots and coldspots of landscape values, visitor use and biodiversity in an urban forest? PLOS ONE, 13(9), e0203611. https://doi.org/10.1371/journal.pone.0203611

La Notte, A., Czúcz, B., Vallecillo, S., Polce, C., & Maes, J. (2022). Ecosystem condition underpins the generation of ecosystem services: An accounting perspective. One Ecosystem, 7, e81487. https://doi.org/10.3897/oneeco.7.e81487

La Notte, A., Vallecillo, S., Grammatikopoulou, I., Polce, C., Rega, C., Zulian, G., Kakoulaki, G., Grizzetti, B., Ferrini, S., Zurbaran-Nucci, M., Garcia Bendito, E., Vysna, V., Paracchini, M. L., & Maes, J. (2022). The Integrated system for Natural Capital Accounting (INCA) in Europe: Twelve lessons learned from empirical ecosystem service accounting. One Ecosystem, 7, e84925. https://doi.org/10.3897/oneeco.7.e84925

Lal, R. (2004). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science, 304(5677), 1623–1627. https://doi.org/10.1126/science.1097396

Lange, S., Campagne, C. S., Comte, A., Bank, E., Santos-Martín, F., Maes, J., & Burkhard, B. (2022). Progress on ecosystem accounting in Europe. Ecosystem Services, 57, 101473. https://doi.org/10.1016/j.ecoser.2022.101473

Li, Z., Chen, D., Cai, S., & Che, S. (2018). The ecological services of plant communities in parks for climate control and recreation—A case study in Shanghai, China. PLOS ONE, 13(4), e0196445. https://doi.org/10.1371/journal.pone.0196445

Ling, P., Prince, S., Baiocchi, G., Dymond, C., Xi, W., & Hurtt, G. (2020). Impact of fire and harvest on forest ecosystem services in a species-rich area in the southern Appalachians. Ecosphere, 11(6). https://doi.org/10.1002/ecs2.3150

Liu, Y., Yang, C., Tan, S., Zhou, H., & Zeng, W. (2022). An approach to assess spatio-temporal heterogeneity of rural ecosystem health: A case study in Chongqing mountainous area, China. Ecological Indicators, 136, 108644. https://doi.org/10.1016/j.ecolind.2022.108644

Liyun, W., Weibin, Y., Zhirong, J., Shihong, X., & Dongjin, H. (2018). Ecosystem health assessment of Dongshan Island based on its ability to provide ecological services that regulate heavy rainfall. Ecological Indicators, 84, 393–403. https://doi.org/10.1016/j.ecolind.2017.09.006

Ma, J., Ding, X., Shu, Y., & Abbas, Z. (2022). Spatio-temporal variations of ecosystem health in the Liuxi River Basin, Guangzhou, China. Ecological Informatics, 72, 101842. https://doi.org/10.1016/j.ecoinf.2022.101842

Maes, J., Bruzón, A. G., Barredo, J. I., Vallecillo, S., Vogt, P., Rivero, I. M., & Santos-Martín, F. (2023). Accounting for forest condition in Europe based on an international statistical standard. Nature Communications, 14(1), 3723. https://doi.org/10.1038/s41467-023-39434-0

Maes, J., Driver, A., Czúcz, B., Keith, H., Jackson, B., Nicholson, E., & Dasoo, M. (2020). A review of ecosystem condition accounts: Lessons learned and options for further development. One Ecosystem, 5, e53485. https://doi.org/10.3897/oneeco.5.e53485

Maes, J., Teller, A., Erhard, M., Condé, S., Vallecillo, S., Barredo, J. I., Paracchini, M., Abdul Malak, D., Trombetti, M., Vigiak, O., Zulian, G., Addamo, A., Grizzetti, B., Somma, F., Hagyo, A., Vogt, P., Polce, C., Jones, A., Marin, A. I., … Santos-Martín, F. (2020). Mapping and assessment of ecosystems and their services: An EU ecosystem assessment. (EUR 30161 EN). Publications Office of the European Union. https://data.europa.eu/doi/10.2760/757183

Mahuli, S. A., Rai, A., Mahuli, A. V., & Kumar, A. (2023). Application ChatGPT in conducting systematic reviews and meta-analyses. British Dental Journal, 235(2), 90–92. https://doi.org/10.1038/s41415-023-6132-y

Mallick, J., AlQadhi, S., Talukdar, S., Pradhan, B., Bindajam, A. A., Islam, A. R. Md. T., & Dajam, A. S. (2021). A Novel Technique for Modeling Ecosystem Health Condition: A Case Study in Saudi Arabia. Remote Sensing, 13(13), 2632. https://doi.org/10.3390/rs13132632

Måren, I. E., & Sharma, L. N. (2021). Seeing the wood for the trees: Carbon storage and conservation in temperate forests of the Himalayas. Forest Ecology and Management, 487, 119010. https://doi.org/10.1016/j.foreco.2021.119010

Marull, J., Padró, R., Cirera, J., Giocoli, A., Pons, M., & Tello, E. (2021). A socioecological integrated analysis of the Barcelona metropolitan agricultural landscapes. Ecosystem Services, 51, 101350. https://doi.org/10.1016/j.ecoser.2021.101350

Matsuzaki, S. S., Kohzu, A., Kadoya, T., Watanabe, M., Osawa, T., Fukaya, K., Komatsu, K., Kondo, N., Yamaguchi, H., Ando, H., Shimotori, K., Nakagawa, M., Kizuka, T., Yoshioka, A., Sasai, T., Saigusa, N., Matsushita, B., & Takamura, N. (2019). Role of wetlands in mitigating the trade-off between crop production and water quality in agricultural landscapes. Ecosphere, 10(11), e02918. https://doi.org/10.1002/ecs2.2918

Mayekar, T. S., Sreekanth, G. B., Paramesh, V., Kumar, P., Patil, A. S., Mujawar, S. Y., & Mathew, A. (2022). Energy transfer and trophic organization in an Integrated Fish-Livestock-Horticulture System (IFLH) from Bicholim (Goa), the western coast of India. Aquaculture, 554, 738164. https://doi.org/10.1016/j.aquaculture.2022.738164

McHugh, M. L. (2012). Interrater reliability: The kappa statistic. Biochemia Medica, 22(3), 276–282.

Millennium Ecosystem Assessment (Ed.). (2005). Ecosystems and Human Well-being: Synthesis. Island Press.

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L. A., & PRISMA-P Group. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic Reviews, 4(1), 1. https://doi.org/10.1186/2046-4053-4-1

Müller, F., & Burkhard, B. (2012). The indicator side of ecosystem services. Ecosystem Services, 1(1), 26–30. https://doi.org/10.1016/j.ecoser.2012.06.001

Müller, F., Schrautzer, J., Reiche, E.-W., & Rinker, A. (2006). Ecosystem based indicators in retrogressive successions of an agricultural landscape. Ecological Indicators, 6(1), 63–82. https://doi.org/10.1016/j.ecolind.2005.08.017

Noss, R. F. (1990). Indicators for Monitoring Biodiversity: A Hierarchical Approach. Conservation Biology, 4(4), 355–364. https://doi.org/10.1111/j.1523-1739.1990.tb00309.x

Ooms, J. (2023). writexl: Export Data Frames to Excel "xlsx" Format. https://CRAN.R-project.org/package=writexl

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, n71. https://doi.org/10.1136/bmj.n71

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S., & Hayes, D. (2011). A Large and Persistent Carbon Sink in the World's Forests. Science, 333(6045), 988–993. https://doi.org/10.1126/science.1201609

Pinto, L. V., Inácio, M., Ferreira, C. S. S., Ferreira, A. D., & Pereira, P. (2022). Ecosystem services and well-being dimensions related to urban green spaces – A systematic review. Sustainable Cities and Society, 85, 104072. https://doi.org/10.1016/j.scs.2022.104072

Postel, S., & Richter, B. (2003). Rivers for life: Managing Water for People and Nature. Island Press.

R Core Team. (2023). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. https://www.R-project.org/

Rendón, P., Steinhoff-Knopp, B., & Burkhard, B. (2022). Linking ecosystem condition and ecosystem services: A methodological approach applied to European agroecosystems. Ecosystem Services, 53, 101387. https://doi.org/10.1016/j.ecoser.2021.101387

Rendón, P., Steinhoff-Knopp, B., Saggau, P., & Burkhard, B. (2020). Assessment of the relationships between agroecosystem condition and the ecosystem service soil erosion regulation in Northern Germany. PLOS ONE, 15(12), e0234288. https://doi.org/10.1371/journal.pone.0234288

Riegels, N., Lynggaard-Jensen, A., Krogsgaard Jensen, J., Gerner, N. V., Anzaldua, G., Mark, O., Butts, M., & Birk, S. (2020). Making the ecosystem services approach operational: A case study application to the Aarhus River, Denmark. Science of The Total Environment, 707, 135836. https://doi.org/10.1016/j.scitotenv.2019.135836

Roche, P. K., & Campagne, C. S. (2017). From ecosystem integrity to ecosystem condition: A continuity of concepts supporting different aspects of ecosystem sustainability. Current Opinion in Environmental Sustainability, 29, 63–68. https://doi.org/10.1016/j.cosust.2017.12.009

Rodriguez-Cabal, M. A., Barrios-Garcia, M. N., Amico, G. C., Aizen, M. A., & Sanders, N. J. (2013). Node-by-node disassembly of a mutualistic interaction web driven by species introductions. Proceedings of the National Academy of Sciences, 110(41), 16503–16507. https://doi.org/10.1073/pnas.1300131110

Sainju, U. M., Liptzin, D., Allen, B. L., & Rana-Dangi, S. (2021). Soil health indicators and crop yield in a long-term cropping system experiment. Agronomy Journal, 113(4), 3675–3687. https://doi.org/10.1002/agj2.20673

Seguin, J., Lange, S., Rendón, P., Barton, D. N., Immerzeel, B., Grêt-Regamey, A., Roche, P., & Thomas, I. N. (2023). Development of the SELINA Super-Query (Internal Report 02; SELINA).

Sharma, R., Gulati, S., Kaur, A., Sinhababu, A., & Chakravarty, R. (2022). Research discovery and visualization using ResearchRabbit: A use case of AI in libraries. COLLNET Journal of Scientometrics and Information Management, 16(2), 215–237. https://doi.org/10.1080/09737766.2022.2106167

Smith, A. C., Harrison, P. A., Pérez Soba, M., Archaux, F., Blicharska, M., Egoh, B. N., Erős, T., Fabrega Domenech, N., György, Á. I., Haines-Young, R., Li, S., Lommelen, E., Meiresonne, L., Miguel Ayala, L., Mononen, L., Simpson, G., Stange, E., Turkelboom, F., Uiterwijk, M., … Wyllie De Echeverria, V. (2017). How natural capital delivers ecosystem services: A typology derived from a systematic review. Ecosystem Services, 26, 111–126. https://doi.org/10.1016/j.ecoser.2017.06.006

Tanács, E., Bede-Fazekas, Á., Csecserits, A., Kisné Fodor, L., Pásztor, L., Somodi, I., Standovár, T., Zlinszky, A., Zsembery, Z., & Vári, Á. (2022). Assessing ecosystem condition at the national level in Hungary—Indicators, approaches, challenges. One Ecosystem, 7, e81543. https://doi.org/10.3897/oneeco.7.e81543

Tasser, E., Schirpke, U., Zoderer, B. M., & Tappeiner, U. (2020). Towards an integrative assessment of land-use type values from the perspective of ecosystem services. Ecosystem Services, 42, 101082. https://doi.org/10.1016/j.ecoser.2020.101082

Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M., & Siemann, E. (1997). The Influence of Functional Diversity and Composition on Ecosystem Processes. Science, 277(5330), 1300–1302. https://doi.org/10.1126/science.277.5330.1300

Townsend, M., Davies, K., Hanley, N., Hewitt, J. E., Lundquist, C. J., & Lohrer, A. M. (2018). The Challenge of Implementing the Marine Ecosystem Service Concept. Frontiers in Marine Science, 5, 359. https://doi.org/10.3389/fmars.2018.00359

Turner, M. G. (1989). Landscape Ecology: The Effect of Pattern on Process. 20, 171–197.

United Nations et al. (2021). System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA) [White cover publication, pre-edited text subject to official editing]. https://seea.un.org/ecosystem-accounting

Vallecillo, S., La Notte, A., Zulian, G., Ferrini, S., & Maes, J. (2019). Ecosystem services accounts: Valuing the actual flow of nature-based recreation from ecosystems to people. Ecological Modelling, 392, 196–211. https://doi.org/10.1016/j.ecolmodel.2018.09.023

Vallecillo, S., Maes, J., Polce, C., & Lavalle, C. (2016). A habitat quality indicator for common birds in Europe based on species distribution models. Ecological Indicators, 69, 488–499. https://doi.org/10.1016/j.ecolind.2016.05.008

Vallecillo, S., Maes, J., Teller, A., Babí Almenar, J., Barredo, J. I., Trombetti, M., Abdul Malak, D., Paracchini, M., Carré, A., Addamo, A., Czúcz, B., Zulian, G., Marando, F., Erhard, M., Liquete, C., Romao, C., Polce, C., Pardo Valle, A., Jones, A., … Gumbert, A. (2022). EU-wide methodology to map and assess ecosystem condition: Towards a common approach consistent with a global statistical standard. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/13048

van der Plas, F. (2019). Biodiversity and ecosystem functioning in naturally assembled communities. Biological Reviews, 94(4), 1220–1245. https://doi.org/10.1111/brv.12499

Van Dinter, R., Tekinerdogan, B., & Catal, C. (2021). Automation of systematic literature reviews: A systematic literature review. Information and Software Technology, 136, 106589. https://doi.org/10.1016/j.infsof.2021.106589

Van Leeuwen, J. P., Creamer, R. E., Cluzeau, D., Debeljak, M., Gatti, F., Henriksen, C. B., Kuzmanovski, V., Menta, C., Pérès, G., Picaud, C., Saby, N. P. A., Trajanov, A., Trinsoutrot-Gattin, I., Visioli, G., & Rutgers, M. (2019). Modeling of Soil Functions for Assessing Soil Quality: Soil Biodiversity and Habitat Provisioning. Frontiers in Environmental Science, 7, 113. https://doi.org/10.3389/fenvs.2019.00113

Van Oudenhoven, A. P. E., Petz, K., Alkemade, R., Hein, L., & De Groot, R. S. (2012). Framework for systematic indicator selection to assess effects of land management on ecosystem services. Ecological Indicators, 21, 110–122. https://doi.org/10.1016/j.ecolind.2012.01.012

Van Oudenhoven, A. P. E., Schröter, M., Drakou, E. G., Geijzendorffer, I. R., Jacobs, S., Van Bodegom, P. M., Chazee, L., Czúcz, B., Grunewald, K., Lillebø, A. I., Mononen, L., Nogueira, A. J. A., Pacheco-Romero, M., Perennou, C., Remme, R. P., Rova, S., Syrbe, R.-U., Tratalos, J. A., Vallejos, M., & Albert, C. (2018). Key criteria for developing ecosystem service indicators to inform decision making. Ecological Indicators, 95, 417–426. https://doi.org/10.1016/j.ecolind.2018.06.020

Vargas, L., Willemen, L., & Hein, L. (2019). Assessing the Capacity of Ecosystems to Supply Ecosystem Services Using Remote Sensing and An Ecosystem Accounting Approach. Environmental Management, 63(1), 1–15. https://doi.org/10.1007/s00267-018-1110-x

Veerkamp, C. J., Loreti, M., Benavidez, R., Jackson, B., & Schipper, A. M. (2023). Comparing three spatial modeling tools for assessing urban ecosystem services. Ecosystem Services, 59, 101500. https://doi.org/10.1016/j.ecoser.2022.101500

Wartenberg, A. C., Moanga, D., Potts, M. D., & Butsic, V. (2021). Limited Economic-Ecological Trade-Offs in a Shifting Agricultural Landscape: A Case Study From Kern County, California. Frontiers in Sustainable Food Systems, 5, 650727. https://doi.org/10.3389/fsufs.2021.650727

Weiskopf, S. R., Myers, B. J. E., Arce-Plata, M. I., Blanchard, J. L., Ferrier, S., Fulton, E. A., Harfoot, M., Isbell, F., Johnson, J. A., Mori, A. S., Weng, E., HarmáCˇková, Z. V., Londoño-Murcia, M. C., Miller, B. W., Pereira, L. M., & Rosa, I. M. D. (2022). A Conceptual Framework to Integrate Biodiversity, Ecosystem Function, and Ecosystem Service Models. BioScience, 72(11), 1062–1073. https://doi.org/10.1093/biosci/biac074

Westgate, M. J. (2019a). revtools: An R package to support article screening for evidence synthesis. Research Synthesis Methods, 10(4), 606–614. https://doi.org/10.1002/jrsm.1374

Westgate, M. J. (2019b). revtools: Tools to Support Evidence Synthesis. https://CRAN.R-project.org/package=revtools

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. https://ggplot2.tidyverse.org

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller, E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V., … Yutani, H. (2019). Welcome to the Tidyverse. Journal of Open Source Software, 4(43), 1686. https://doi.org/10.21105/joss.01686

Wickham, H., & Bryan, J. (2023). readxl: Read Excel Files. https://CRAN.R-project.org/package=readxl

Wickham, H., François, R., Henry, L., Müller, K., & Vaughan, D. (2023). dplyr: A Grammar of Data Manipulation. https://CRAN.R-project.org/package=dplyr

Wübbelmann, T., Bender, S., & Burkhard, B. (2021). Modelling flood regulation ecosystem services dynamics based on climate and land use information. Landscape Online, 88, 16. https://doi.org/10.3097/LO.202188

Zhao, R., Gabriel, J. L., Rodríguez Martín, J. A., Feng, Z., & Wu, K. (2022). Understanding trade-offs and synergies among soil functions to support decision-making for sustainable cultivated land use. Frontiers in Environmental Science, 10, 1063907. https://doi.org/10.3389/fenvs.2022.1063907

SELINA

SCIENCE FOR EVIDENCE-BASED AND SUSTAINABLE DECISIONS ABOUT NATURAL CAPITAL

https://project-selina.eu/

10. Annex

All Annex material is available online through the following link:
https://seafile.projekt.uni-hannover.de/d/500a62e4dbac4f4a90f4

Annex 1:
Inclusion Criteria
Filename: SELINA_D61_Annex1_InclusionCriteria_vfulltext.pdf

Annex 2:
Review template
Filename: SELINA_D61_Annex2_ReviewTemplate_raw.xlsm

Annex 3:
List of literature items included in the review
Filename: SELINA_D61_Annex3_LiteratureList.pdf