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Review

Ecosystem service indicators along the cascade: How do assessment and mapping studies position their indicators?

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ABSTRACT

As the mapping and assessment of ecosystem services (MAES) becomes a widely used tool in environmental governance, there is an increasing need for structure and standardization. In this study we present a systematic review of European MAES studies focussing on two important, but rarely documented aspects of ecosystem service (ES) indicators: (1) their 'position' with respect to the ecosystem service cascade model, and (2) their 'position' in geographical space, i.e. whether the maps are 'anchored' at the locations of their supply or their demand.

From the 82 papers reviewed we found 427 ES indicators, which represented 33 ES. Among these indicators there were 108 (25%) that were mapped. ES are quite different in terms of their relationship with the main conceptual model of ES assessment studies. Most ES are typically measured at a specific point in the cascade, which is more or less the same across the different studies. While some ES (including most of the regulating ES, e.g. bio-remediation, hydrological cycle maintenance, or soil fertility) can clearly be linked to the 'natural' endpoint of the cascade, some others (including all cultural and some provisioning ES, like cultivated crops, or wild animals) are more frequently measured as actual flows or benefits delivered to humanity. There are few ES that are markedly heterogeneous in their cascade levels (e.g. water provision, pest control) for which apparently different assessment approaches exist.

Considering spatial anchor, we have found that mapping at the source predominates in ES mapping studies: 91% of the mapped indicators are clearly linked to the source ecosystems. There were relatively few studies that applied a mixed approach, whereas indicators clearly anchored at beneficiaries were extremely rare.

These two aspects of ES indicators discussed in this paper are critical in the successful operationalization and standardization of MAES assessments, which have been neglected in the MAES literature so far, which might be seen as key components in the future standardization of mapping and assessment approaches.

1. Introduction

Mapping and assessment of ecosystem services (MAES) studies have become an increasingly widespread tool for environmental governance and policies in the last few decades (Maes et al., 2012; IPBES, 2016; Bouwma et al., 2018). Such studies aim to create a comprehensive inventory of the contributions of nature to society and economy in a concrete geographical region (Burkhard et al., 2018). Nevertheless, there is little standardization in the underlying concepts and methods (Schröter et al., 2014a; Vihervaara et al., 2019), which both creates ambiguities and hampers policy applications (Paulin et al., 2020). For example, although the ecosystem services cascade model (Haines-Young et al., 2010) has generally been recognized (and applied) as a central conceptual framework in MAES studies, even the core concepts of this framework are burdened with a broad diversity of conflicting interpretations (Heink and Jax, 2019). In this paper we focus on two relatively fundamental aspects of the use of indicators in concrete MAES studies: the 'position' of indicators with respect to the ecosystem service cascade framework; and the 'position' of mapped indicators in geographical space. Both of these aspects are rarely documented aspects of MAES studies with divergent interpretations.

The flow of ES from nature to society is generally considered as a

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stepwise process, consisting of several consecutive steps of 'enabling' and 'appropriation' (Haines-Young et al., 2010; Heink and Jax, 2019). The flow of the services (from step to step) is governed by an interaction of biophysical and socio-economic drivers, which act in the 'gaps' between the steps, involving individual and societal choices (use value attribution) and activities (mobilization processes; Spangenberg et al., 2014a,b; Heink and Jax, 2019). One key aspect of the cascade model is that it can be seen as an indicator framework for ES assessments, highlighting the key points of information needs of the studied system (e.g. Schröter et al., 2014; Pagella and Sinclair, 2014; Heink et al., 2016; Heink and Jax 2019; Vallecillo et al., 2019). While the elementary goal of all ES assessments is to measure the 'services', it is actually unclear in what kind of relationship these metrics are to the elements of the cascade framework. For example, it is often undocumented that the ES indicators that are mapped/assessed are indicators of ES capacity (for potentially available quantities/flows) or actual use (quantities/flows that were really consumed/enjoyed), thus creating much confusion for further applications.

Mapping studies and the 'mapped' indicators in them are particularly relevant in a MAES context. In the case of mapping studies there is a related interesting aspect (similarly easily determinable, but rarely declared feature): how the ES assessed are linked to spatial locations ('spatial anchor'). There are two main options for establishing this link: services can either be linked to the locations where they were produced (source ecosystems), or to the locations where they eventually get used (beneficiaries). Both approaches can be logical choices in different contexts: studies which discuss sustainability thresholds inevitably need to map services at their source ecosystems, whereas using a beneficiaries-anchor can be justified for mapping benefits, or even actual use. Nevertheless, this aspect of mapping is rarely considered in studies, which might lead to treating source and beneficiary-anchored indicators inconsistently (Schröter et al., 2012).

In this paper we present a systematic review exploring which ES are assessed at which steps of the cascade, and how ES indicators are linked to spatial locations in published MAES studies. To this end we build on our previous systematic review (Czúcz et al., 2018a), linking each indicator to the steps of the cascade framework (Fig. 1), and determining the spatial anchor of each mapped indicator. With this we aim to

- assess the role of each cascade level in MAES studies, and reveal any potential imbalances in practice;
- check if there are some patterns in specific ES (e.g. some ES predominantly measured at a single specific level of the cascade, like capacity);
- give an overview on the way how mapping studies anchor their indicators in geographical space; and
- formulate recommendations for future MAES studies based on the lessons learned.

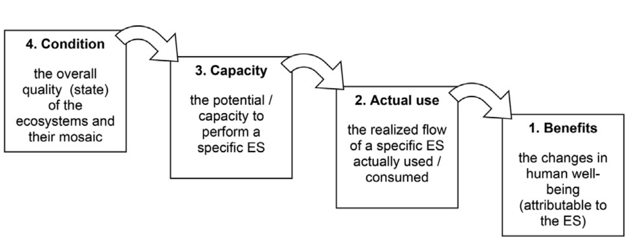

Fig. 1. The four steps of the ES cascade framework adapted from Spangenberg et al. (2014a) and La Notte et al. (2015) (originally based on Haines-Young et al., 2010).

2. Materials and methods

2.1. The ES cascade framework

The key elements of the cascade framework come from the very early days of ES assessment (e.g. de Groot et al., 2002; see more examples in Bordt and Saner, 2018), but they were first proposed as a universal framework by Haines-Young and Potschin (2010). Unfortunately, the practical application of the cascade has been hampered from the start by several critical issues related to definitions and methods (Spangenberg et al., 2014b; La Notte et al., 2017; Heink and Jax, 2019). As a response several variants of the cascade framework have emerged (for an overview see e.g. Heink and Jax, 2019), and some reviews even propose that there is little added value of applying such a contested framework in concrete studies (Costanza et al., 2017). The relatively undocumented and inconsistent way how practical assessment studies have applied the cascade framework is probably also a consequence of the controversies around the cascade framework, which are best documented by Heink and Jax (2019).

In this paper we follow a relatively unambiguous and operative 4-level cascade variant (Fig. 1), which has frequently been proposed in assessment and accounting contexts (e.g. Schröter et al., 2014b; Spangenberg et al., 2014a,b; La Notte et al., 2015; Czúcz and Arany, 2016; Heink and Jax, 2019; Vallecillo et al., 2019). This variant essentially equates functions with capacities (Ansink et al., 2008; Heink and Jax, 2019), structures (and processes) with condition, and considers value as a type of indicators that can be applied to all levels of the cascade (Ansink et al., 2008; La Notte et al., 2015; Maynard et al., 2015). This cascade is also more coherent with the conceptual framework of SEEA-EEA (UNSD, 2017). To concretize each cascade level, we applied the definitions of Czúcz and Condé (2017):

- **Benefit**: positive change in wellbeing from the fulfilment of individual or societal needs and wants. Benefits generated by ES are no longer directly connected to the source ecosystems.
- **Actual use**: the amount of an ES that is actually mobilized in a specific area and time
- **Capacity**: the ability of a given ecosystem to generate a specific ecosystem service in a sustainable way.
- **Condition**: the overall quality of an ecosystem, in terms of its main characteristics underpinning its capacity to generate ecosystem services.

Further concepts (wellbeing, ecosystem, etc) were also defined and interpreted in line with the glossary of Czúcz and Condé (2017).

2.2. Literature selection and characterization of ES indicators

To review the indicators used in practical ES assessments we continued the systematic review work of Czúcz et al. (2018a; which already had been relying on the work done by Boerema et al. 2017). This review involves 82 peer reviewed ecosystem service assessment studies performed in Europe. We extended the previous work (Czúcz et al., 2018a) with further metadata extracted from the studied papers: we assigned an ordinal 'cascade level' (CL) score, and a binary 'spatial anchor' (SA) score to each indicator (see below). To assign the cascade level (CL) score to each indicator we used the framework shown in Fig. 1 as a four-grade ordinal scale. Thus, we considered

- CL = 1 (*benefits*) if the indicator predominantly described the benefits that individuals or the society gains from the studied ES.
- CL = 2 (*actual use*) if the indicator characterized the quantity of the ES being actually used or extracted by people; and
- CL = 3 (*capacity*) if the indicator described the capacity for a specific ES potentially available for people;
- CL = 4 (*condition*) for indicators that predominantly characterized

Table 1
Indicators for the most frequently assessed ecosystem services (CICES classes) characterized in terms of cascade level and spatial anchor. NP: number of papers, NI: number of indicators, mCL: mean cascade level, dCL: median cascade level, vCL: variance of cascade level, NM: share of mapped indicators, mSA: mean spatial anchor (among mapped indicators). The ES with significantly high or low mCL and mSA values are highlighted with asterisks (*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$).

CICES class	NP	NI	mCL	dCL	vCL	NM	mSA
All ecosystem services and indicators reviewed	82	427	2.72	2.50	0.85	24%	0.05
2.3.5.1: Global climate regulation by greenhouse gas reduction	26	37	2.81	2.50	0.67	22%	0.00
3.1.2.5: Aesthetic value, sense of place, artistic inspiration	26	43	2.18	2.50	0.56	38%	0.03
D: Recreational (experiential and physical) use of land-/seascapes (3.1.1.1, 3.1.1.2)	25	37	1.81 ***	1.50	0.50	31%	0.23 ***
A: Bio-remediation and water quality maintenance services (2.1.1.1, 2.1.1.2, 2.1.2.1, 2.1.2.2, 2.3.4.1)	24	44	3.24 ***	3.00	0.62	30%	0.00
2.3.1.1: Pollination and seed dispersal	22	47	2.70	2.75	0.82	13%	0.07
F: Spiritual, symbolic and inherent values of nature (3.2.1.1, 3.2.1.2, 3.2.2.1, 3.2.2.2)	20	25	2.06	2.00	0.59	28%	0.00
E: Intellectual and representational interactions with nature (3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.2.4)	18	30	1.63 ***	1.25	0.69	30%	0.00
1.1.1.1: Cultivated crops	17	25	2.07 *	2.00	0.51	36%	0.00
1.2.1.1: Fibres and other materials for direct use or processing	12	26	2.10 *	2.00	0.49	27%	0.00
2.3.1.2: Maintaining nursery populations and habitats	12	21	3.20 **	3.50	0.96	19%	0.00
2.2.1.1: Mass stabilisation and control of erosion rates	11	15	2.57	2.50	0.30	36%	0.08
2.2.2.2: Flood protection	11	12	2.71	3.00	0.82	40%	0.17 *
C: Maintenance of soil fertility (2.3.3.1, 2.3.3.2)	11	38	2.93 *	2.50	0.72	5%	0.00
1.1.1.2: Reared animals and their outputs	10	12	2.25	2.00	0.50	25%	0.00
1.1.1.4: Wild animals and their outputs	10	17	1.71 ***	2.00	0.38	12%	0.00
1.2.1.2: Materials from plants, algae and animals for agricultural use	10	18	2.36	2.00	0.52	22%	0.00
2.2.2.1: Hydrological cycle and water flow maintenance	10	11	3.25 *	3.00	0.43	27%	0.00
B: Pest and disease control services (2.3.2.1, 2.3.2.2)	10	16	3.29 **	3.75	1.07	44%	0.00

the (state of the) source ecosystem itself.

This way of ordering the scores from the benefits (1) to the ecosystem state/condition (4) follows the attribution/valuation perspective underlying the whole cascade framework (Spangenberg et al., 2014a,b; Potschin-Young et al., 2018; Heink and Jax, 2019), and it also follows the 'natural' orientation of the cascade (with levels 'higher' in the cascade flow having a higher score).

Due to the huge methodological differences we did not use the assignments to the "parts of the ES cascade" by Boerema et al. (2017), which were available for some of our indicators from their original review. To determine the CL scores, we paid particular attention to the indicandum (the system property being indicated) and the unit of the indicator. To distinguish condition and capacity, we considered that capacity is defined to be service-specific, whereas condition should be relatively general (a characteristic of the ecosystem that can affect multiple services). In cases where this was not obvious, we relied on the unit of the indicator, scoring an indicator with a 'non-flow' and not directly ES-related unit as 4 (condition). Similarly, indicators that measure the (net) societal impact of an ES (in terms of increased well-being) were scored as 1 (benefits). Indicators that used natural units of the ES being delivered (typically in time-normed flow units, e.g. $t*ha^{-1}*y^{-1}$) were assigned 2 or 3 based on the way they were presented and calculated: in most cases the description and the method made it very clear if they referred to actual use (2) or capacity (3). However, in the case of many regulating services (e.g. for global climate regulation, see e.g. Schröter et al., 2014) capacities instantly become useful for the society without any extraction or harvesting activities, so in such contexts an indicator can be seen as a capacity and an actual use indicator at the same time. Reviewers were allowed to register two adjacent cascade levels in such cases.

To characterize the studied services with respect to the cascade model, we calculated the median, as well as the arithmetic mean and the variance of the CL scores for all indicators pertaining to the specific ES. 'Transitional' indicators assigned to two adjacent cascade levels were considered with a single intermediate value (e.g. CL = 2.5) in these computations. An ES that has a high mean CL score means that the ES in question is perceived to be closer to the higher (left) end of the cascade, thus measuring the 'ecological underpinning' of the service. On the other hand, an ES with lower CL scores is assessed mostly by indicators positioned closer to the lower (right) end of the cascade quantifying it closer to the society (e.g. as a benefit).

We also evaluated whether the indicator values were assigned spatially to their source ecosystems, or destination (consumer, beneficiary) communities. To determine this, we assigned one of the following classes to each indicator that was mapped:

- SA = 0 for indicators that were mapped at their source ecosystems;
- SA = 1 for indicators that were spatially assigned to beneficiaries.

In cases where the indicator mapped was composed of both source- and beneficiary-anchored components, the reviewers could also assign a "mixed" rating as the SA score, and completely unclear/ambiguous spatial assignments were also distinguished. Similarly to mean CL we defined mean SA as the mean value of SA scores within a group of indicators, with the "mixed" indicators considered with an intermediate value (SA = 0.5), and the 'unclear' cases as missing values.

To identify the ecosystem services, we applied the 4-digit CICES 4.3 codes as documented by Czúcz et al. (2018), including the six class clusters (A-F) also identified there. These class clusters merge 19 ES that are practically always assessed together, thus considerably simplifying CICES 4.3, which was partly integrated later in the new CICES 5.1 typology (Haines-Young and Potschin, 2018). Similarly to our previous work, indicators that characterize multiple ES were counted for all ES that they could be linked to.

Finally, to check if the mean CL or the mean anchor of the indicators belonging to a specific ES class is different from the grand means of all ES indicators, we performed simple permutation tests. For these tests we applied sum contrasts with a one-way design and 5000 permutations using the *permuco* (Frossard and Renaud, 2019) add-on package in the R statistical environment (R Core Team, 2019).

3. Results

From the 82 papers reviewed we found 427 ES indicators, which represented 33 ES according to the simplified CICES 4.3 classes (see Czúcz et al., 2018a). Among these indicators there were 108 (25%) that were mapped. The percentage of mapped indicators varies between the different ES, with 2.1.2.3 (smell/noise/visual mediation), 2.3.5.2 (microclimate), 1.1.1.3 (wild plants), cluster B (pest control), 2.2.2.2 (flood protection), and 3.1.2.5 (aesthetic) being the most popular. The summary statistics of the CL and SA scores of the indicators are shown in

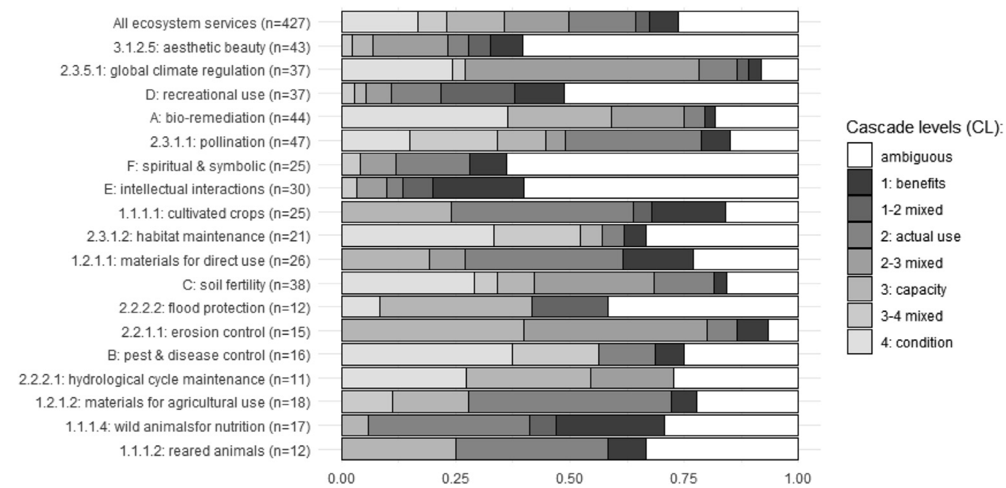

Fig. 2. The cascade level spectrum for the most important CICES classes in mapping and assessment papers. Services are listed in decreasing order of popularity (number of papers, see Table 1), while n is the number of indicators (the value of 100% in each bar chart).

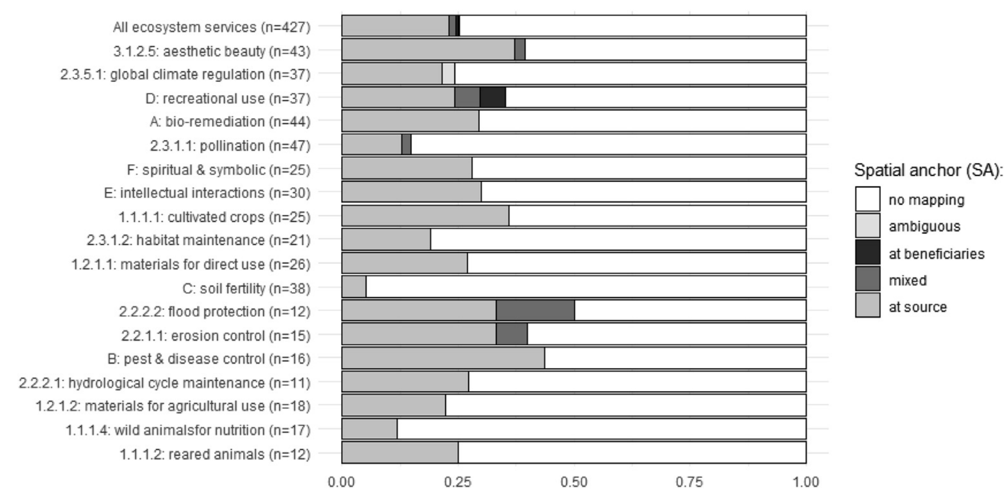

Fig. 3. The distribution of spatial anchor for the most important CICES classes in mapping and assessment papers. Services are listed in decreasing order of popularity (number of papers, see Table 1), while n is the number of indicators (the value of 100% in each bar chart).

Table 1 for the most frequently assessed CICES classes, and in Table A.1 (in the Appendix) for all CICES classes. Summaries for ES that have been assessed in at least 10 papers are also shown visually in Figs. 2 and 3.

The median cascade level of all ES indicators reviewed is 2.5, which is exactly the midpoint of the cascade scale. The overall mean CL score is 2.72, which is also very close to the midpoint. Services of high cascade level include mostly regulating services, like cluster A (bio-remediation, $p = .0002$), 2.2.2.1 (hydrological cycle, $p = .008$), cluster C (soil fertility, $p = 0.01$), and 2.3.1.2 (habitat maintenance, $p = 0.03$); whereas cultural services and a few provisioning ones (e.g. 1.1.1.1: Cultivated crops, $p = .02$; 1.1.1.4: Wild animals and their outputs, $p = .0006$) were characterised with low mean CL scores (Fig. 2). Most CICES classes are relatively homogeneous in terms of the CL of the indicators that could be assigned to them. The few notable exceptions include surface water provision (1.1.2.1, 1.2.2.1; see Table A.1), as well as several regulating services (2.3.1.2: habitat maintenance, B: pest control, 2.2.2.2: flood control, and C: soil fertility) which apparently involve indicators with contrastive cascade levels.

Considering the spatial anchor, we have found that mapping at the source predominates in ES mapping studies: 91% of the mapped indicators are clearly linked to the source ecosystems. There were relatively few studies that applied a mixed approach, combining spatial information on source and beneficiaries into the same indicator mostly for two services recreation (cluster D, $p = .0004$) and flood control (2.2.2.2, $p = .048$). Indicators clearly anchored at beneficiaries were extremely rare: among the 23 mapping studies reviewed we only found two studies applying such indicators (Larondelle and Haase, 2013; Maes et al., 2013). Both of these studies applied a beneficiary-anchored indicator to map recreation demand (cluster D, Fig. 3).

4. Discussion

The ecosystem services concept can be regarded as a 'boundary object' (sensu Star and Griesemer, 1989; see e.g. Steger et al., 2018) and so some ambiguity in interpretation is unavoidable, even desirable in order that it could facilitate the discussion between disciplines. Nevertheless, as the concept becomes institutionalized as a policy tool, this ambiguity becomes a burden and standardization is required (Star, 2010; Steger et al., 2018). This has to be underpinned by broadly agreed clear concepts and methods, operative guidelines, and transparent documentation practices.

The two aspects of ES indicators discussed in this paper are critical in the successful operationalization and standardization of MAES assessments, which have been neglected in the MAES literature so far. Luckily, there is a tendency in ES assessment and accounting studies to address each service at multiple cascade levels systematically (e.g. Bastian et al., 2013; Schröter et al., 2014b; Mononen et al., 2015; Czúcz et al., 2018b; Vallecillo et al., 2019; Potschin-Young et al., 2018). This is consistent with the original goal of the cascade framework "to trace the complete 'production chain' from ecological structure and processes through to human well-being" (Haines-Young et al., 2010:122). Nevertheless, a high proportion of the ES studies still follows a weak approach of taking only one indicator per ES, thus fixing each ES at the 'point' where it feels 'easier' or 'more natural' without any considerations for consistency (Maes et al., 2012). This way the cascade levels estimated in this paper document the authors' choices on how to measure each service, which can depend on a number of factors (e.g. data availability, the purposes of the study), but, in principle, also reflects the definition and the characteristics of the ES itself. McElwee (2017) observed clear patterns in terms of which ES are most frequently quantified, and linked this to complexities in defining and measuring these ES (their "resistance to measurement"). We think that the pattern that we observe in mean CLs is, in fact, an extension of this pattern. In this sense the mean CL of an ES can be seen as the point in the cascade framework where the given service shows the least resistance to measurement, i.e. where it can be defined or measured in the most intuitive way. In this context high variances in CL can also be very interesting: they might indicate a divergence in the interpretations, and thus highlight issues with ES definitions, where an ES needs to be defined and measured with more care.

Our results show that almost all services can be measured at almost all levels of the cascade, nevertheless, there are several ES that are predominantly measured at 1–2 neighbouring cascade levels and show relatively little variance in their CL scores. This is in line with the observations of La Notte and Rhodes (2020) that the flow of ES along the cascade "is tackled in a less anchored way" by CICES. The mean cascade level can be seen aligned with the amount of human input that is needed to generate the ES. Provisioning services are an obvious example, where a relatively high amount of human input is needed to get the final output (Bengtsson, 2015; Geijzendorffer et al., 2017; Vallecillo et al., 2019), but this relationship is also valid for cultural services, where a person is needed who perceives the (aesthetic, cultural, inspirational, etc) values of the landscape/nature (Spangenberg et al., 2014). In contrast, most regulating ES (e.g. 2.2.2.1: hydrological cycle maintenance; A: bio-remediation; 2.3.1.2: habitat maintenance; or C: soil fertility) function without any human addition and have a high mean CL, which also results in a stronger connection of these services to the capacities of nature (or potential supply, as documented by Geijzendorffer et al., 2017). This also indicates that the reliance of these ES on the source ecosystems and their condition is better recognized (or easier to measure) than their effects on human wellbeing. Several authors point to the lack of knowledge on how to measure/quantify wellbeing in relation to changes in ecosystem functions, in the landscape, or in the "nature" (Smith et al., 2013, Bateman et al., 2011, Iniesta-Arandia et al., 2014). It is important to note, however, that indicators assigned to the benefit level are not necessarily more useful for policy and decision makers. For example, Olander et al. (2017, 2018) consider any indicators that reflect "the causal chain from actions to changes in ecological conditions to changes in ecosystem services" as "benefit-relevant" (i.e. highly policy-relevant) indicators.

Nevertheless, there are a few ES, for which we have found a relatively large variance in CL scores, which might suggest that for these ES there are multiple 'entry points', i.e. they can be efficiently quantified both through the characteristics of the source ecosystems and the societal benefits eventually induced. This involves two water-related provisioning ES (1.1.2.1: drinking water, vCL = 1.64; and 1.2.2.1: non-drinking water, vCL = 1.75), even though in relatively few papers (n = 7 and 5 respectively; see Table A.1). This can be explained by the fact that water provision can be both assessed at the very biophysical level (the amount of water available in the ecosystem, e.g. Vidal-Legaz et al., 2013), and as an economic commodity (water used for specific purposes, e.g. Pinto et al., 2010, 2013). A few regulating services also share this duality: for example, flood control (2.2.2.2) can be quantified in a GIS system based on landscape characteristics (e.g. Jackson et al., 2013), or assessed directly through its estimated benefits (e.g. Larondelle and Haase, 2012, Boerema et al., 2014). Similarly, pest control or pollination can be assessed using species diversity indicators (e.g. Ford et al., 2012), as well as using farm economic output metrics (Ghaley et al., 2014).

In contrast with the cascade level which can be determined for each ES indicator, spatial anchor can only be studied for mapped (i.e. spatially explicit) indicators. The overwhelming majority (over 90%) of the mapping studies applied the source-anchored approach. If we consider that (e.g. in contrast with a life-cycle analysis, or an environmental footprint assessment) the primary focus of ES assessments is to evaluate *the ecosystems* through their contributions to human society, then this result is not so surprising. Nevertheless, in a few cases mapped indicators were not (purely) linked to the source ecosystems. In addition to the very few clearly beneficiary-anchored indicators, we also identified some "mixed" cases, i.e. composite indicators which combined spatial information linked to source ecosystems with spatial information linked to beneficiaries. Although this might seem inconsistent at first sight, such a modelling strategy can be justified for many 'spatially confined' ES (Schröter et al., 2012), where demand can only be met by supply from nearby ecosystems (Syrbe and Grunewald, 2017). We have documented such mixed anchorage for recreation (D: Larondelle and Haase, 2012; Maes et al., 2013), flood protection (2.2.2.2: Maes et al., 2013; Liquete et al., 2013) or pollination (2.3.1.1: Maes et al., 2013). This seems to be largely coherent with the recommendation from Schröter et al. (2012), who suggest that only demand indicators for spatially confined ES (when the beneficiaries can be delimited) should be mapped at the location of the beneficiaries.

It was, however, not always easy, or even possible to determine the spatial anchor of each ES map in each paper. As our recommendation for future mapping studies, we would like to emphasise that the spatial anchor of the indicators should be made clear (explicitly, if necessary). Source and beneficiary anchored indicators should be applied consciously and consistently (Schröter et al., 2012). This seems to be a reasonable strategy, since the two types of maps have very different meanings and messages in a decision-making context. Mixing the two approaches without a careful discussion can be a potential source of confusion.

For studies where both CL and SA scores could be determined there was a slightly asymmetrical relationship between these two indicator characteristics. While indicators with high cascade levels were always linked to the source ecosystems, studies mapping indicators near the benefit end of the cascade were not so consistent in their choice of spatial anchor. The source anchoring strategy was still the dominant approach for these indicators, but not exclusively. Surprisingly, mixed (source + beneficiary) or beneficiary-anchored indicators appeared mainly in 'high-variance' ES classes where indicators targeting different levels of the cascade were similarly popular, measuring characteristics of either the source ecosystems of the ES, or the benefits generated by them. Maybe in such cases where there are multiple valid entry points, the modellers felt more 'justifiable' to depart from the dominant source-anchored mapping approaches.

5. Conclusions

ES are quite different in terms of their relationship with the main conceptual model of ES assessment, mapping and accounting activities, i.e. the cascade concept. Most ES are typically measured at a specific point in the cascade, which is more or less consistent across the different studies. While some ES (including most of the regulating ES) can clearly be linked to higher cascade levels at the 'functional end' of the cascade, some others (including all cultural and most provisioning ES) are more frequently measured as actual flows or benefits delivered to humanity. This preference for specific cascade levels can probably be related to intuitive interpretation (definition) of each ecosystem service. In this study we made a first attempt at documenting this normally hidden characteristic of the different ES using a systematic review approach. Linking indicators to levels of the ES cascade model is also essential as a way of better understanding supply and demand issues. In contrast to Costanza et al. (2017), we think that the ES cascade is highly useful as a conceptual framework in a broad range of ecosystem service assessments, as it can create an intuitive and logical structure for the collection and the presentation of the information assessed. In line with Boerema et al. (2017) we recommend that for every indicator its 'cascade level' should be clearly specified.

Furthermore, we also found that mapping studies are not consistent in the way they link indicators to spatial locations. The new concept of 'spatial anchor' describes a vital aspect of ES mapping that was largely missing from MAES guidelines so far. Accordingly, we recommend that in future mapping and assessment or ecosystem accounting studies, the spatial anchor of the indicators should also be specified clearly, and handled consistently.

Thus, cascade level and spatial anchor can be seen as two key characteristics ("meta-indicators") of ES indicators, which should be explicitly documented and reported in ES studies for improving the consistency of ES assessment. We think that ecosystem assessments will soon reach an institutionalized 'production' phase, where standardization will be inevitable (Polasky et al., 2015; Steger et al., 2018). We hope that this study will be useful as setting the foundations of two useful concepts which might be seen as key components in future standardization studies.

CRediT authorship contribution statement

Bálint Czúcz: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization, Supervision, Project administration, Funding acquisition. **Roy Haines-Young:** Conceptualization, Writing - original draft, Funding acquisition. **Márton Kiss:** Investigation, Data curation. **Krisztina Bereczki:** Investigation, Data curation. **Miklós Kertész:** Investigation, Data curation, Writing - original draft. **Ágnes Vári:** Writing - original draft. **Marion Potschin-Young:** Conceptualization, Funding acquisition. **Ildikó Arany:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Project administration, Funding acquisition.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

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