How to Analyse Ecosystem Services in Landscapes

IEA Bioenergy

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1 Introduction

Society benefits in a multitude of ways from ecosystem services (ES) that are delivered by natural and managed ecosystems. Some ES are recognized as essential (e.g., food and wood supply), but several ES may not be valued unless diminishing; the provisioning of clean drinking water and the decomposition of wastes are today commonly recognized as essential, but at the same time may be taken for granted when available. It can also be difficult to identify causes behind diminishing ES, the pollination by insects being one example.

The Millennium Ecosystem Assessment (MA) in 2003 brought global attention to the importance of ES and grouped these into four broad categories: provisioning, such as the production of food and water; regulating, such as the control of climate and disease; supporting, such as nutrient cycles and crop pollination; and cultural, such as spiritual and recreational benefits. Since the MA was published, it has been shown that many ES are diminishing due to degradation and/or depletion of resources such as productive soils and fresh water. Human land use has been identified a major cause. Biodiversity loss is an additional concern since the variety of life at genetic, species and ecosystem level is a prerequisite for many ES. A great challenge for society´s path towards a biobased economy is to develop sustainable landscape management systems that provide biomass, support biodiversity and ensure conditions for a multitude of ES. This requires methods to assess impacts on the conditions for ES and biodiversity, and stakeholder involvement in land use decisions.

Life Cycle Assessment (LCA) is often used to assess the environmental performance of bioenergy options and biomass production systems. Whilst LCA is very useful for comparing specific environmental impacts of food and bioenergy supply chains, it has so far been of limited use to evaluate and inform spatially-explicit strategies for sustainable bioenergy deployment. LCA is, traditionally, not a tool that examines local impacts and thus has crucial gaps in this respect. There is a need for geographically explicit assessment methods that can incorporate site-specific characteristics and differentiate between management regimes in agriculture and forestry. In the latest UNEP/SETAC LCA guidelines[1], further research was encouraged on how existing methods for quantifying and assessing ES (as well as impacts on these) can be adapted and incorporated into the life cycle impact assessment (LCIA) framework. As an alternative, other methodological approaches can be used in parallel with LCA and provide complementary information about impacts on ES.

This summary report presents a review of methods for analysing and mapping[2] ES in terrestrial landscapes, and attempts to clarify the associated terminology. More extensive information and supporting references can be found in: *Englund, O., Berndes, G., Cederberg, C. (2017). How to Analyze Ecosystem Services in Landscapes — a systematic review. Ecological Indicators, 73:492-504.*

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[1] Koellner T, De Baan L, Beck T, Brandão M, Civit B, Margni M, Milà i Canals L, Saad R, De Souza DM, Müller-Wenk R (2013) UNEP- SETAC guideline on global land use impact assessment on biodiversity and ecosystem services in LCA. Int J Life Cycle Assess 18: 1188–1202

[2] Mapping refers to the organization of spatially explicit quantitative information. It is used here as a collective term for all kinds of geoexplicit analysis.
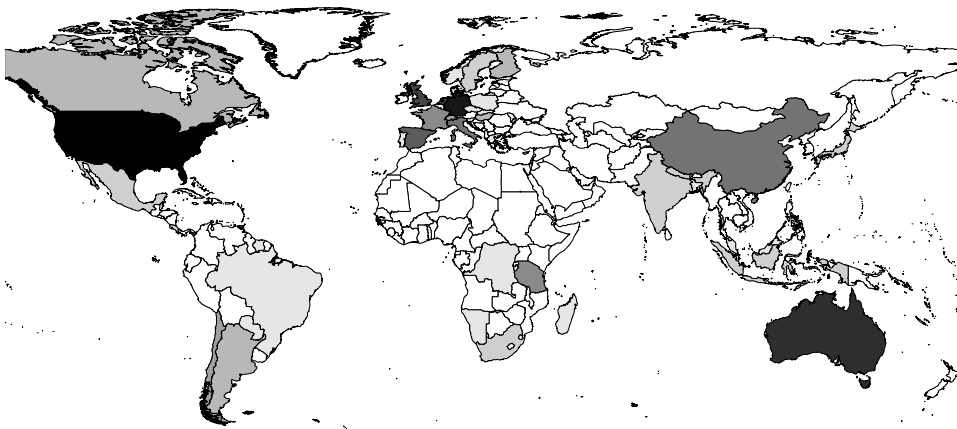
Figure 1: Geographical distribution of reviewed studies (n=170). The number of studies performed in each country ranges from 1 (light grey) to 26 (black). White = zero.

1.1 TYPOLOGY AND TERMINOLOGY

Several ES classification systems have been proposed. There are many useful ways to classify ecosystem goods and services, and a pluralism of typologies that can be useful for different purposes may be preferred to a single, consistent system. A drawback is that the use of multiple classification systems makes comparisons and integration of assessments with other data difficult. The Common International Classification of Ecosystem Services (CICES, see www.cices.eu), is developed from the work on environmental accounting undertaken by the European Environment Agency (EEA). The aim of CICES is to propose a universal classification of ES that is both consistent with accepted categorizations and allows easy translation of statistical information between different applications.

The terminology in ES research remains inconsistent. For example, studies that use the MA typology include *supporting* services. The same "services" are in other studies considered to be ecological (or ecosystem) processes, following, e.g., The Economics of Ecosystems and Biodiversity (TEEB) typology. These are also sometimes referred to as intermediate ES. Furthermore, some consider ecosystem functions to be synonymous with ecosystem processes,

while others do not. While terms are often used arbitrarily, inconsistency is also due to an ongoing scientific discourse. It has been argued that definitions of ES are purpose-dependent and should be judged on their usefulness for a specific purpose. However, co-existence of different terminologies and definitions could impede on-the-ground use of the concept. Diversity is important for advancing science and knowledge, but can create difficulties in situations where governance agreements are to be made—particularly where multiple goals need to be considered. At present, work is in progress to establish working definitions of commonly used terms. This may, along with the advancement of the CICES classification, help to harmonize the terminology and make studies more consistent and comparable. Definitions of commonly used terms are presented in Table 1.

Table 1: Definitions of commonly used terms

Term	Definition
Ecosystem structure	Static ecosystem characteristics: spatial and non-spatial structure, composition and distribution of biophysical elements *Example:* land use, standing crop, leaf area, % ground cover, species composition
Ecosystem processes	Dynamic ecosystem characteristics: Complex interactions among biotic and abiotic elements of ecosystems causing physical, chemical, or biological changes or reactions. *Examples:* decomposition, photosynthesis, nutrient cycling and energy fluxes.
Ecosystem functions	The subset of *processes* and *structures* that, if benefiting to human well-being, provide *ES*. Can be defined as the capacity of ecosystems to provide *ES*. Example: carbon sequestration
Ecosystem properties	Refers collectively to *ecosystem structure* and *processes*.
Ecosystem services	Direct and indirect contributions of *ecosystem functions* to human well-being. *Example:* climate regulation, provision of food
Intermediate ecosystem service	*Ecosystem functions* that do not directly benefit to human well-being, but that support other functions that do. Synonymous with 'supporting services'
Ecosystem service providers	The ecosystems, component populations, communities, functional groups, etc. as well as abiotic components such as habitat type, that are the main contributors to specific *ES*. *Example:* Forest tree communities are ES providers for global climate regulation.
Human well-being	A state that is intrinsically or instrumentally valuable for a person or society. *Example:* The MA classifies components of human well-being into: basic material for a good life, freedom and choice, health and bodily wellbeing, good social relations, security, peace of mind, and spiritual experience.
Ecosystem service supply	ES provisioned by a specific area over a given time period.
Ecosystem service	ES demanded in a specific area over a given time period.

demand	
Ecosystem service providing units/areas	Spatial units that are the source of *ES*. Commensurate with *ecosystem service supply*.
Ecosystem service benefiting areas	The complement to ES providing areas. *ES benefiting areas* may be far distant from respective *providing areas*. Commensurate with *ES demand*.
Landscape	An area viewed at a scale determined by ecological, cultural-historical, social and/or economic considerations'
Landscape services	The contributions of landscapes and landscape elements to human well-being
Landscape multifunctionality	The capacity of a landscape to simultaneously support multiple benefits to society

1.2 THE CONCEPT OF LANDSCAPE

In the year 2000, the European Landscape Convention (ELC) defined landscape as 'an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors'. The ELC, as well as the Convention for the Safeguarding of the Intangible Cultural Heritage and the Framework Convention on the Value of Cultural Heritage for Society, formally recognized and highlighted the landscape concept as central to matters of sustainability and the management of public spaces. It received a higher status in spatial planning and the meaning of 'landscape' – what it is and what it does – is subject to on-going discussions in relation to legislation, policy, planning, and management.

As summarised in Box. 2, there are diverging views on the meaning of *landscape*, and *landscape scale*, as well as the spatial extent of a landscape as a *spatial unit*. Landscape scale has been defined as an intermediate integration level between the field and the physiographic region, but with an extent depending on the spatial range of the biophysical and anthropogenic processes driving the processes (or services) under study. Landscape units can be aggregated at various levels of abstraction, allowing – in principle – to build a hierarchical system of different landscape levels. Landscapes can therefore have very different character and size, and studies that relate to very different kinds of study areas may still claim to be performed at a landscape scale.

Box 2: "Landscapes" in the scientific ES literature

Amongst the reviewed papers, 94 areas referred to as "landscape" were identified (Fig. 2). Their sizes range from 24 hectares (ha) (roughly 34 football fields) to 122 million ha (roughly the size of South Africa). The extent of a landscape has been suggested to range from 100 to 10,000 ha, but only 23 out of the 94 areas were within this range. It is thus obvious that there are diverging views on the spatial extent of landscapes in the ES literature. The term is also sometimes used rather arbitrarily. To avoid this, areas referred to as landscapes should be described in a way that explains *why* they are considered landscapes.

Given the diverging views on the spatial extent of a landscape, there are also diverging views on the meaning of *landscape scale*. The view that landscape scale is referred to as having a landscape as a study area is common in the ES literature, although while some attempt to map ES across the landscape, others aggregate the ES under study to one value for the entire landscape. A study area can also be described as containing several "landscapes", each assigned an aggregated ES value. In such cases, some also refer to the entire study area as a landscape. Two studies may thus focus on the same area, refer to it as a landscape, but have widely varying views on what is meant by landscape scale.

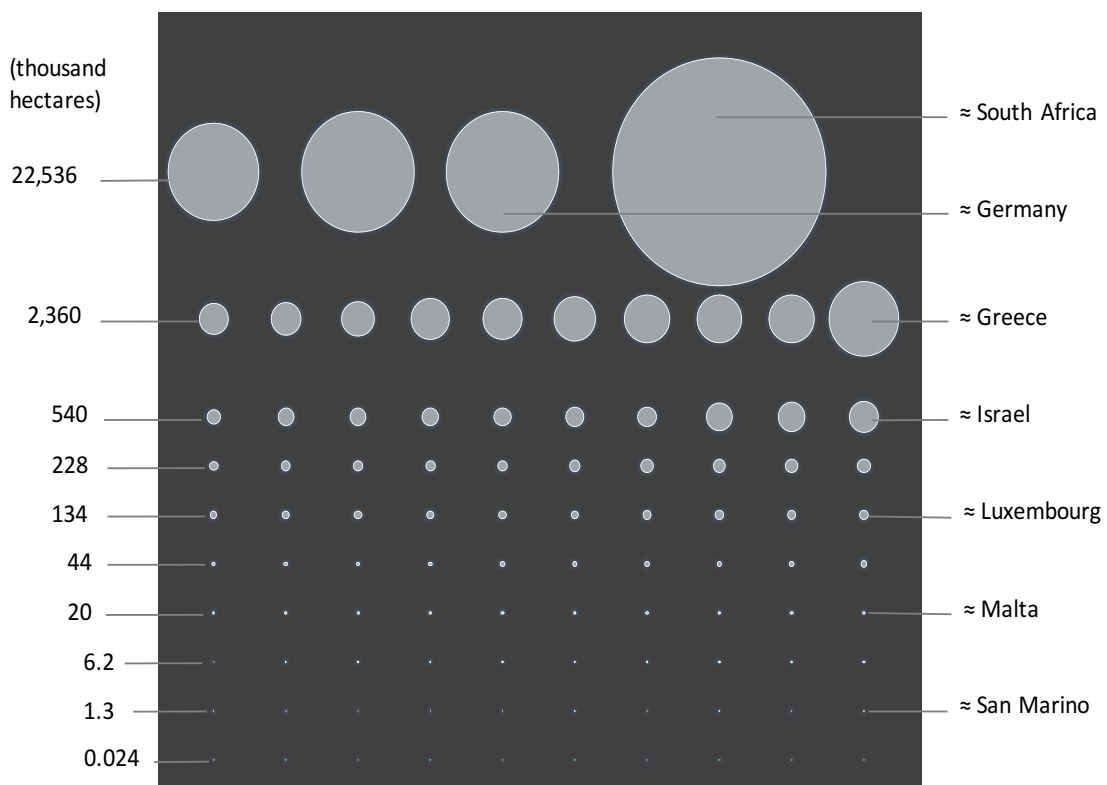**Figure 2:** Size of the 94 areas referred to as "landscape" in the reviewed papers. Size is specified using absolute numbers for the areas at the far left of the figure, and using countries of an approximately equivalent size for the areas at the far right, to aid comprehension. Due to the large differences, the smallest 15 areas would not be visible in this figure without their outline. Hence, they appear similar in size.

2 Methods for analysing ES in landscapes

There are a multitude of methods and tools available for mapping and analysing ES at different scales. This, along with inconsistencies in the terminology, creates uncertainties about appropriateness of methods. The inconsistent terminology can even cause uncertainty about what is being analysed. Most ES assessment studies so far use proxy methods, i.e., assigning ES values to an area based on simple characteristics, such as land cover type. Proxy-based methods may be appealing since they are much less complex than, for example, direct mapping with survey and census approaches, or empirical production function models. But there are disadvantages, such as the risk of generalization error, which makes them unsuitable for landscape scale studies. As landscapes are typically not mere combinations of ecosystems, but shaped by the interactions between ecosystem structures/processes and humans, the use of proxies at the landscape level is particularly sensitive to local conditions. Careful calibration and validation is therefore necessary, but this has typically not been done. Proxies may be suitable for identifying broad-scale trends in ES, or for global level and rapid assessments. But they are likely unsuitable for identifying, e.g., hotspots of single or multiple ES values, areas where ES are at risk, and how interventions to enhance ES could be designed. Additional data beyond land cover observation are therefore often necessary for an adequate assessment of ecosystem functions or services, especially at the landscape scale.

Figure 3 shows how many times different ES were mapped at a landscape scale in a selection of 347 cases where geoexplicit ES values were estimated. *Regulating and maintenance* services were most commonly mapped, followed by *cultural*, and *provisioning* services. An additional 24 "services" were mapped, that were either a combination (bundle) of individual ES or not covered by the CICES classification system. This includes "landscape services" where landscapes or specific landscape elements, rather than ecosystems, provide benefits to human well-being. A comparison with previous reviews indicates that mapping of cultural services is relatively more common in studies claimed to be done at the landscape scale. Concerning methodology approaches, *Logical models* and *Empirical models* were most commonly used, followed by *Extrapolation*, *Simulation/Process models*, *Data integration*, and *Direct mapping*. In ten cases, a combination of several method types was used.

The large variation shown in Fig. 3 may reflect the perceived importance of different ES, but it may also reflect that some ES are easier to map than others. For example, the two most frequently mapped ES, global climate regulation and biomass production, are indisputably high priority in society and they are also easily mapped with adequate accuracy using proxies and statistics. Other ES that are also high priority, e.g., surface water and flow mediation, are much less frequently mapped. This may be explained by the more complicated methods required to map such ES with adequate accuracy. Furthermore, the supply of ES is much more commonly mapped than the demand, and few studies attempt to analyse or discuss spatial links between providing and benefiting areas.
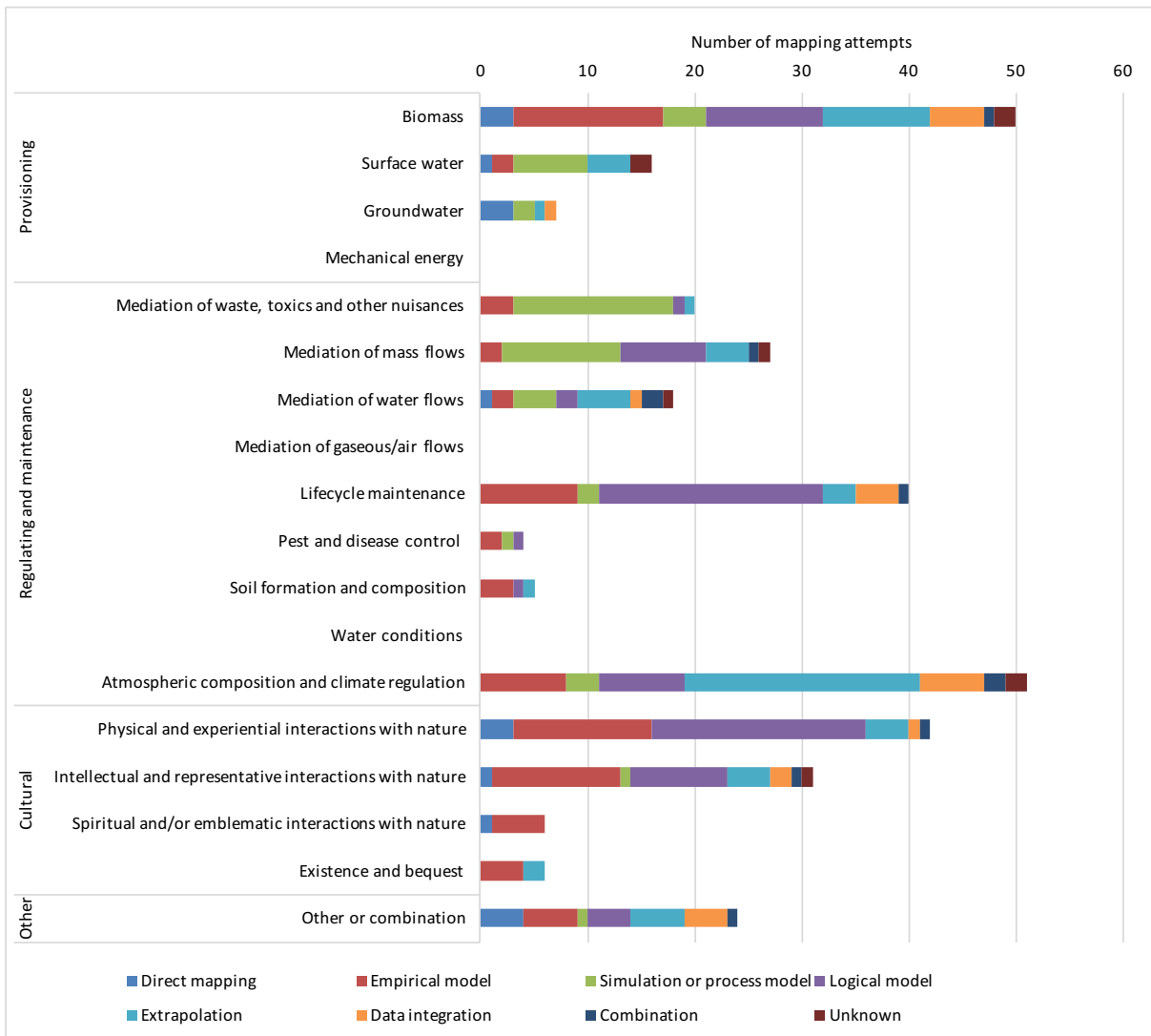
Figure 3: Number of times different ecosystem services have been mapped at a landscape scale, in 347 cases identified in our systematic review of the scientific literature (Englund et al. (2017). Methods (identified via colours in the diagram) were in many cases difficult to assess and categorize due to very brief or otherwise insufficient method description. In nine cases, it was not possible to determine which type of method had been used. This should serve as a reminder that method descriptions in scientific literature should not only facilitate understanding, but also reproduction. Several of the reviewed papers failed to facilitate the latter.

3 Validation of results

Excluding the cases that used *direct mapping* (that does not require validation), only twelve percent of all reviewed ES mapping cases were validated with empirical data. No difference was found between recent and older articles in this regard. Validation was almost exclusively applied in studies employing empirical models, simulation and process models, or logical models (Fig 4). It was most common for biomass, lifecycle maintenance, and physical and experiential interactions with nature, followed by mediation of waste, and mediation of mass flows. For all mapped ES, at least one study included validation (Fig. 5).

The common lack of validation is noteworthy and the widespread use of non-validated proxy-based methods is a reason for concern. Collection of empirical data is time consuming and this probably explains why validation is most commonly made in studies that map ES using empirical

models, or simulation and process models (fed with empirical data), where empirical data must be collected anyway. However, results that are not validated can be difficult to evaluate and thus be of limited use for both academia and society in, e.g., landscape planning. Validation should therefore be prioritised in ES mapping studies.
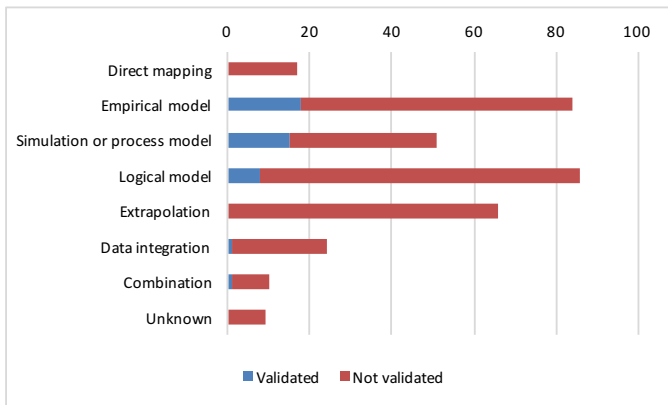

Figure 4: Number of cases where mapping results were validated (blue) and not validated (red) with empirical data, for the different method types.
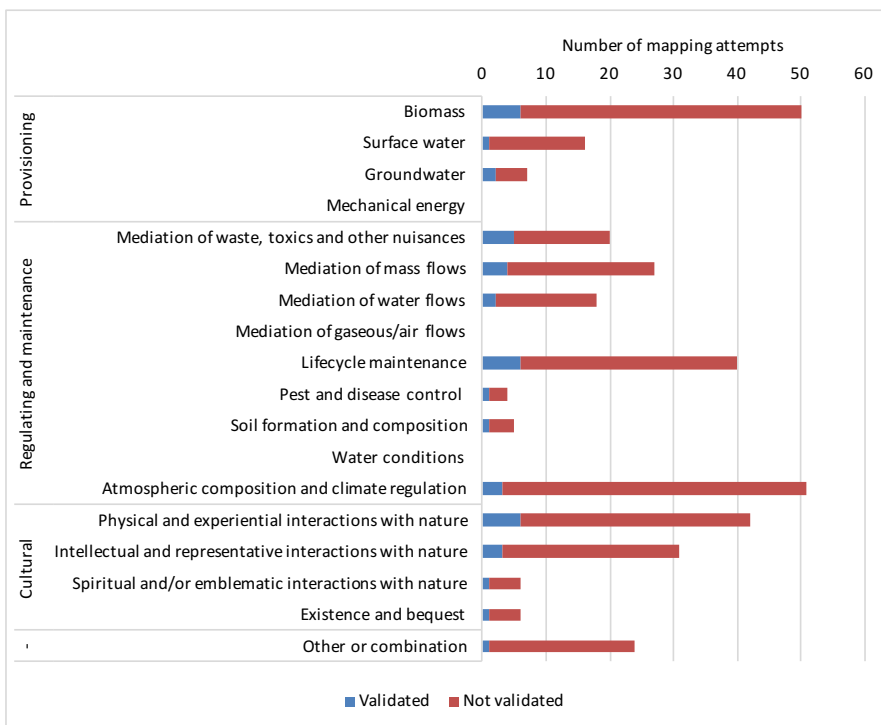

Figure 5: Number of cases where mapping results were validated (blue) and not validated (red) with empirical data, for the different ecosystem services.

4 Discussion and Recommendations

Landscapes are commonly heterogeneous and the ES supply is unequally distributed across space. To support spatial planning and decision-making, ES assessments therefore need to be carried out in spatially explicit ways. A high level of detail and accuracy is necessary at varying spatial and

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temporal scales. Given the importance of high resolution and need for more complex methods and validation, most ES assessments with a landscape scope will need to limit the number of ES included in the study. To ensure that the most relevant ES are included, it is essential to involve stakeholders in the selection process. Furthermore, the capacity of the research group and available resources for the project may determine which ES can be included. In some cases (e.g., for global climate regulation or biomass production), proxy-based methods can provide ES values with acceptable accuracy, especially if they can be combined with empirical data, e.g., production statistics. But in general, ES that cannot be studied in other ways than with simple proxies, or be sufficiently validated, should preferably be omitted.

The suitability of methods depends on context as well as practitioners' competence, data availability, time frame, etc. Carefully calibrated empirical or process based models, validated against empirical data, can provide accurate and easily evaluated results, but they might not be relevant for certain ES, study areas, or research groups. The use of simple proxies in landscape level studies may generate misleading results. Practitioners with advanced GIS skills may benefit from creating their own models. However, some existing models, e.g., the InVEST model, have been applied many times, in several cases with validated and acceptably accurate results. When using third-party models, it is imperative that these are properly evaluated on their suitability for the specific project beforehand, and also calibrated and validated using empirical data.

Studies use different classification systems, but experience indicates that translation of ES into the CICES classification system is in most cases relatively straight-forward. Most of the ES that could not be fitted into CICES were either bundles of ES mapped together or examples of ecosystem processes rather than ES. Further development of CICES should consider whether to only include direct ES and thus exclude ecosystem processes and functions. For example, it can be argued that soil formation and composition is not a direct ES, but rather an intermediate ES, or an ecosystem function. The direct ES should rather be associated with what benefits to humans the soils facilitate; e.g., production of crops, or—indirectly, since soils facilitate vegetation growth—mediation of water and nutrient flows. Furthermore, "water conditions" was found to be redundant, as it refers to ensuring favourable living conditions for biota, which is similar to "lifecycle maintenance". Possible additions to CICES could be mediation of UV radiation, i.e., shade, which is an ES commonly used by humans and animals that is rarely described in the literature.

Finally, the comprehensiveness and use of more technical terms in CICES may create a barrier for communication and interaction with those that lack in-depth understanding of ES. Given the importance of stakeholder involvement in ES assessments, this is a clear disadvantage. It may therefore be beneficial to review the wording or to complement the typology with alternative, less technical, descriptions. This can preferably be coordinated with other initiatives that aim to inform policies and everyday practices, such as the Nature's contributions to people (NCP) concept within the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

This report highlights the diversity of approaches to assess how land use influences ES, as well as the ICES initiative to harmonize the terminology and make studies more consistent and comparable. The systematic literature review, that provided the basis for this report, can serve as a starting point for further work to identify the methods and tools that appear to be most suited for adaptation and incorporation into the LCIA framework – and to clarify the direction for such an endeavor, including key data and knowledge gaps that need to be filled. Harmonization initiatives such as the ICES are naturally highly relevant in relation to such an ambition. One conclusion of further work may be that it is preferable to complement LCA studies with separate assessments of ES that are based on other methodology frameworks.

5 Recommended reading

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