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A guide to assess and value ecosystem services of grasslands

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ABSTRACT

Comprehensive mapping of Ecosystem Services (ES) is necessary to understand the impact of global change on crucial ES and to find strategies to sustain human wellbeing. Economic valuation of ES further translates their biophysical values into monetary values, which are then comparable across different ES and easily understandable to decision makers. However, a comprehensive synthesis of methods to measure ES indicators in grasslands, a central element of many landscapes around the globe, is still lacking, hampering the implementation of grassland ES-multifunctionality surveys. To identify suitable and recommendable methods, we reviewed the literature and evaluated labor intensiveness, equipment costs and predictive power of all methods. To facilitate the translation of biophysical ES into monetary terms, we further provide an overview of available methods for the economic valuation of ES.

This review resulted in a toolbox comprising 85 plot-scale methods for assessing 29 different ES indicators for 21 provisioning, regulating, supporting or cultural ES. The available methods to measure ES indicators vary widely in labor intensiveness, costs, and predictive power. Based on this synthesis, we recommend 1) to choose direct over indirect methods and ES indicators, 2) to use the most accurate methods to estimate ES indicators, 3) to take into account that one ES indicator can have implications for more than one final ES, and 4) to utilize the wealth of available methods and indicators to assess as many ES for ES-multifunctionality studies as possible, especially including cultural ES. Moreover, the overview of approaches that can be used for the economic valuation of different grassland ES shall facilitate economic ES-multifunctionality assessments. Thus, this methodological guidance will considerably support researchers and stakeholders in setting up ES comprehensive assessments and monitoring schemes in grasslands and shall ultimately help overcome incomplete or superficial surveys based on single or few ES only.

1. Introduction

1.1. Monitoring ecosystem services – A crucial task

Humans depend on well-functioning ecosystems for vital resources, protection from natural hazards and general well-being. This is acknowledged and explored by the concept of Ecosystem Services (ES), describing the multiple ways people benefit from ecosystems (MA, 2005). Given the great importance of ES for human welfare, it is essential to guarantee their provision in a changing future. On-going global change, i.e. climate and environmental change, land use change and biodiversity loss, affects the functioning of ecosystems and therefore the delivery of many ES (Leemans and Eickhout 2004; Metzger et al. 2006; Gosling 2013; Lawler et al. 2014). Closing knowledge gaps in understanding how ES respond to these drivers is a crucial task for researchers and stakeholders around the world (Staudinger et al. 2012; Gosling 2013; Pedrono et al. 2016; Giling et al. 2019). Mapping and measuring ES is required to identify mechanisms of ES change and enable us to find strategies to actively support ES with targeted management decisions and well-informed policymaking (Mooney et al. 2009; European Commission 2011).

To capture the degree of human benefits from ES, a number of ES valuation concepts have been put forward. These can be grouped into ecological, sociocultural and economic valuation concepts (Gómez-Baggethun et al. 2016). Of these three, the economic valuation of ES has been recognized as an important tool for developing strategies for the sustainable management of ecosystems (Costanza 2006; Morse-Jones et al. 2011; Costanza et al. 2014), albeit a rather challenging one. The lack of economic assessments limits the possibilities to use existing ecological and sociocultural ES assessments. Nevertheless, the monetization of ES can contribute to increase public concern about ES (Cheng et al. 2019). If successful, it enables the easier integration of these services in public decision-making (Brauman et al. 2007; Sekercioglu 2010; Pascual et al. 2012) and especially helps policy-makers to better understand the trade-offs in the use of ecosystems (Lazo 2002). However, economic valuations of grassland ES, and especially those considering multiple services, are scarce. This paper contributes to close this gap.

In the following, we will refer to the CICES ES typology as defined by Haines-Young and Potschin (2018), because studies applying the ES concept greatly outnumber the few publications considering Nature's

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Contributions to People (NCP) (Pascual et al. 2017). Nevertheless, methods used for assessing ES can also be applied in NCP research.

Specifically, the CICES typology for ES is a hierarchical and comprehensive ES classification framework (Haines-Young and Potschin 2018). As such it serves as an important standardized basis for independent ES assessments (Maes et al. 2016), and this is why we chose to adopt the CICES ES typology in this review.

1.2. Grasslands – Ecosystems with High ES-Multifunctionality

Grasslands cover almost one-third of the terrestrial Earth surface and are important for a wide range of provisioning, supporting, regulating and cultural ES (Bengtsson et al. 2019), making grasslands highly multifunctional ecosystems (Lemaire et al. 2011; Hönigová et al. 2012; Egoh et al. 2016). ES-multifunctionality according to Manning et al. (2018) describes the degree to which one ecosystem can provide multiple ES at once. Grasslands for example regulate water flow, prevent soil erosion, sequester carbon, contain medicinal plants, and provide habitat for non-plant organisms such as insects needed for crop pollination, besides playing an important role for food security by facilitating efficient ruminant conversion of grass biomass to milk and meat (O'Mara 2012; Erb et al. 2018; Bengtsson et al. 2019). Further, permanent natural and semi-natural grasslands can be of great nature conservation value, supporting high species diversity of vascular plants and other organism groups (Veen et al. 2009; Habel et al. 2013; Dengler et al. 2014). Nevertheless, studies assessing ES-multifunctionality of on-farm permanent grasslands in most cases assessed only few to up to ten ES (Zavaleta et al. 2010; Allan et al. 2015; Van Vooren et al. 2018), while especially in grassland-based biodiversity-ecosystem functioning experiments a larger number of functions was studied (Allan et al. 2013; Meyer et al. 2018). A review by Hölting et al. (2019) for instance showed that a majority of studies quantitatively assessing ecosystem function or service multifunctionality considered only up to six services or functions, which is considerably below the numbers of ES detailed by the framework "Common International Classification of Ecosystem Services" (CICES) (Haines-Young and Potschin 2018) . Thus, a comprehensive assessment of all ES provided by a land use type is needed to inform policy-making and take land-use decisions (Tasser et al. 2020).

Despite their high multifunctionality, natural and managed grassland areas are being lost to e.g. degradation, conversion to other land uses, and expanding settlements (Rounsevell et al. 2005; Wright and Wimberly 2013). Additionally, grasslands are subject to changes in ES delivery due to climate change and land use intensification (Hopkins and Del Prado 2007; Tscharntke et al. 2012), further increasing the uncertainty of future grassland ES-multifunctionality. Thus, efforts to map and understand grassland ES and their environmental and management drivers are essential to understand processes leading to changes in grassland ES-multifunctionality and potential feedbacks to human wellbeing.

1.3. Need for a robust set of indicators and corresponding methods for ES assessments

The assessment of an ES is conceptually based on two steps. First, one or more field and lab methods can be used to measure an ES indicator. Second, one or more ES indicators estimate one individual, final ES (Tasser et al. 2020; Fig. 1). Thus, one **final ES** is usually assessed by one or more **ES indicators**. The term "indicators" is understood here as a proxy for an ecosystem's capacity to provide a certain ES. These ES indicators describe the ecosystem's biological, chemical or physical characteristics and have a specific direction (for instance high or low) to indicate the desired outcome and to make clear, in what way an increase or decrease of an indicator's value will influence the final ES (Reyers et al. 2010; Tasser et al. 2020). For example, field measurements using the method of *standard litter decomposition* estimate the indicator *high litter and feces decomposition*, which is used for the ES Decomposition and fixing processes and their effect on soil quality (CICES 2.2.4.1) (Fig. 1).

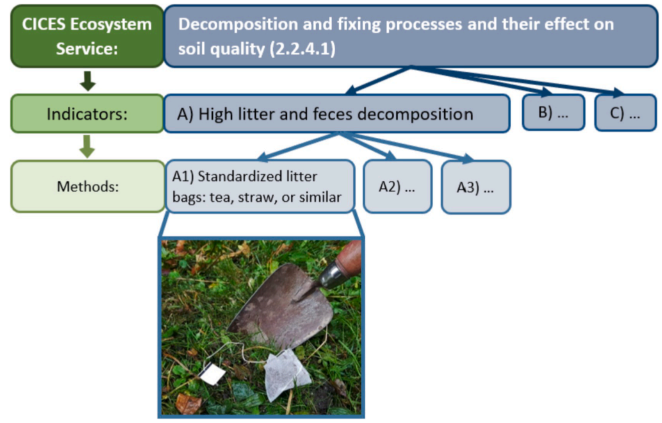

Fig. 1. For a given ES, more than one indicator exists that can be used to assess the ES. The indicators themselves can be measured with different field and plot level methods. This is illustrated here with the CICES ES Decomposition and fixing processes and their effect on soil quality (CICES 2.2.4.1) (Haines-Young and Potschin 2018).

Adequate and robust indicators are needed to reliably assess single ES and ES-multifunctionality to inform policy-making (Manning et al. 2018). Valuable steps in this direction have already been made, by identifying and evaluating indicators for ES and multifunctionality assessments (Meyer et al. 2015; Maes et al. 2016; Tasser et al. 2020; Garland et al. 2021).

Furthermore, one ES indicator can relate positively to one ES and negatively to another: e.g. microbial activity and litter decomposition have positive impacts on nutrient cycling, but negative impacts on carbon sequestration (Prescott 2010). Similarly, the presence of so-called weeds in agroecosystems might lower food or fodder production, but these at the same time also present a good habitat for pollinators and provide other ecological benefits (Bretagnolle and Gaba 2015). Thus, an overview of relevant ES indicators pointing at positive and negative implications for the different ES is urgently needed to effectively assess ES-multifunctionality.

In addition, in many cases, numerous different **methods** exist for measuring one specific ES indicator in the field and/or in the lab, often with poor comparability among the results. Finding the method best suited in a given situation can be challenging and time consuming, as it is difficult to oversee the vast diversity of available methods. These methods differ strongly in properties such as labor force requirements and equipment costs as well as in their predictive power for a given ES (Griffiths et al. 2016).

1.4. Objectives

The overarching goal of this review is to provide guidance for efficient ES assessment and valuations in grasslands and grassland-like ecosystems. To that end, we conducted a literature review to 1) identify the multiple positive and negative links between ES indicators and the final ES (according to CICES version 5.1). We further 2) provide a comprehensive overview of field and lab methods to measure ES indicators resulting in a versatile toolbox for grassland ES assessments including an evaluation of the methods with regard to costs and effort required. To facilitate economic ES valuation, we 3) provide an overview of methods available for the economic valuation of grassland ES for each ES category (provisioning, regulating and supporting, cultural) separately. Finally, we discuss implications for mapping and valuing grassland ES-multifunctionality to support policy- and decision-making in the future.

2. Methods

Our study is based on the ES nomenclature proposed by CICES version 5.1 (Haines-Young and Potschin 2018) to identify ES relevant for grassland systems. When reviewing the existing literature (online available back to 1930ies), we excluded 1) ES not applicable to grasslands (e.g. services 1.1.4.1 to 1.1.4.3 concerning aquaculture), 2) ES not especially relevant or hardly studied in grasslands (e.g. 2.1.2.2 noise attenuation, 2.2.2.2 seed dispersal), and 3) ES provided only under specific circumstances such as bioremediation of toxic wastes. From the 59 biotic ES included in CICES, we identified 21 as particularly important ES in grassland ecosystems and included those in our study. The final review of ES indicators and the methods for measuring these indicators, a literature review was conducted in *Web of Science* and *Google scholar*, using search strings containing either "Ecosystem* Service*" (OR "multifunctionality") or an individual ES or ES-indicator (e.g. "carbon sequestration", "carbon stock*"), with and without keywords for grassland (e.g. "grassland*", "pastur*", "meadow*", "rangeland*"). This way, papers not explicitly focusing on grasslands, but giving useful insight in specific methods were also included. Here, the list of indicators compiled by Maes et al. (2016) provided helpful orientation and starting point for the search. For the compilation and evaluation of methods for measuring ES indicators, we finally included 223 papers, book chapters, and reports dating from 1934 to 2021 and describing or evaluating methods to measure ES indicators. These contributions ranged from studies focusing on one method to compilations of methods, and from papers assessing a few ES to assessments of multiple ES, at different spatial scales. From this literature, we extracted specific, recommendable methods for assessing the final ES. Next, we grouped the methods into indicators, if the methods essentially measured the same process or ecosystem property and thus roughly formed a homogeneous set of information to indicate a final ES. This approach was chosen because many papers did not use an indicator-framework but directly used a method to assess an ES. To account for the vast amount of literature on single ES, we further condensed information about the widely used methods per indicator in a table evaluating labor intensiveness, equipment costs and predictive power for ES for each method.

For the evaluation of the indicators, we compared different methods per indicator, resulting in relative rankings of the methods for one indicator concerning the labor intensiveness, equipment costs, and the predictive power for ES. For *labor intensiveness*, we considered estimated person hours of the methods; *equipment costs* refer to costs for instrumentation and consumables needed for analyses. These two variables correspond to e.g. "installation and maintenance efforts", "equipment and running costs" or "instrument and maintenance costs", respectively (e.g. Eugster and Merbold 2015; Halbritter et al. 2020). For *predictive power*, we evaluated the methods concerning information value provided for estimating or measuring the respective ES indicator. This included 1) precision of the method (e.g. erosion estimates using surface-runoff measurements can detect smaller differences in erosion than erosion sticks), 2) whether more than one aspect of an indicator is captured, i.e. comprehensiveness of the method (e.g. estimating invertebrate and fungal damage on plants provides more information than estimating unclassified damage), and 3) how strongly the method contributes to explaining the ES in question (e.g. surface runoff experiments measure water infiltration for the ES water cycling at a larger and thus more relevant scale than infiltrometers or disc permeameters).

This means, that "predictive power" depicts a ranking of the methods based on the above-mentioned points, to guide readers in finding the optimal method, which available labor force and budget allow.

For these rankings, we relied on existing method reviews where possible (e.g. Griffiths et al. 2016) or estimated labor intensiveness, equipment costs and predictive power based on the literature reviewed, own experience and expert knowledge. We also recorded whether a method *directly* or *indirectly* measures the indicator in question (e.g. plant biomass quality can be directly measured with different methods, but also estimated more coarsely on the basis of sward composition and harvest time (Tasser et al. 2020)) as well as whether an indicator assesses the ES *directly* or *indirectly*.

For the general overview of the approaches available for the economic valuation of ES, we conducted a second review and searched the existing literature independently of whether it dealt with grassland or any other ecosystem type. This was because papers on economic valuation of ES specifically from grassland were extremely scarce. In a first step, relying on i) the comprehensive introduction and overview provided by Pascual et al. (2012), which was the starting point of our review, and on ii) further general methodological literature on ES valuation such as Fisher et al. (2008) or Morse-Jones et al. (2011), we compiled frequently used valuation methods and address important methodological issues regarding ES valuation. In a second step, we searched for empirical applications of these methods from the grassland literature. Since the type of approach that can be used for the economic valuation of ES strongly depends on the category of the ES to be valued (provisioning, regulating and supporting, cultural ES), the search was performed separately for each ES category and the overview is presented accordingly.

3. Toolbox for grassland ES assessment

3.1. Relationship between Indicators and ES

Our literature review revealed the relationships between ES indicators and final ES do not describe a straightforward one-to-one relationship, but rather a multi-faceted network of positive and negative relationships (Fig. 2). It became evident that several indicators can be used to adequately estimate one ES, as pointed out by Manning et al. (2018) stating that ES with several components also need several indicators. A good example for this is the ES Decomposition and fixing processes and their effect on soil quality (CICES 2.2.4.1), which has many facets and for which we identified eight frequently used indicators (Fig. 2). On the other hand, one indicator can also simultaneously act as an indicator for several ES, as illustrated by Paul and Helming (2019) for different soil functions and their connection to ES. Soil nutrient availability for instance represents the ES Decomposition and fixing processes and their effect on soil quality (CICES 2.2.4.1) as well as some provisioning services by influencing the production potential. Similarly, the indicator plant diversity provides information not only for the ES Nursery populations and habitat (CICES 2.2.2.3), but also for Pollination (CICES 2.2.2.1), Education (CICES 3.1.2.2) and Existence (CICES 3.2.2.1). These two examples show that careful consideration is necessary in setting up an ES assessment, as multicollinearity of ES can become a problem when using indicators providing information on several ES (Tasser et al. 2020). If on the other hand many indicators are used to quantify one ES (as e.g. for Decomposition and fixing processes (CICES 2.2.4.1), an ES with many indicators), these must be weighted less than indicators for ES represented by less indicators, to guarantee equal weighting of indicators for individual ES (Manning et al. 2018).

3.2. ES indicators and assessment methods

In total, we reviewed 29 indicators for assessing ES in grasslands with 85 most commonly used methods, with more than half of the methods measuring indicators for regulating and supporting ES (Table 1, S1). The outcomes of the literature review are presented in a comprehensive table (Table 1) and a guide, i.e. an extensive text document (**S1**), which gives a more detailed overview over the different methods pointing at their strengths and weaknesses. In the following sections, this guide is summarized, and the most important results are highlighted, sorted by ES categories.

3.2.1. Provisioning services

The ES **Cultivated and wild plants for nutrition (CICES 1.1.1.1**

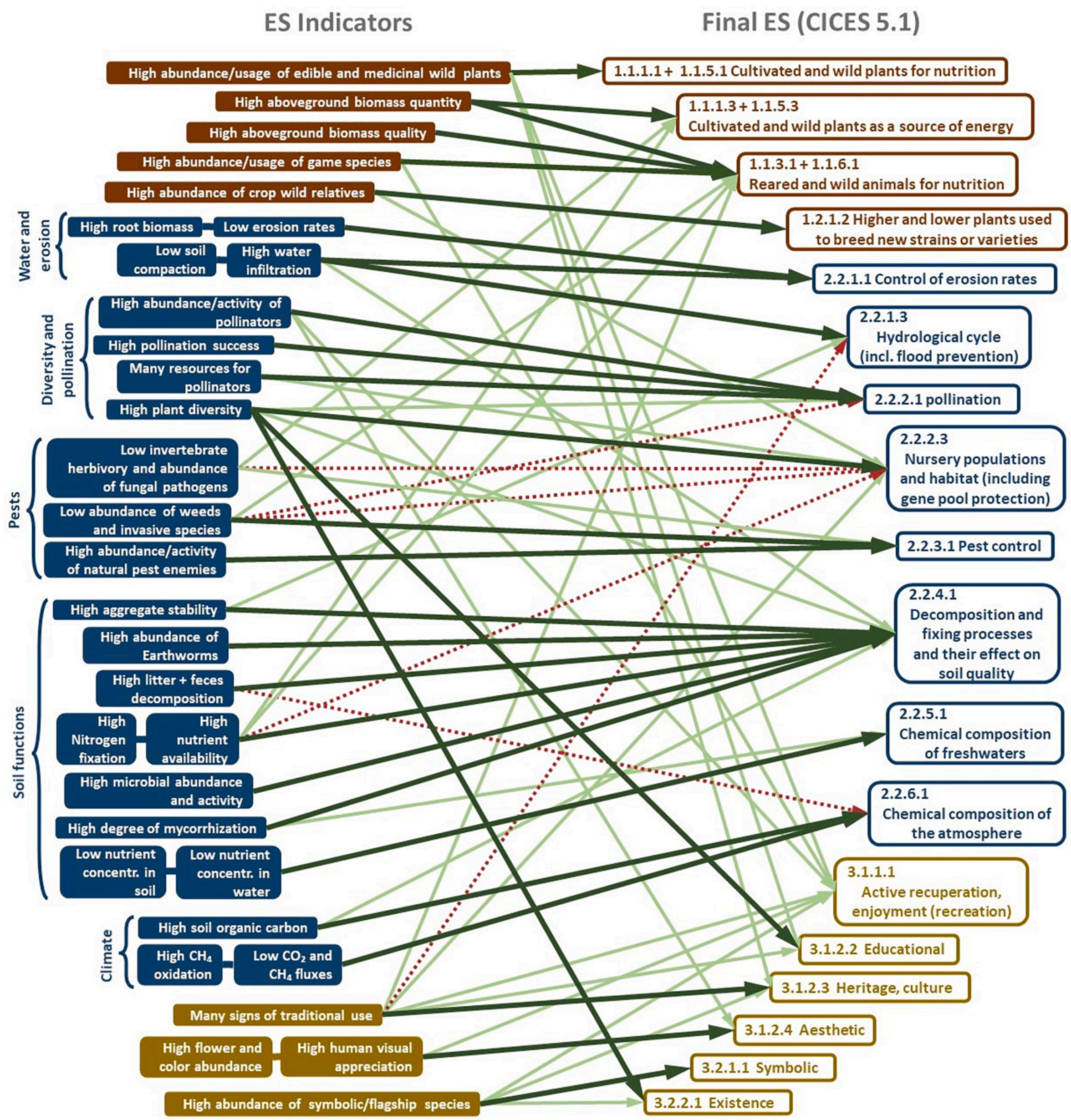

Fig. 2. Relationships between grassland ES indicators (left), according to Tasser et al. (2020), and final ES (right) following "Common International Classification of Ecosystem Services" (CICES) nomenclature v.5.1 (Haines-Young and Potschin 2018). Provisioning ES and corresponding ES indicators displayed in brown, regulating and supporting ES in blue, cultural ES in dark yellow. Solid green arrows indicate positive relationships, with strong positive relationships in dark green and weaker positive relationships in light green. Dotted red arrows show negative relationships. This visualization cannot capture the entirety of all relationships but attempts to give an overview of the most important and most frequently studied connections. Most ES indicators reveal information concerning more than one ES and some can be positively related to one ES and negatively to another ES. Note that usually several different field and lab methods exist to measure a single ES indicator (see Table 1).

and 1.1.5.1) can be assessed by different methods estimating the indicator *High abundance and usage of edible and medicinal plants and fungi* **(S1.1.1)**. More indirect methods use the abundance, i.e. cover and/or biomass, of the plants or fungi in question, while more direct methods grasp the actual use by the local population, which is best assessed via interviews and questionnaires. Ideally, both approaches are combined to acquire the full picture, though methods are quite labor-intensive. In addition, this indicator for a provisioning ES can also be regarded as belonging to the cultural ES Active recuperation, enjoyment (recreation) (CICES 3.1.1.1) and Heritage, culture (CICES 3.1.2.3). Which ES it is finally assigned to depends strongly on the region under study, as in some parts of the world wild food still contributes substantially to food security (Lulekal et al. 2011; Ju et al. 2013), while in others the recreational, heritage and gourmet aspects of gathering wild food is of greater importance today (Tardío et al. 2006; Abbet et al. 2014; Schulp et al. 2014).

Cultivated and wild plants as a source of energy (CICES 1.1.1.3. and 1.1.5.3) and **Reared animals for nutrition (CICES 1.1.3.1):** *High aboveground biomass production* and *High biomass quality* (forage value) (**S1.1.2 and S1.1.3**) are the most significant indicators for the ES Cultivated and wild plants as a source of energy (CICES 1.1.1.3. and 1.1.5.3) and Reared animals for nutrition (CICES 1.1.3.1), as only the interplay between amount and quality of aboveground biomass, the quality-adjusted yield, allows to directly assess the amount of livestock that can be fed for dairy and/or meat production or the amount of bioenergy and/or raw material (fibers) that can be generated. Thus, these

Table 1
Overview of the most commonly used methods for measuring a given ES indicator; grouped by the ES. Note that some indicators have predictive power for more than one ES (see Fig. 2), but they only appear in the table once. Number of symbols denote the suitability of the method considering the different criteria, from small 👤 to high 👤 👤 👤 labor force needed, low $ to high $ $ $ equipment costs, and low * to high * * * predictive power. This evaluation is relative and compares methods for the same indicator. The ES are color coded as in Fig. 2.

ES-indicator	Direct or Indirect Indicator	Direct or Indirect Method	Field/Lab Method	Labor Force	Equipment Costs	Predictive Power	References
			Cultivated and wild plants for nutrition (1.1.1.1 and 1.1.5.1)				
High abundance/usage of edible and medicinal plants and fungi	D	I	Actual use: interviews and questionnaires	👤 👤 👤	$	* * *	(Ju et al. 2013; Abbet et al. 2014; Vitalini et al. 2015)
		I	Cover/biomass of edible and medicinal plants and fungi	👤 👤 👤	$	* *	(Schulp et al. 2014)
			Biomass for energy + reared animals for nutrition (1.1.1.3, 1.1.3.1 and 1.1.5.3)				
High aboveground biomass quantity	D	D	Biomass harvest	👤 👤 👤	$	* * *	(Singh et al. 1975; Ni 2004)
		I	Sward height	👤 👤	$	*	(Marshall et al. 1998)
		I	Estimation with rising plate meter	👤	$ $	* *	(Dale 2015)
		I	Remote sensing techniques (ultrasonic distance sensors, etc.)	👤	$ $	*	(Wachendorf et al. 2018)
High aboveground biomass quality	D	D	Metabolizable substance in vivo	👤 👤 👤	$	* * *	(Holecheck et al. 1982)
		D	Metabolizable substance in vitro	👤 👤	$ $	* * *	(Tilley and Terry 1963; Schubiger et al. 2001)
		D	NIRS, C-N Analyzer and similar methods	👤	$ $	*	(Kleinebecker et al. 2011)
		I	Mean pastoral feed value index based on species specific indicator values	👤 👤	$	* *	(Daget and Poissonet 1971; Briemle and Dierschke 2002)
		I	Estimate quality from information on sward composition and harvest time	👤	$	*	(Daccord et al. 2007)
			Wild animals for nutrition (1.1.6.1)				
High abundance/use of wild game species	D	D	Statistics on game hunted (national statistics, hunters' associations etc.)	👤	$	* * *	(Remme et al. 2014)
		D	Questionnaire/interview surveys	👤 👤 👤	$ $	* * *	(Knoche and Lupi 2007; García-Nieto et al. 2013)
		I	Abundance of species from databases with species occurrence data	👤	$	* *	(Schulp et al. 2014; Ala-Hulkko et al. 2016)
		I	Recording game with remote cameras	👤 👤	$ $	* *	(Williams et al. 2018)
			Higher and lower plants used to breed new strains or varieties (1.2.1.2)				
High abundance of crop wild relatives	D	D	Vegetation survey (see also 2.2.2.3)	👤 👤	$	* * *	(Häner et al. 2010; Jarvis et al. 2015)
			Control of erosion rates (2.2.1.1)				
Low soil erosion rates	D	D	Sediment in surface runoff	👤	$ $	* * *	(Merz et al. 2009; Pulley and Collins 2019)
		D	Erosion sticks	👤	$	* *	(Trogisch et al. 2017)
		D	Apparent signs of erosion (gullies, rills etc.)	👤 👤	$	*	(Fernández-Ugalde et al. 2017; Xu et al. 2019)
		I	Visual estimation of vegetation cover/bare soil	👤 👤	$	* *	(Floyd and Anderson 1982; Murphy and Lodge 2002; Suter et al. 2007; Patrignani and Ochsner 2015)
High belowground plant biomass	I	D	Root biomass via soil cores	👤 👤	$	*	(do Rosário G. Oliveira et al., 2000; Ni 2004)
		D	Root biomass via soil monoliths	👤 👤 👤	$	* *	(Ni 2004)
			Hydrological cycling (incl. Flood prevention) (2.2.1.3)				
High water infiltration	D	D	Infiltrometer	👤 👤 👤	$	* *	(Naeth et al. 1991; Ford et al. 2012; Griffiths et al. 2016)
		D	Disc permeameter	👤 👤 👤	$ $	* *	(Fiedler et al. 2002; Eldridge et al. 2015)
		D	Surface runoff measurement (with or without artificial rain treatment)	👤 👤 👤	$ $	* * *	(Fiedler et al. 2002; Halvorson et al. 2003; Thierfelder et al. 2005; Leitinger et al. 2010; Qi et al. 2015)
Low soil compaction	I	D	Soil penetration resistance	👤	$ $	*	(Halvorson et al. 2003; Thierfelder et al. 2005; Qi et al. 2015)
		D	Bulk density	👤 👤	$	*	(Halvorson et al. 2003; Leitinger et al. 2010)
			Pollination (2.2.2.1)				
High abundance/activity of pollinators							
	D	D	Pan traps	👤 👤	$	* *	(Westphal et al. 2008)
		D	Transect catching methods	👤 👤 👤	$	* *	(Westphal et al. 2008)
		D	Visitation rates		$	* *	(Santos Oleques et al. 2017; Bartholomée and Lavorel 2019)

(continued on next page)

Table 1 (*continued*)

				👤👤👤			
		D	Amount of pollen on insects	👤👤👤	$	**	(Bartholomée and Lavorel 2019)
High pollination success	D	D	Phytometer or crop seed/fruit production	👤👤👤	$$	***	(Albrecht et al. 2007; Orford et al. 2016; Bartholomée and Lavorel 2019)
Many resources for pollinators	I	D	Measure of flower abundance in the field (transect or plot)	👤👤	$	***	(Ricou et al. 2014; Kütt et al. 2016; Bartholomée and Lavorel 2019; Villoslada Peciña et al. 2019)
		I	Nectar and pollen provision from trait databases following vegetation survey	👤👤	$	*	(Kwaiser and Hendrix 2008; Weiner et al. 2011; Binkenstein et al. 2013; Lucas et al. 2017; Santos Oleques et al. 2017)
Nursery populations and habitat (incl. Gene pool protection) (2.2.2.3)							
High plant diversity	D	D	Vegetation survey: point-intercept methods	👤👤👤	$	**	(Floyd and Anderson 1982; Tracy et al. 2004)
		D	Vegetation survey: visual estimation	👤👤	$	**	(Knop et al. 2006; Socher et al. 2013)
Pest control (2.2.3.1)							
Low invertebrate herbivory and abundance of fungal pathogens	D	D	Visual estimation of damage	👤👤👤	$	***	(Scherber et al. 2006; Fischer et al. 2012; Loranger et al. 2014; Rottstock et al. 2014; Liu et al. 2016; Egorov et al. 2017; Capelli et al. 2019)
		I	Herbivore numbers from traps	👤👤👤	$	**	(Woodcock and Pywell 2010)
Low abundance of weeds and invasive species	D	D	Field records: percent cover, transects	👤👤	$	***	(Suter et al. 2007; Goodall et al. 2010; Pywell et al. 2010; Martín-Forés et al. 2017)
		D	UAV based detection	👤	$$	*	(Binch et al. 2018; Valente et al. 2019; Petrich et al. 2020)
High abundance/activity of natural pest enemies	D	D	Abundance via netting, traps, observation *(see also: abundance of pollinators)*	👤👤👤	$	**	(Werling et al. 2011; Werling et al., 2014; Kim et al. 2017)
		D	Activity via sentinel prey removal	👤👤👤	$	***	(Bennett and Gratton 2012; Meehan et al. 2012; Meyer et al. 2015; Kim et al. 2017)
Decomposition and fixing processes and their effect on soil quality (2.2.4.1)							
High aggregate stability	I	D	Laboratory test	👤👤	$$	***	(Díaz-Zorita et al. 2002)
		D	Field test	👤	$	**	(Herrick et al. 2001)
High Earthworm abundance (individuals or biomass per area)	D	D	Pit with hand sorting	👤👤👤	$	**	(Didden 2001; Schmidt 2001)
		D	Extraction with expellant (mustard, electricity etc.)	👤	$	*	(Pelosi et al. 2009; Singh et al. 2016)
		D	Combination of both of the above	👤👤	$	***	(Pelosi et al. 2009; Singh et al. 2016)
High microbial abundance and activity: unspecific	I	D	Microbial biomass: fumigation extraction and substrate induced respiration	👤👤	$$	*	(Winding et al. 2005)
		D	Basal respiration	👤👤	$$	*	(Cabral et al. 2017)
High microbial abundance and activity: organism-/activity-specific	D	I	PLFAs	👤👤	$$$	**	(Winding et al. 2005)
		D	Quantification of enzyme activity	👤👤👤	$$$	***	(Griffiths et al. 2016)
		I	PCR based: quantification of functional genes, organism groups etc.	👤👤	$$	**	(Griffiths et al. 2016; Schloter et al. 2018)
High soil nutrient availability	I	D	N, P, K availability (soil sampling)	👤👤	$$	**	(Mallarino et al., 2005)
		D	Plant Root Simulator probes	👤	$$$	***	(Qian and Schoenau 2005)
		D	Cation exchange capacity, soil electronic conductivity	👤👤	$	*	(Halbritter et al. 2020), protocol 1.4
Decomposition and fixing processes and their effect on soil quality (2.2.4.1) ***continued***							
High nitrogen fixation	D	I	Cover of legumes	👤	$	*	(Maseyk et al. 2017)
		D	Evaluation of nodulation	👤👤👤	$	**	(Peoples et al. 1989)
		D	^{15}N natural abundance methods	👤👤	$$$	***	(Carranca et al. 1999; Kleinebecker et al. 2014)
High litter and dung decomposition	D	D	Local litter	👤👤	$	***	(Knops et al. 2001)
		I	Standardized litter (bait lamina)	👤	$$$	***	(Griffiths et al. 2016)
		I	Standardized litter bags (tea, straw, or similar)	👤	$	**	(Carranca et al. 1999; Kleinebecker et al. 2014)
High degree of mycorrhization	I	D	Visual root scanning	👤👤	$	***	(Giovannetti and Mosse 1980; Cavagnaro et al. 2015)
		I	Spore isolation and identification	👤👤👤	$$	*	(Robinson-Boyer et al. 2009)
		I				**	(Robinson-Boyer et al. 2009)

(*continued on next page*)

Table 1 (*continued*)

			qPCR of soil or rhizosphere samples	👤👤	$$$		
		Chemical composition of freshwaters (2.2.5.1)					
Low nutrient (N and P) concentration in surface or soil water	D	D	Water intercepting troughs	👤👤👤	$$	***	(Heathwaite and Dils 2000)
		D	Macropore samplers or suction lysimeters	👤👤	$$	**	(Heathwaite and Dils 2000; Cooper 2016)
		D	Lysimeters	👤👤👤	$$$	***	(Haygarth et al. 1998; Djodjic et al. 2004; Andersson et al. 2013)
		D	Laboratory leaching of soil columns	👤👤👤	$	*	(de Vries et al. 2012)
		I	Ion-exchange resin methods	👤👤	$$$	**	(Binkley and Matson 1983; Langlois et al. 2003; Klaus et al. 2018)
Low nutrient (N and P) concentration in soil	I	D	(Sub-)Soil concentrations	👤👤	$	*	(Blüthgen et al. 2012; Newell-Price 2020)
		I	Quantity of fertilizer applied/ stocking density	👤	$	*	(Heckrath et al. 1995; Haygarth et al. 1998; Bhogal et al. 2000; Maguire and Sims 2002; Risch et al. 2019)
		Chemical composition of the atmosphere (2.2.6.1)					
High uptake of CO_2 and other greenhouse gases	D	D	Fluxes via Eddy covariance (long term)	👤👤👤	$$$	***	(Ammann et al. 2007; Merbold et al. 2014)
		D	Fluxes via Flux chambers (long term)	👤👤👤	$$	**	(Pumpanen et al. 2009)
		I	Potential methane oxidation rates (PMOR)	👤👤	$$	*	(Hütsch et al. 1993; Shrestha et al. 2012; Zhang et al. 2019)
High organic carbon storage (replicated measurements)	I	D	Dry combustion (fine soil samples)	👤👤	$$	***	(Nelson and Sommers 1996)
		D	Walkley-Black method (fine soil samples)	👤👤👤	$	**	(Walkley and Black 1934)
		D	Optical sensing techniques (infrared spectroscopy) (fine soil samples)	👤	$$	**	(O'Rourke and Holden 2011; Stevens et al. 2013)
		D	Thickness of peat layer	👤	$	**	(Webster and Oliver 1990)
		Active recuperation, enjoyment (recreation) (3.1.1.1)					
High abundance/ usage of edible and medicinal plants and fungi	D		Listed as indicator for provisioning services, above. Equally important for cultural services, as argued in reference given on the right. Especially economic evaluation methods differ.				(Schulp et al. 2014)
High abundance/use of wild game species	D		Listed as indicator for provisioning services, above. Equally important for cultural services, as argued in reference given on the right. Especially economic evaluation methods differ.				(Schulp et al. 2014)
		Heritage, culture and Education (3.1.2.3 + 3.1.2.2)					
Many signs of traditional usage	D	D	Assessing elements via field survey	👤👤	$	***	(Tieskens et al. 2017)
		D	Assessing elements via satellite/aerial images	👤	$	***	(Špulerová et al. 2015; Kušar and Komac 2019)
		D	Cultural/natural monuments or presence of grazers from specific databases	👤	$	***	(Marsoner et al. 2018; Thiele et al. 2020)
		D	Existence and age of shepherding treaties/regulations	👤	$	***	(Razquin Lizarraga et al. 2012)
		Aesthetic (3.1.2.4)					
High human visual appreciation	D	D	Off-site interviews (with photographs)	👤👤	$	**	(Lindemann-Matthies et al. 2010a; Zoderer et al. 2016)
		D	On-site interviews	👤👤👤	$	***	(Southon et al. 2017; Hoyle et al. 2018; Müller et al. 2019)
		I	Online geo-tagged photographs on social media platforms	👤	$	*	(Figueroa-Alfaro and Tang 2017; Le Clec'h et al., 2019)
Flower abundance and diversity	I	I	Flower size and color from trait databases calculated after vegetation survey	👤👤	$	**	

(*continued on next page*)

Table 1 (*continued*)

							(Lindemann-Matthies et al. 2010b; Hoyle et al. 2018; Kütt et al. 2018)
		D	Measure of flower abundance in the field (transect or plot)	♟♟♟	$	***	(Kwaiser and Hendrix 2008; Weiner et al. 2011; Binkenstein et al. 2013; Lucas et al. 2017; Santos Oleques et al. 2017)
		Symbolic and Existence (3.2.1.1 + 3.2.2.1)					
High abundance of symbolic/flagship species	D	Includes the identification of target species (e.g. via interviews and questionnaires) and the subsequent mapping. For latter, see *abundance of game species, edible/medicinal plant species, abundance of pollinators* and *plant diversity* for assessment methods; references on the right for identification of symbolic species	(Root-Bernstein and Armesto 2013; Schirpke et al. 2018)				

two indicators need to be used in concert, since using only the amount of biomass produced is potentially misleading (e.g. Zavaleta et al. 2010; Allan et al. 2015; Kohler et al. 2017; Tasser et al. 2020). Besides a direct, ideally temporally repeated harvest of biomass, various less labor-intensive methods exist for estimating *High aboveground biomass production* – from sward height measurements to remote sensing techniques. For *High biomass quality*, several indirect methods exist providing quick estimates, besides the more direct but quite laborious and expensive laboratory methods **(S1.1.3)**. It is also crucial to note, that natural grasslands and sown grasslands can differ very strongly in their provisioning services, calling for a differentiated choice of indicators. For example, for extensively grazed natural grasslands, using forage value indices from the vegetation relevé can be more insightful due to stronger selection by animals whereas on intensively used and/or sown grasslands standard laboratory techniques are better suited for assessing forage quality. However, the information content of all production and quality indicators could be compromised in situations or locations, in which the grasslands are hard to reach (in difficultly accessible terrain), very steep, or without access to water. These kinds of limitations can decrease the provisioning services and would have to also be factored in when they apply.

Furthermore, Maes et al. (2016) include livestock densities as an indicator of actual forage provision. However, the number of livestock units is highly dependent on the respective grazing management such as supplementary feed from other sources, making this indicator only useful for farm level studies such as in life cycle analyses (e.g. Kohler et al. 2017). In cases or areas where livestock feed is not supplemented, assessing livestock numbers and even livestock product quality and/or market prices can be informative (Farruggia et al. 2014).

Wild animals for nutrition (CICES 1.1.6.1) are assessed via the indicator *High abundance/use of wild game species* (**S1.1.4**). As for *High abundance/usage of edible and medicinal plants and fungi* **(S1.1.1)**, indirect methods measure abundance of species, and direct methods target the number of hunted animals. Furthermore, just like mentioned above, this indicator can also be an important indicator for the assessment of cultural services, depending on the study area and focus of the study.

Higher and lower plants used to breed new strains or varieties (CICES 1.2.1.2) are assessed via *High abundance of crop wild relatives* (CWR; **S 1.1.5**). CWR are receiving increasing attention and are vital in the face of a depletion of genetic diversity of crops, stresses on crops from climate change, and new opportunities for the use of genes from CWR with modern biotechnological and genome-editing methods (Ford-Lloyd et al. 2011). They are best quantified using standard vegetation assessments (see *High plant diversity* for discussion of methods).

3.2.2. Regulating and supporting services

The regulating ES **Control of erosion rates (CICES 2.2.1.1)** can be assessed by measuring *potential Low soil erosion rates* targeting bare soil cover or realized soil erosion - with the most revealing but labor-intensive of the three methods measuring sediment in surface runoff (**S 1.2.1**). A further indirect indicator for soil erosion is *High belowground plant biomass* (**S1.2.2**), as plant roots play a large role in stabilizing the soil.

For the ES **Hydrological cycling (CICES 2.2.1.3)**, the indicators *High water infiltration* and *Low soil compaction* are commonly used (**S 1.2.3**). The methods for measuring *water infiltration* are all either quite laborious or require specialized equipment, making this indicator rather challenging to measure. On the contrary, *soil compaction* is assessed with more rapid and cheap methods, but only investigates the soil aspect of the hydrological cycle.

The ES **Pollination (CICES 2.2.2.1)** can be assessed in three ways: measuring the indicators *High abundance/activity of pollinators, high pollination success,* and *Many resources for pollinators* (**S 1.2.4**). Of these, *high pollination success* is probably the indicator best reflecting this ES as supporting service, but it is also the most challenging to measure and usually requires the involvement of crops and are rather landscape-scale methods. Methods to measure *abundance/activity of pollinators* tend to be labor-intensive but are cheap. Methods involving catching or trapping of insects can yield additional insights concerning other ES, such as Pest control (CICES 2.2.3.1) and Symbolic species (CICES 3.2.1.1). *Resources for pollinators* can be assessed by either directly assessing flower abundances or estimating them from vegetation surveys, both methods with comparable workloads, except that a vegetation survey might have already been conducted to measure other indicators, such as *High plant diversity*.

Nursery populations and habitat (CICES 2.2.2.3): *High plant diversity* (**S1.2.5**) itself is the indicator of choice for the ES Nursery populations and habitat (including gene pool protection) (CICES 2.2.2.3). Vascular plants provide habitat and food for higher trophic levels and are thus the most often used indicator for this service also regarding non-plant taxa. The two main methods here are visual estimates of ground cover and the point-intercept method, the first one requiring more experienced surveyors (Halbritter et al. (2020) protocol 4.8, Plant community composition, Supporting Information S4) and the latter being more time consuming.

For the ES **Pest control (CICES 2.2.3.1)**, three indicators exist, each measuring a different aspect of pest control. *Low invertebrate herbivory and fungal pathogens* (**S1.2.6**) are most often assessed by visually estimating damage to plant organs, but in the case of estimating herbivory, herbivore numbers from traps can also be used as an indirect method. For assessing *High abundance of "weeds" and invasive species* (**S1.2.7**), automated detection methods (for instance using unmanned aerial vehicles) are being developed and can increasingly present an alternative for conventional methods such as vegetation surveys. These two previous indicators are on the one hand important regulators of yield and palatability for livestock and modulate pesticide inputs, but on the other hand, invertebrate herbivores, phytoparasitic fungi and so-called weeds can also contribute substantially to biodiversity and pollination (Gossner et al. 2014). Thus, depending on the ES considered or the focus of the assessment, this trade-off needs to be integrated in multifunctionality assessments accordingly. Concerning the third indicator *High abundance and activity of natural pest enemies* (**S1.2.8**), measuring abundances of predatory or parasitoid species in question can be used as an indirect method, while the activity of natural pests can also be measured directly, in most cases via sentinel prey removal. For all three indicators, methods tend to be labor-intensive but comparatively cheap, similar to the cluster of indicators assessing the ES Pollination (CICES 2.2.2.1) (Meyer et al. 2015).

A great variety of processes and organisms influence **Decomposition and fixing processes and their effect on soil quality (CICES 2.2.4.1)**, and consequently many indicators exist to capture these as comprehensively as possible. Like *High aggregate stability*, *High earthworm abundance* (**S1.2.9**) provides information about how well the soil is structured, but also sheds light on decomposition processes, which can in turn also be assessed via *High litter and feces decomposition* (**S1.2.12**). *High Nitrogen fixation* and *High soil nutrient availability* (**S1.2.11**) are indicators focusing on the atmospheric N_2 fixing processes and their contribution to soil fertility. *High degree of mycorrhization* (**S1.2.13**) contributes to supplying grassland plants with nutrients, making this another valuable indicator for processes enhancing plant growth. And as microorganisms are major agents of decomposition and N_2 fixing processes in the soil, *High microbial abundance and activity* (**S1.2.10**) is a further important indicator (Griffiths et al. 2016). Here, methods exist for measuring biomass and activity together, compared to methods investigating organismic composition and enzyme activities separately and thus measuring specific processes or potentials for processes. Methods for measuring these indicators of Decomposition and fixing processes and their effect on soil quality (CICES 2.2.4.1) for the most part tend to be laboratory methods which are either quite labor-intensive or require expensive equipment as for instance neither microbes nor arbuscular mycorrhiza or soil nutrients are visible to the naked eye. Some cheap and comparatively easy methods do exist though, such as measuring the cover of legumes for N_2 fixation, the use of standardized litter for decomposition, and extracting earthworms for subsequent counting with an expellant (Meyer et al. 2015).

The ES **Chemical composition of freshwaters (CICES 2.2.5.1)** is most comprehensively assessed by measuring the indicator *Low nutrient concentrations in surface or soil water* (**S1.2.14**). Methods for collecting water from different soil depths and analyzing its nutrient concentrations often require specialized equipment, are labor-intensive, and thus are typically restricted to a limited number of spatial observations. Therefore, *Low nutrient concentrations in soil* (**S1.2.14**) and soil water samples are used as an indicator for this service instead, with information on nutrient inputs from management being an indirect method to estimate this (if applicable, e.g. quantities of fertilizer applied and stocking densities (Blüthgen et al. 2012); **S 1.2.14**).

The last regulating service, **Chemical composition of the atmosphere (CICES 2.2.6.1)**, is most accurately assessed via the *Fluxes of CO_2 and other greenhouse gases* (**S 1.2.15**). These measurements (especially using the eddy covariance technique) require expensive equipment and at best continuous measurements (Pumpanen et al. 2009; Eugster and Merbold 2015). Much easier and less expensive than the latter are methods for measuring *High soil organic carbon* **(S1.2.16)**, but these must be temporally repeated to assess an increase or decrease in carbon stocks over time, typically decades (Post and Kwon 2000). Comparing single time point measurements of *soil organic carbon* reveals insight in differences in carbon storage only if sites are environmentally absolutely similar, and still, this does not inform about the actual change in soil carbon.

3.2.3. Cultural services

Active recuperation, enjoyment (recreation) (CICES 3.1.1.1): Hunting wild game and gathering wild plants and fungi are regarded in many regions as recreational activities (Schulp et al. 2014), and thus *High abundance/usage of edible and medicinal plants and fungi* (**S1.1.1**) as well as *High abundance/usage of wild game species* (**S1.1.4**) are meaningful indicators for the ES Active recuperation, enjoyment (recreation) (CICES 3.1.1.1). Alternatively, these indicators are important for assessing provisioning services, as discussed above. Hiking or biking are also widely practiced in grassland areas, but depend very much on available infrastructure and other factors related to the landscape. The presence of nature trails has been suggested as an indicator (Newell-Price 2020), but this indicator is only to a very small extent dependent on small-scale characteristics and is thus not well suited for plot-level assessments.

For the ES **Heritage, culture (CICES 3.1.2.3)**, most studies assess the indicator *Many signs of traditional usage* (**S1.3.1**) in a given area. Which buildings, installations or old shepherding contracts are to be taken into account is dependent on the traditions and culture in the region studied, but can be assessed with different methods: via field surveys, satellite and/or aerial images or from databases, where available, or interviews with local experts.

To assess the ES **Aesthetics (CICES 3.1.2.4)**, an ES especially important in the landscape context, the most straightforward indicator is *High human visual appreciation* (**S1.3.2**), which estimates how beautiful humans find an area. This is either directly assessed by interviewing people on-spot or indirectly inferred via photographs e.g. on social media. As humans have been shown to appreciate diverse and flower-rich plant assemblages (Lindemann-Matthies et al. 2010b), *High flower abundance and diversity* (**S1.3.2**), which could be extracted from vegetation records, can also be a useful indicator for aesthetics. Here too, direct and indirect measures exist (Table 1). All reviewed methods for measuring the indicators assessing aesthetics are relatively low-cost methods, but tend to be labor-intensive, especially when on-site interviews are performed.

The ES **Symbolic value (CICES 3.2.1.1)** can be assessed with the indicator *High abundance of symbolic/flagship species* (**S1.3.3**). For every nation and region, the species that have a symbolic cultural importance differ and need to be identified by expert interviews or searching cultural history archives (e.g. collections of poems; (Hiron et al. 2018)). After identifying the species in question, depending on the organism group, different methods of assessing their presence can be used. For butterflies, a frequently used group of species, methods described for the service Pollination (CICES 2.2.2.1) can be used; for plants, methods described for the services Nursery populations and habitat or Pest control (CICES 2.2.2.3) are applicable.

4. Economic valuation of ES

4.1. Concept, classification of value types and valuation approaches

The economic value of an ES attempts to assess the contribution of the respective ES to human well-being (Costanza 2020). According to the well-established Total Economic Value (TEV) Framework, the economic value of an ecosystem is made up of two components: the (total) output value and the insurance value (Pascual et al. 2012). Whereas the output value relates to the benefits provided by the services from an ecosystem in a given (biophysical) state, the insurance value refers to the ecosystem resilience, i.e. to its capacity to maintain a sustained flow of services (Pascual et al. 2012). In this work, we focus on the ES benefits and thus on the output value because we concentrate on the service flows from the ecosystem in its current state and do not address the ecosystem's ability to maintain its flow of services under disturbance. Within the output value, we focus on the use value[1], and more precisely on the actual value[2] (see Fig. 3), which encompasses direct and indirect use values. The direct use value describes the benefits that are obtained from directly using an ES (Kaval et al., 2013). It encompasses both extractive use (e.g. consumption of food or timber) and non-extractive use (e.g. recreational benefits; Pascual et al. 2012). The indirect use value refers to the value derived from regulating services provided by the ecosystem such as air quality regulation or erosion prevention (Kaval et al., 2013). Whereas provisioning and cultural ES only generate direct use benefits, regulating ES provide by contrast only indirect use ones (Pascual et al. 2012). The supporting ES, defined as the services required for the production of other types of ES (MA, 2005), are usually not valued directly but indirectly through their contribution to other ES categories (Hein et al. 2006; Pascual et al. 2012). For instance, soil biodiversity may be valued with respect to its contribution to provisioning ES, in which case the direct benefits in terms of agricultural production or, more precisely, crop production is the object of the valuation. Soil biodiversity may also be valued in terms of its contribution to regulating ES services or, more precisely, to (i) **Hydrological cycling (CICES 2.2.1.3)** and (ii) climate regulation through **Chemical composition of the atmosphere (CICES 2.2.6.1)** (Pascual et al. 2015).

For valuation purposes, Fisher et al. (2009) recommend using a classification scheme dividing ES into intermediate services, final services, and benefits. Benefits can be basically derived from intermediate and final services (Fisher and Turner 2008). For the sake of ES economic valuation, the several interlinkages among ES and especially between intermediate services and final services should be identified to avoid any double counting. Only the benefits derived from final services (for example food consumption), to which the intermediate services contribute (e.g. pollination), should be the object of the economic valuation (Fisher et al. 2008; Morse-Jones et al. 2011). Whether an ES is considered as an intermediate service or a final service depends on the benefits of interest and is linked to social systems and social decisions (Fisher et al. 2009). It must therefore be defined before any economic valuation in each specific case.

The available methods used to value a specific ES can be divided into direct and indirect market valuation approaches depending on the availability of market price information (Pascual et al. 2012; see Fig. 4)[3]. The **direct market valuation** derives the value of ES directly from available market price information. It encompasses four main approaches: (i) the market price-based approaches, (ii) the cost-based approaches, (iii) the net factor income approach, and (iv) approaches based on production functions (Pascual et al. 2012; Ojea et al. 2017). The **indirect market valuation** can be divided into the revealed- and

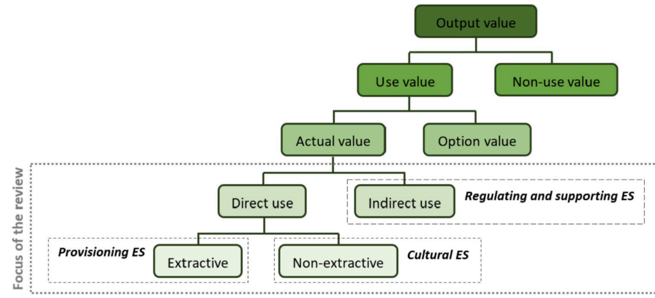

Fig. 3. Value types within the output value (modified after Pascual et al. 2012; Kaval et al., 2013).

the stated-preference approach, depending on whether market transactions associated indirectly with the respective ES are available or not (Pascual et al. 2012). Whereas the revealed-preference approach estimates the value of services by analyzing how people act (i.e. by revealing the value they implicitly attribute to a service through their observable choices in the surrogate market), the stated-preference approach relies on the analysis of what people say (i.e. what people explicitly state about their preference within a survey; Lazo 2002; Pascual et al. 2012).

When collecting primary data for the economic valuation of ES by means of one of the previously mentioned approaches is not feasible due to resource or time constraints, it is possible to use the benefit transfer approach (Mishra et al. 2019). This approach consists of transferring the ES value (for instance, the unit value of fertilizer reduction per kg nitrogen) that has been estimated at one or more study site(s), i.e. the site (s) where the study and primary data collection were originally conducted, to a policy site, i.e. the site that is of interest and whose ES should be valued, with similar characteristics (Mishra et al. 2019). The so-called correspondence, which is the degree to which the characteristics of the study site(s) are similar to those of the policy site, determines the validity and accuracy of the benefit-transfer (Plummer 2009).

To allow for a deeper insight in this topic, a detailed overview of the different methods available for direct and indirect market valuation as well as fr benefit transfer is provided in supplementary material 2.

4.2. *Economic valuation of grassland ES*

Even though an extensive body of literature exists on the biodiversity of grassland and on experiments relating for example plant diversity to ecosystem functioning, literature on the economic valuations of ES of grasslands (besides production yields and yield quality) is scarce as compared to forests, croplands and wetlands (Frélichová et al. 2014) (Frélichová et al. 2014). Based on the existing literature, this section provides an overview of the most commonly used methods for the economic valuation of provisioning, regulating and cultural ES. As explained in section 4.1, supporting services are valued through their contribution to other ES categories. The methods available for their valuation thus depend on the ES categories (provisioning, regulating and cultural) to which they contribute. The overview provided in this section is illustrated with application examples relevant to grassland ecosystems.

4.2.1. *Provisioning services*

Provisioning services of grasslands comprise mainly the production of fodder for roughage consuming animals with the final services being principally the production of milk and meat for human consumption. As provisioning services are harvested and provide direct use values, market price-based approaches are commonly used for their economic valuation (de Groot et al. 2012). This valuation should rely on quality-adjusted forage yields derived from the ES indicators assessment as

[1] Non-use values reflect "*the preference towards an ES without having to use it or experience it*" (Naime et al. 2020). They encompass the bequest, altruist, and existence values (Pascual et al. 2010). Since they relate to moral, ethical, or religious properties, their economic valuation is particularly challenging.

[2] The use value encompasses the actual value and the option value. The option value relates to the future use value of an ES (Naime et al. 2020) and is a value that results from uncertainty about the future demand of ES (Bartkowski 2017). Since the present work focuses on the actual provision and use of grassland ES, the option value is not further considered in our review.

[3] For the sake of completeness, we would like to mention that another classification of the methods for the monetary valuation of ES can be found in the statistical standard SEEA-EA (System of Environmental-Economic Accounting – Ecosystem Accounting) developed by the United Nations for the integration of ecosystem services in the System of National Accounts (SNA) at macro-level (United Nations, 2021). As our review focuses on a lower analysis scale (plot or field level) and do not relate to SNA, we do not elaborate on the SEAA-EA classification and rely in lieu thereof on the more generic and comprehensive classification proposed by Pascual et al. (2012).

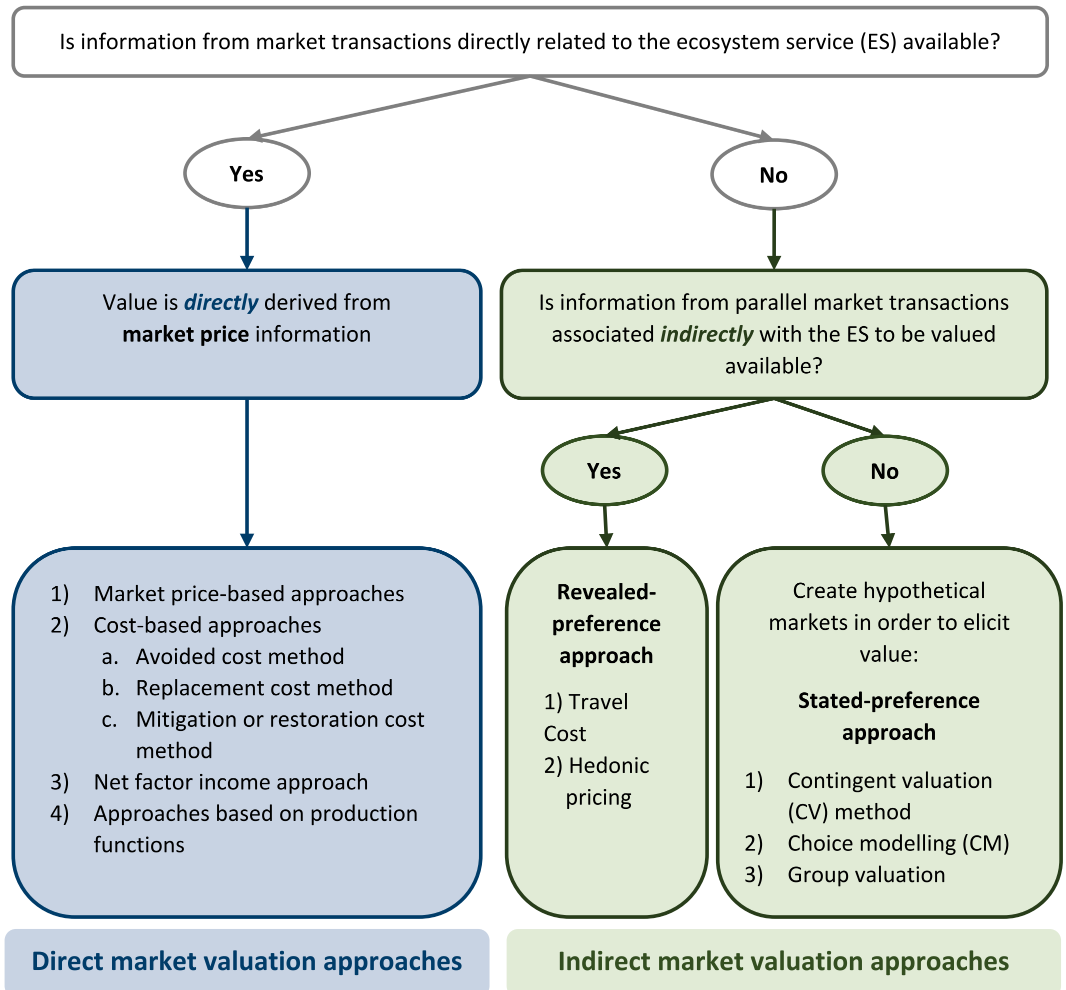

Fig. 4. Categorization of the available techniques to valuate ES based on market information availability (Source: own representation based on Pascual et al. 2012). Further information on the single approaches mentioned can be found in supplementary material 2.

not only the quantity of grass but also its quality (i.e. its nutritional characteristics) is important for the conversion of grass into meat and milk (see for instance Schaub et al. 2020b; Schaub et al., 2020a). To derive the market revenues from the forage produced, milk production potential yields must be multiplied by milk and/or meat prices, which are usually available from international or national statistical offices. When selecting the appropriate market price, the raw product use, which is closely related with the product characteristics especially in terms of quality, need to be considered as they additionally affect the market price. For instance, raw milk can be used for the production of drinking milk or cheese and destined for different markets such as organic or conventional markets. The prices used for the economic valuation have to be selected accordingly.

4.2.2. Regulating services

A meta-analysis of the studies assessing the economic value of regulating services at global scale shows the highest number of studies dealing with climate regulation services, followed by water regulation, erosion, air quality regulation and natural hazard regulation (Balasubramanian 2019). This meta-analysis shows furthermore that only few studies valued specifically regulating ES of grasslands. The study additionally revealed a wide range of different methods being used for the economic valuation of regulating services, inhibiting a standardized way of valuing theses ES. However, cost-based approaches are especially well suited and therefore frequently used for valuing regulating ES (Martín-López et al. 2009; de Groot et al. 2012). An illustration of this type of approach can be found in Keeler and Polasky (2014), who valued the regulating services provided by grassland in terms of groundwater protection from nitrate contamination in Southeastern Minnesota. The authors used two different valuation techniques in combination, namely the costs of replacement or remediation measures (e.g. to install a filtration system), and the costs of avoidance behaviors, defined as the costs of purchasing bottled water for drinking and cooking to avoid exposure to elevated nitrate concentrations in the water (Keeler and Polasky 2014).

A further example of the use of cost-based approaches for the economic valuation of regulating ES in grassland can be found in Paletto et al. (2015). This case study uses the replacement cost approach to value the protection against natural hazards such as soil erosion, landslides, rockfalls and avalanches. The total costs incurred by replacing (permanent) grasslands with an artificial substitute with a lifetime of 15 years, was used to calculate an annual cost per hectare grassland (Paletto et al. 2015).

Some regulating ES can also be valued using market-price based approaches. This applies for example for carbon sequestration. The tons of carbon stored in soil can be multiplied by the market price for greenhouse gas emissions in carbon equivalents (e.g. Kay et al. 2019). Market prices in such a case can be provided by the State of the Voluntary Carbon Market (e.g. Donofrio et al. 2019), the Emission Trading Scheme of the European Union (EU ETS) or other regional, national or subnational trading schemes (Stern 2007; World Bank and Ecofys, 2017).

Benefit transfer methods relying on primary data from cost-based approaches can also be used to valuate regulating ES. For example, Gascoigne et al. (2011), who assessed the environmental and economic trade-offs of different future land use scenarios in the Prairie Pothole Region of the Dakotas, United States, used the benefit transfer approach to monetize the carbon sequestration services provided by native prairie. The transfer relied on the central value of the four estimates of the so-called social cost of carbon from the Social Cost of Carbon (SCC) working group, a US governmental interagency working-group (Gascoigne et al. 2011). The social cost of carbon was defined as the marginal cost resulting from the expected economic damages associated with an increase in carbon dioxide emissions in a particular year (Gascoigne et al. 2011).

4.2.3. Cultural services

In a meta-analysis of the willingness to pay for cultural ES from grassland in Europe, Huber and Finger (2020) found that the economic valuation of cultural services usually relies on stated-preference techniques, which encompass contingent valuation methods and discrete choice experiments. Hedonic pricing and the travel cost method, which both belong to the revealed-preference approaches, can also be used for the economic valuation of cultural services (de Groot et al. 2012; Huber and Finger 2020). However, according to Huber and Finger (2020), these methods have not yet been applied to grassland. An example of application of the discrete choice technique to grasslands can be found in Barkmann and Zschiegner (2010), who assessed the willingness of local citizens to pay for grassland conservation management with cattle and sheep for two regions in Germany.

5. Discussion and general insights

This review describes a wealth of plot-scale ES indicators and respective methods, but before diving into these it must be kept in mind, that the demand for an individual ES can vary strongly from location to location depending on the respective geographical or cultural circumstances (Wei et al. 2017; Root-Bernstein and Jaksic 2017; Mehring et al. 2018). For instance, the demand for flood regulation depends strongly on the location where people live and on the associated flooding risk (Wei et al. 2017). This context dependency in turn means that indicators and methods to assess the respective ES, as well as valuation methods, should be chosen according to the local conditions, so that less demanded ES can be assessed and valued with less effort or precision than highly demanded ES. The spatial variability of ecosystem services demand is furthermore a crucial valuation issue that should be accounted for in order to reduce the risk of an over- or underestimation of ecosystem services values (Morse-Jones et al. 2011). This is especially relevant when using the benefit transfer approach.

For most ES indicators, several different methods exist for their assessment, especially for the regulating and supporting ES. On the contrary, for cultural ES, plot-scale indicators are less numerous, as many studies consider these services on spatial scales larger than plot or field level (Blicharska et al. 2017). A further challenge concerning cultural services is the inevitable close tie to the local stakeholders and their needs, perceptions and values that differ from stakeholder group to stakeholder group (Daniel et al. 2012; Kosanic and Petzold 2020). This implies that the choice and the exact nature of the cultural services and corresponding indicators must be made after considering these specific needs and values (Blicharska et al. 2017). Tools for economic valuation of cultural services have been, on the other hand, readily available for quite a long time. Due to the inevitable involvement of the public in assessing cultural ES, revealed- and stated-preference methods are recommended for the economic valuation of these services.

Concerning the technical aspect of measuring ES indicators, some methods directly measure an indicator, whereas others provide estimates or proxies and thus only indirectly assess the indicator in question (as indicated in Table 1). However, one level higher, the indicators themselves can also either directly measure an ES (e.g. High pollination success for Pollination (CICES 2.2.2.1), High human visual appreciation for Aesthetics (CICES 3.1.2.4)), while others indirectly assess the ES by measuring vital ecological processes and attributes reflecting the state of the ecosystem (e.g. *Many resources for pollinators, High flower abundance and diversity*) (Layke et al. 2012; Tasser et al. 2020). As this indirect approach can accumulate inaccuracy in estimating a final ES, direct methods and indicators are generally preferred over indirect ones. However, using an indirect method or indicator is in most cases still far better for a robust measure of ES-multifunctionality than ignoring an ES when time or economic resources are limited.

In many cases, trade-offs become apparent concerning the equipment costs and labor force needed for different methods, with some methods using cheap equipment but being labor-intensive or vice versa, also described by Griffiths et al. (2016) for soil diversity and related ES. For instance, using local or standard litter for decomposition measurements is cheaper but more labor-intensive than using expensive premanufactured bait lamina. Similarly, isolating and identifying fungal spores is more laborious, but uses less costly equipment than qPCR techniques for estimating the degree of mycorrhization. Additionally, cheap and quick methods often have a lower predictive power for an ES than more costly and work intensive methods, presenting a further trade-off. Thus, we recommend using direct methods with high predictive power, whenever this is economically feasible.

Similarly, the economic valuation of ES involves a trade-off between valuation accuracy and costs. The benefit-transfer approach is – compared to the other valuation methods that rely on primary data collection – significantly less expensive and time consuming (Rosenberger and Loomis 2000). This explains its popularity in conservation planning and ecosystem management (Morrison and Bennett 2004; Plummer 2009). However, a greater potential inaccuracy often results from using benefit transfer compared to generating original estimates (Morrison and Bennett 2004). For this reason, economists have developed guidelines aiming at improving the validity and accuracy of ES values estimated using this specific approach (Plummer 2009).

In choosing indicators, it is important to keep in mind the possibility of one ES indicator influencing multiple ES, as well as (in some cases) the necessity to measure several indicators to assess different aspects of a given ES while avoiding multicollinearity. This complexity underlines the need to economically value final ES in order to avoid any double counting (Morse-Jones et al. 2011). This is especially true for economic valuations conducted within multifunctionality assessments, in which multiple ES are considered. The literature review on the economic valuation of ES showed that a wide range of approaches exist. It furthermore revealed that there are so few studies on the economic valuation of more than one ES in grasslands that we cannot review the suitability of single ES field assessment methods and related biophysical ES indicators for economic valuation. In order to promote the valuation of ES in grasslands, the development of a comprehensive framework providing detailed practical guidance and recommendations on how to economically value each final ES depending on the available ES indicators would be needed.

6. Conclusions

A plethora of methods to measure ES-indicators exists, ranging from expensive and laborious to cheap and easy methods. Using these latter ones in the case of limited resources is much more advisable than not assessing an ES at all, but the higher uncertainty associated with cheap and easy methods also needs to be acknowledged. Especially cultural ES, that only recently received increasingly attention and whose assessment methods are less established than those for provisioning and supporting ES, must not be neglected, since many useful and easy indicators have been developed to date. The trade-off between costs and efforts on the one hand and accurateness or information content on the other hand become apparent for both assessing and economically valuing ES. Thus, outcomes from seemingly comprehensive but rather inaccurate multifunctionality assessments can also pose a threat to policy-advice and decision-making. To improve this situation, we recommend 1) to choose direct over indirect methods and indicators and 2) to use the most accurate methods; 3) take into account that one indicator can have implications for more than one ES, and that these implications can be positive or negative; and 4) to assess as many ES as possible for multifunctionality studies and especially to include cultural services. In order to promote the economic valuation of grassland ES, especially within multifunctionality assessments, we see the urgent need to develop a comprehensive framework on how to value each final ES depending on the available (biophysical) ES indicator(s).

Besides assisting researchers and stakeholders in identifying a robust set of indicators and methods to use for grassland ES assessments, our work calls for using comparable sets of indicators and methods to facilitate synthesis of ES and multifunctionality studies. By assigning methods to indicators and identifying the positive and negative relations of the respective indicators to the final ES, this study represents an important first step in this direction. By providing an overview of the approaches available for the economic valuation of ES in grassland, we further acknowledge the importance of economic valuations and, above all, of interdisciplinary research for the sustainable management of grasslands. We believe that our work can add structure and clarity to the essential but complex field of applied ES-multifunctionality research, which is needed to assure human well-being in the future.

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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References

Abbet, C., Mayor, R., Roguet, D., et al., 2014. Ethnobotanical survey on wild alpine food plants in Lower and Central Valais (Switzerland). J. Ethnopharmacol. 151, 624–634. https://doi.org/10.1016/j.jep.2013.11.022.

Ala-Hulkko, T., Kotavaara, O., Alahuhta, J., et al., 2016. Introducing accessibility analysis in mapping cultural ecosystem services. Ecol. Ind. 66, 416–427. https://doi.org/10.1016/j.ecolind.2016.02.013.

Albrecht, M., Duelli, P., Müller, C., et al., 2007. The Swiss agri-environment scheme enhances pollinator diversity and plant reproductive success in nearby intensively managed farmland. J. Appl. Ecol. 44, 813–822. https://doi.org/10.1111/j.1365-2664.2007.01306.x.

Allan, E., Manning, P., Alt, F., et al., 2015. Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. Ecol. Lett. 18, 834–843. https://doi.org/10.1111/ele.12469.

Allan, E., Weisser, W.W., Fischer, M., et al., 2013. A comparison of the strength of biodiversity effects across multiple functions. Oecologia 173, 223–237. https://doi.org/10.1007/s00442-012-2589-0.

Ammann, C., Flechard, C.R., Leifeld, J., et al., 2007. The carbon budget of newly established temperate grassland depends on management intensity. Agric. Ecosyst. Environ. 121, 5–20. https://doi.org/10.1016/j.agee.2006.12.002.

Andersson, H., Bergström, L., Djodjic, F., et al., 2013. Topsoil and subsoil properties influence phosphorus leaching from four agricultural soils. J. Environ. Qual. 42, 455–463. https://doi.org/10.2134/jeq2012.0224.

Balasubramanian, M., 2019. Economic value of regulating ecosystem services: a comprehensive at the global level review. Environ. Monit. Assess. 191, 616. https://doi.org/10.1007/s10661-019-7758-8.

Barkmann, J., Zschiegner, A.K., 2010. Grasslands as a sustainable tourism resource in Germany: Environmental knowledge effects on resource conservation preferences. Int J Serv Technol Manag 13, 174–191. https://doi.org/10.1504/ijstm.2010.032076.

Bartholomée, O., Lavorel, S., 2019. Disentangling the diversity of definitions for the pollination ecosystem service and associated estimation methods. Ecol. Ind. 107, 105576 https://doi.org/10.1016/j.ecolind.2019.105576.

Bengtsson, J., Bullock, J.M., Egoh, B., et al., 2019. Grasslands—more important for ecosystem services than you might think. Ecosphere 10, 1–20. https://doi.org/10.1002/ecs2.2582.

Bennett, A.B., Gratton, C., 2012. Measuring natural pest suppression at different spatial scales affects the importance of local variables. Environ. Entomol. 41, 1077–1085. https://doi.org/10.1603/en11328.

Bhogal, A., Murphy, D.V., Fortune, S., et al., 2000. Distribution of nitrogen pools in the soil profile of undisturbed and reseeded grasslands. Biol. Fertil. Soils 30, 356–362. https://doi.org/10.1007/s003740050016.

Binch, A., Cooke, N., Fox, C., 2018. Rumex and Urtica detection in grassland by UAV. In: In: 14th International Conference on Precision Agriculture. Montreal, pp. 1–10.

Binkenstein, J., Renoult, J.P., Schaefer, H.M., 2013. Increasing land-use intensity decreases floral colour diversity of plant communities in temperate grasslands. Oecologia 173, 461–471. https://doi.org/10.1007/s00442-013-2627-6.

Binkley, D., Matson, P., 1983. Ion exchange resin bag method for assessing forest soil nitrogen availability. Soil Sci. Soc. Am. J. 47, 1050–1052. https://doi.org/10.2136/sssaj1983.03615995004700050045x.

Blicharska, M., Smithers, R.J., Hedblom, M., et al., 2017. Shades of grey challenge practical application of the cultural ecosystem services concept. Ecosyst. Serv. 23, 55–70. https://doi.org/10.1016/j.ecoser.2016.11.014.

Blüthgen, N., Dormann, C.F., Prati, D., et al., 2012. A quantitative index of land-use intensity in grasslands: Integating mowing, grazing and fertilization. Basic Appl. Ecol. 13, 207–220. https://doi.org/10.1016/j.baae.2012.04.001.

Brauman, K.A., Daily, G.C., Duarte, T.K., Mooney, H.A., 2007. The nature and value of ecosystem services: An overview highlighting hydrologic services. Annu. Rev. Environ. Resour. 32, 67–98. https://doi.org/10.1146/annurev.energy.32.031306.102758.

Bretagnolle, V., Gaba, S., 2015. Weeds for bees? A review. Agron Sustain Dev 35, 891–909. https://doi.org/10.1007/s13593-015-0302-5.

Briemle, G., Dierschke, H., 2002. Kulturgrasland. Ulmer: Stuttgart 39, 205–213.

Cabral, I., Keim, J., Engelmann, R., et al., 2017. Ecosystem services of allotment and community gardens: A Leipzig, Germany case study. Urban For Urban Green 23, 44–53. https://doi.org/10.1016/j.ufug.2017.02.008.

Capelli, S., Pichon, N., Kempel, A., Allan, E., 2019. Sick plants in grasslands: a growth-defense tradeoff is the main driver of fungal pathogen abundance and impact. Prep.

Carranca, C., De Varennes, A., Rolston, D.E., 1999. Biological nitrogen fixation estimated by 15N dilution, natural 15N abundance, and N difference techniques in a subterranean clover-grass sward under mediterranean conditions. Eur. J. Agron. 10, 81–89. https://doi.org/10.1016/S1161-0301(98)00056-2.

Cavagnaro, T.R., Bender, S.F., Asghari, H.R., van der Heijden, M.G.A., 2015. The role of arbuscular mycorrhizas in reducing soil nutrient loss. Trends Plant Sci. 20, 283–290. https://doi.org/10.1016/j.tplants.2015.03.004.

Cheng, X., Van Damme, S., Li, L., Uyttenhove, P., 2019. Evaluation of cultural ecosystem services: A review of methods. Ecosyst. Serv. 37, 100925 https://doi.org/10.1016/j.ecoser.2019.100925.

Cooper, J.D., 2016. Solution sampling. In: Soil water measurement. Jon Wiley & Sons Ltd, Hoboken, pp. 283–291.

Costanza, R., 2006. Nature: ecosystems without commodifying them. Nature 443, 749. https://doi.org/10.1038/443749b.

Costanza, R., 2020. Valuing natural capital and ecosystem services toward the goals of efficiency, fairness, and sustainability. Ecosyst. Serv. 43, 101096 https://doi.org/10.1016/j.ecoser.2020.101096.

Costanza, R., de Groot, R., Sutton, P., et al., 2014. Changes in the global value of ecosystem services. Glob Environ Chang 26, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002.

Daccord, R., Wyss, U., Jeangros, B., et al., 2007. Bewertung von Wiesenfutter. Nährstoffgehalt für die Milch- und Fleischproduktion, AGFF (Arbeitsgemeinschaft zur Förderung des Futterbaus), Zürich, Reckenholz.

Daget P, Poissonet J (1971) Une méthode d'analyse phytologique des prairies: critères d'application.

Dale, A., 2015. A review of herbage mass estimation techniques appropriate for Northern Ireland, and suggested developments to improve adoption and accuracy of grassland management assessments. Hilsborough.

Daniel, T.C., Muhar, A., Arnberger, A., et al., 2012. Contributions of cultural services to the ecosystem services agenda. Proc Natl Acad Sci U S A 109, 8812–8819. https://doi.org/10.1073/pnas.1114773109.

de Groot, R., Brander, L., van der Ploeg, S., et al., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst. Serv. 1, 50–61. https://doi.org/10.1016/j.ecoser.2012.07.005.

de Vries, F.T., Bloem, J., Quirk, H., et al., 2012. Extensive management promotes plant and microbial nitrogen retention in temperate grassland. PLoS ONE 7, 1–12. https://doi.org/10.1371/journal.pone.0051201.

Dengler, J., Janišová, M., Török, P., Wellstein, C., 2014. Biodiversity of palaearctic grasslands: A synthesis. Agric. Ecosyst. Environ. 182, 1–14. https://doi.org/10.1016/j.agee.2013.12.015.

Díaz-Zorita, M., Perfect, E., Grove, J.H., 2002. Disruptive methods for assessing soil structure. Soil Tillage Res. 64, 3–22. https://doi.org/10.1016/S0167-1987(01)00254-9.

Didden, W.A.M., 2001. Earthworm communities in grasslands and horticultural soils. Biol. Fertil. Soils 33, 111–117. https://doi.org/10.1007/s003740000297.
Djodjic, F., Börling, K., Bergström, L., 2004. Phosphorus leaching in relation to soil type and soil phosphorus content. J. Environ. Qual. 33, 678–684. https://doi.org/10.2134/jeq2004.6780.
do Rosário G. Oliveira M, van Noordwijk M, Gaze SR, et al (2000) Auger sampling, ingrowth cores and pinboard methods. In: Smit AL, Bengough AG, Engels C, et al. (eds) Root Methods. Springer-Verlag, Berlin Heidelberg, pp 175–210.
Donofrio S, Maguire P, Merry W, Zwick S (2019) Forest Trends' Ecosystem Marketplace. Financing Emission Reductions for the Future: State of Voluntary Carbon Markets 2019. Washington, D.C.
Egoh BN, Bengtsson J, Lindborg R, et al (2016) The importance of grasslands in providing ecosystem services - opportunities for poverty alleviation. In: Potschin M, Haines-Young R, Fish R, Turner RK (eds) Routledge Handbook of Ecosystem Services. Routledge Handbooks Online, pp 421–441.
Egorov, E., Gossner, M.M., Meyer, S.T., et al., 2017. Does plant phylogenetic diversity increase invertebrate herbivory in managed grasslands? Basic Appl. Ecol. 20, 40–50. https://doi.org/10.1016/j.baae.2017.03.004.
Eldridge, D.J., Wang, L., Ruiz-Colmenero, M., 2015. Shrub encroachment alters the spatial patterns of infiltration. Ecohydrology 8, 83–93. https://doi.org/10.1002/eco.1490.
Erb, K.H., Kastner, T., Plutzar, C., et al., 2018. Unexpectedly large impact of forest management and grazing on global vegetation biomass. Nature 553, 73–76. https://doi.org/10.1038/nature25138.
Eugster, W., Merbold, L., 2015. Eddy covariance for quantifying trace gas fluxes from soils. Soil 1, 187–205. https://doi.org/10.5194/soil-1-187-2015.
European Commission (2011) Communication from the commission to the European parliament, the council, the economic and social committee and the committee of the regions: Our life insurance, our natural capital: an EU biodiversity strategy to 2020. Brussels.
Farruggia, A., Pomiès, D., Coppa, M., et al., 2014. Animal performances, pasture biodiversity and dairy product quality: How it works in contrasted mountain grazing systems. Agric. Ecosyst. Environ. 185, 231–244. https://doi.org/10.1016/j.agee.2014.01.001.
Fernández-Ugalde O, Orgiazzi A, Jones A, et al (2017) LUCAS 2018 - Soil component: Sampling instructions for surveyors. Luxemburg.
Fiedler, F.R., Frasier, G.W., Ramirez, J.A., Ahuja, L.R., 2002. Hydrologic response of grasslands: Effects of grazing, interactive infiltration, and scale. J. Hydrol. Eng. 7, 293–301. https://doi.org/10.1061/(ASCE)1084-0699(2002)7.
Figueroa-Alfaro, R.W., Tang, Z., 2017. Evaluating the aesthetic value of cultural ecosystem services by mapping geo-tagged photographs from social media data on panoramio and flickr. J Environ Plan Manag 60, 266–281. https://doi.org/10.1080/09640568.2016.1151772.
Fischer, M., Weyand, A., Rudmann-Maurer, K., Stöcklin, J., 2012. Omnipresence of leaf herbivory by invertebrates and leaf infection by fungal pathogens in agriculturally used grasslands of the Swiss Alps, but low plant damage. Alp. Bot. 122, 95–107. https://doi.org/10.1007/s00035-012-0108-x.
Fisher, B., Turner, K., Zylstra, M., et al., 2008. Ecosystem services and economic theory: Integration for policy-relevant research. Ecol. Appl. 18, 2050–2067. https://doi.org/10.1890/07-1537.1.
Fisher, B., Turner, R.K., 2008. Ecosystem services: Classification for valuation. Biol. Conserv. 141, 1167–1169. https://doi.org/10.1016/j.biocon.2008.02.019.
Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecol. Econ. 68, 643–653. https://doi.org/10.1016/j.ecolecon.2008.09.014.
Floyd, D.A., Anderson, J.E., 1982. A new point interception frame for estimating cover of vegetation. Vegetatio 50, 185–186. https://doi.org/10.1007/BF00364113.
Ford-Lloyd, B.V., Schmidt, M., Armstrong, S.J., et al., 2011. Crop wild relatives—undervalued, underutilized and under threat? Bioscience 61, 559–565. https://doi.org/10.1525/bio.2011.61.7.10.
Ford, H., Garbutt, A., Jones, D.L., Jones, L., 2012. Impacts of grazing abandonment on ecosystem service provision: Coastal grassland as a model system. Agric. Ecosyst. Environ. 162, 108–115. https://doi.org/10.1016/j.agee.2012.09.003.
Frélichová, J., Vačkář, D., Pártl, A., et al., 2014. Integrated assessment of ecosystem services in the Czech Republic. Ecosyst. Serv. 8, 110–117. https://doi.org/10.1016/j.ecoser.2014.03.001.
García-Nieto, A.P., García-Llorente, M., Iniesta-Arandia, I., Martín-López, B., 2013. Mapping forest ecosystem services: From providing units to beneficiaries. Ecosyst. Serv. 4, 126–138. https://doi.org/10.1016/j.ecoser.2013.03.003.
Garland, G., Banerjee, S., Edlinger, A., et al., 2021. A closer look at the functions behind ecosystem multifunctionality: A review. J. Ecol. 109, 600–613. https://doi.org/10.1111/1365-2745.13511.
Gascoigne, W.R., Hoag, D., Koontz, L., et al., 2011. Valuing ecosystem and economic services across land-use scenarios in the Prairie Pothole Region of the Dakotas, USA. Ecol. Econ. 70, 1715–1725. https://doi.org/10.1016/j.ecolecon.2011.04.010.
Giling, D.P., Beaumelle, L., Phillips, H.R.P., et al., 2019. A niche for ecosystem multifunctionality in global change research. Glob Chang Biol 25, 763–774. https://doi.org/10.1111/gcb.14528.
Giovannetti, M., Mosse, B., 1980. An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. New Phytol. 84, 489–500.
Gómez-Baggethun E, Barton DN, Berry P, et al (2016) Concepts and methods in ecosystem services valuation. In: Potschin M, Haines-Young R, Fish R, Turner RK (eds) Routledge handbook of ecosystem services. Routledge Handbooks Online, pp 99–111.
Goodall, J., Witkowski, E.T.F., Ammann, S., Reinhardt, C., 2010. Does allelopathy explain the invasiveness of Campuloclinium macrocephalum (pompom weed) in the South African grassland biome? Biol. Invasions 12, 3497–3512. https://doi.org/10.1007/s10530-010-9747-2.
Gosling, S.N., 2013. The likelihood and potential impact of future change in the large-scale climate-earth system on ecosystem services. Environ. Sci. Policy 27, S15–S31. https://doi.org/10.1016/j.envsci.2012.03.011.
Gossner, M.M., Weisser, W.W., Meyer, S.T., 2014. Invertebrate herbivory decreases along a gradient of increasing land-use intensity in German grasslands. Basic Appl. Ecol. 15, 347–352. https://doi.org/10.1016/j.baae.2014.03.003.
Griffiths, B.S., Römbke, J., Schmelz, R.M., et al., 2016. Selecting cost effective and policy-relevant biological indicators for European monitoring of soil biodiversity and ecosystem function. Ecol. Ind. 69, 213–223. https://doi.org/10.1016/j.ecolind.2016.04.023.
Habel, J.C., Dengler, J., Janišová, M., et al., 2013. European grassland ecosystems: Threatened hotspots of biodiversity. Biodivers. Conserv. 22, 2131–2138. https://doi.org/10.1007/s10531-013-0537-x.
Haines-Young, R., Potschin, M., 2018. CICES V5. 1. Guidance on the application of the revised structure. Fabis Consult 53.
Halbritter, A.H., De Boeck, H.J., Eycott, A.E., et al., 2020. The handbook for standardized field and laboratory measurements in terrestrial climate change experiments and observational studies (ClimEx). Methods Ecol. Evol. 11, 22–37. https://doi.org/10.1111/2041-210X.13331.
Halvorson, J.J., Gatto, L.W., McCool, D.K., 2003. Overwinter changes to near-surface bulk density, penetration resistance and infiltration rates in compacted soil. J Terramechanics 40, 1–24. https://doi.org/10.1016/S0022-4898(03)00014-4.
Häner, R., Schierscher, B., Kleijer, G., Rometsch, S., 2010. Mit Kulturpflanzen verwandte Wildarten erhalten. Agrar Schweiz 16, 204–209.
Haygarth, P.M., Hepworth, L., Jarvis, S.C., 1998. Forms of phosphorus transfer in hydrological pathways from soil under grazed grassland. Eur. J. Soil Sci. 49, 65–72. https://doi.org/10.1046/j.1365-2389.1998.00131.x.
Heathwaite, A.L., Dils, R.M., 2000. Characterising phosphorus loss in surface and subsurface hydrological pathways. Sci. Total Environ. 251 (252), 523–538. https://doi.org/10.1177/014920638701300111.
Heckrath, G., Brookes, P.C., Poulton, P.R., Goulding, K.W.T., 1995. Phosphorus leaching from soils containing different phosphorus concentrations in the Broadbalk experiment. J. Environ. Qual. 24, 904–910. https://doi.org/10.2134/jeq1995.00472425002400050018x.
Hein, L., van Koppen, K., de Groot, R.S., van Ierland, E.C., 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecol. Econ. 57, 209–228. https://doi.org/10.1016/j.ecolecon.2005.04.005.
Herrick, J.E., Whitford, W.G., De Soyza, A.G., et al., 2001. Field soil aggregate stability kit for soil quality and rangeland health evaluations. Catena 44, 27–35. https://doi.org/10.1016/S0341-8162(00)00173-9.
Hiron, M., Pärt, T., Siriwardena, G.M., Whittingham, M.J., 2018. Species contributions to single biodiversity values under-estimate whole community contribution to a wider range of values to society. Sci. Rep. 8, 1–7. https://doi.org/10.1038/s41598-018-25339-2.
Holecheck, J.L., Vavra, M., Pieper, R.D., 1982. Methods for determining the nutritive quality of range ruminant diets: a review. J. Anim. Sci. 54, 363–376. https://doi.org/10.2527/jas1982.542363x.
Hölting, L., Beckmann, M., Volk, M., Cord, A.F., 2019. Multifunctionality assessments – More than assessing multiple ecosystem functions and services? A quantitative literature review. Ecol. Ind. 103, 226–235. https://doi.org/10.1016/j.ecolind.2019.04.009.
I. Hönigová D. Vačkář E. Lorencová J. Melichar Survey on grassland ecosystem services. Report of the EEA - European Topic Centre on Biological Diversity. Nature Conservation Agency of the Czech Republic 2012 Prague.
Hopkins, A., Del Prado, A., 2007. Implications of climate change for grassland in Europe: Impacts, adaptations and mitigation options: A review. Grass Forage Sci. 62, 118–126. https://doi.org/10.1111/j.1365-2494.2007.00575.x.
Hoyle, H., Norton, B., Dunnett, N., et al., 2018. Plant species or flower colour diversity? Identifying the drivers of public and invertebrate response to designed annual meadows. Landsc Urban Plan 180, 103–113. https://doi.org/10.1016/j.landurbplan.2018.08.017.
Huber, R., Finger, R., 2020. A Meta-analysis of the willingness to pay for cultural services from grasslands in Europe. J. Agric. Econ. 71, 357–383. https://doi.org/10.1111/1477-9552.12361.
Hütsch, B.W., Webster, C.P., Powlson, D.S., 1993. Long-term effects of nitrogen fertilization on methane oxidation in soil of the broadbalk wheat experiment. Soil Biol. Biochem. 25, 1307–1315. https://doi.org/10.1016/0038-0717(93)90045-D.
Jarvis, S., Fielder, H., Hopkins, J., et al., 2015. Distribution of crop wild relatives of conservation priority in the UK landscape. Biol. Conserv. 191, 444–451. https://doi.org/10.1016/j.biocon.2015.07.039.
Ju, Y., Zhuo, J., Liu, B., Long, C., 2013. Eating from the wild: Diversity of wild edible plants used by Tibetans in Shangri-la region, Yunnan. China. J Ethnobiol Ethnomed 9, 28. https://doi.org/10.1186/1746-4269-9-28.
Kaval, P., Baskaran, R., 2013. Key ideas and concepts from economics for understanding the roles and value of ecosystem services. In: Wratten, S.D., Sandhu, H.C.R. (Eds.), Ecosystem services in agricultural and urban landscapes. John Wiley & Sons, New York, USA, pp. 28–41.
Kay, S., Graves, A., Palma, J.H.N., et al., 2019. Agroforestry is paying off – Economic evaluation of ecosystem services in European landscapes with and without agroforestry systems. Ecosyst. Serv. 36, 100896 https://doi.org/10.1016/j.ecoser.2019.100896.
Keeler, B.L., Polasky, S., 2014. Land-use change and costs to rural households: a case study in groundwater nitrate contamination. Environ. Res. Lett. 9, 74002. https://doi.org/10.1088/1748-9326/9/7/074002.

Kim, T.N., Fox, A.F., Wills, B.D., et al., 2017. Harvesting biofuel grasslands has mixed effects on natural enemy communities and no effects on biocontrol services. J. Appl. Ecol. 54, 2011–2021. https://doi.org/10.1111/1365-2664.12901.

Klaus, V.H., Hoever, C.J., Fischer, M., et al., 2018. Contribution of the soil seed bank to the restoration of temperate grasslands by mechanical sward disturbance. Restor. Ecol. 26, S114–S122. https://doi.org/10.1111/rec.12626.

Kleinebecker, T., Hölzel, N., Prati, D., et al., 2014. Evidence from the real world: 15N natural abundances reveal enhanced nitrogen use at high plant diversity in Central European grasslands. J. Ecol. 102, 456–465. https://doi.org/10.1111/1365-2745.12202.

Kleinebecker, T., Klaus, V.H., Hölzel, N., 2011. Reducing sample quantity and maintaining high prediction quality of grassland biomass properties with near infrared reflectance spectroscopy. J. Near Infrared Spectrosc. 19, 495–505. https://doi.org/10.1255/jnirs.957.

Knoche, S., Lupi, F., 2007. Valuing deer hunting ecosystem services from farm landscapes. Ecol. Econ. 64, 313–320. https://doi.org/10.1016/j.ecolecon.2007.07.023.

Knop, E., Kleijn, D., Herzog, F., Schmid, B., 2006. Effectiveness of the Swiss agri-environment scheme in promoting biodiversity. J. Appl. Ecol. 43, 120–127. https://doi.org/10.1111/j.1365-2664.2005.01113.x.

Knops, J.M.H., Wedin, D., Tilman, D., 2001. Biodiversity and decomposition in experimental grassland ecosystems. Oecologia 126, 429–433. https://doi.org/10.1007/s004420000537.

Kohler, M., Devaux, C., Grigulis, K., et al., 2017. Plant functional assemblages as indicators of the resilience of grassland ecosystem service provision. Ecol. Ind. 73, 118–127. https://doi.org/10.1016/j.ecolind.2016.09.024.

Kosanic, A., Petzold, J., 2020. A systematic review of cultural ecosystem services and human wellbeing. Ecosyst. Serv. 45, 101168 https://doi.org/10.1016/j.ecoser.2020.101168.

Kušar D, Komac B (2019) A geographical and architectural perspective on alpine hay meadow abandonment in Bohinj , Slovenia. eco.mont 11:32–42.

Kütt, L., Lõhmus, K., Rammi, I.J., et al., 2016. The quality of flower-based ecosystem services in field margins and road verges from human and insect pollinator perspectives. Ecol. Ind. 70, 409–419. https://doi.org/10.1016/j.ecolind.2016.06.009.

Kütt, L., Paal, T., Lõhmus, K., et al., 2018. Multi-user quality of floral services along a gradient of margin habitats between semi-natural grasslands and forests. Appl. Veg. Sci. 21, 363–372. https://doi.org/10.1111/avsc.12376.

Kwaiser, K.S., Hendrix, S.D., 2008. Diversity and abundance of bees (Hymenoptera: Apiformes) in native and ruderal grasslands of agriculturally dominated landscapes. Agric. Ecosyst. Environ. 124, 200–204. https://doi.org/10.1016/j.agee.2007.09.012.

Langlois, J.L., Johnson, D.W., Mehuys, G.R., 2003. Adsorption and recovery of dissolved organic phosphorus and nitrogen by mixed-bed ion-exchange resin. Soil Sci. Soc. Am. J. 67, 889–894.

Lawler, J.J., Lewis, D.J., Nelson, E., et al., 2014. Projected land-use change impacts on ecosystem services in the United States. Proc Natl Acad Sci U S A 111, 7492–7497. https://doi.org/10.1073/pnas.1405557111.

Layke, C., Mapendembe, A., Brown, C., et al., 2012. Indicators from the global and sub-global millennium ecosystem assessments: An analysis and next steps. Ecol. Ind. 17, 77–87. https://doi.org/10.1016/j.ecolind.2011.04.025.

Lazo, J.K., 2002. Economic valuation of ecosystem services: discussion and application. Drug Chem. Toxicol. 25, 349–374. https://doi.org/10.1081/DCT-120014788.

Le Clec'h S, Finger R, Buchmann N,, et al., 2019. Assessment of spatial variability of multiple ecosystem services in grasslands of different intensities. J. Environ. Manage. 251, 109372 https://doi.org/10.1016/j.jenvman.2019.109372.

Leemans, R., Eickhout, B., 2004. Another reason for concern: Regional and global impacts on ecosystems for different levels of climate change. Glob Environ Chang 14, 219–228. https://doi.org/10.1016/j.gloenvcha.2004.04.009.

Leitinger, G., Tasser, E., Newesely, C., et al., 2010. Seasonal dynamics of surface runoff in mountain grassland ecosystems differing in land use. J. Hydrol. 385, 95–104. https://doi.org/10.1016/j.jhydrol.2010.02.006.

Lemaire, G., Hodgson, J., Chabbi, A., 2011. Grassland productivity and ecosystem services. CAB International, Cambridge.

Lindemann-Matthies, P., Briegel, R., Schüpbach, B., Junge, X., 2010a. Aesthetic preference for a Swiss alpine landscape: The impact of different agricultural land-use with different biodiversity. Landsc Urban Plan 98, 99–109. https://doi.org/10.1016/j.landurbplan.2010.07.015.

Lindemann-Matthies, P., Junge, X., Matthies, D., 2010b. The influence of plant diversity on people's perception and aesthetic appreciation of grassland vegetation. Biol. Conserv. 143, 195–202. https://doi.org/10.1016/j.biocon.2009.10.003.

Liu, X., Lyu, S., Zhou, S., Bradshaw, C.J.A., 2016. Warming and fertilization alter the dilution effect of host diversity on disease severity. Ecology 97, 1680–1689. https://doi.org/10.1890/15-1784.1.

Loranger, H., Weisser, W.W., Ebeling, A., et al., 2014. Invertebrate herbivory increases along an experimental gradient of grassland plant diversity. Oecologia 174, 183–193. https://doi.org/10.1007/s00442-013-2741-5.

Lucas, A., Bull, J.C., de Vere, N., et al., 2017. Flower resource and land management drives hoverfly communities and bee abundance in seminatural and agricultural grasslands. Ecol. Evol. 7, 8073–8086. https://doi.org/10.1002/ece3.3303.

E. Lulekal Z. Asfaw E. Kelbessa P. Van Damme Wild edible plants in Ethiopia: a review on their potential to combat food insecurity. Afrika Focus 24 71–121 2011 10.21825/af.v24i2.4998.

MA (Millennium Ecosystem Assessment Board) (2005) Ecosystems and human well-being - health synthesis.

Maes, J., Liquete, C., Teller, A., et al., 2016. An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020. Ecosyst. Serv. 17, 14–23. https://doi.org/10.1016/j.ecoser.2015.10.023.

Maguire, R.O., Sims, J.T., 2002. Soil testing to predict phosphorus leaching. J. Environ. Qual. 31, 1601–1609. https://doi.org/10.2134/jeq2002.1601.

Mallarino, A.P., 2005. Testing of soils. In: Hilell, D., Hatwield, J.L., Powlson, D.S. (Eds.), Encyclopedia of Soils in the Environment, 1st edn. Elsevier Academic Press, Amsterdam, pp. 143–149.

Manning, P., Van Der Plas, F., Soliveres, S., et al., 2018. Redefining ecosystem multifunctionality. Nat Ecol Evol 2, 427–436. https://doi.org/10.1038/s41559-017-0461-7.

Marshall, S.A., Campbell, C.P., Buchanan-Smith, J.G., 1998. Herbage biomass and intake of beef cows with calves grazing a grass-legume pasture in southern Ontario. Can. J. Anim. Sci. 78, 211–218. https://doi.org/10.4141/A97-003.

Marsoner, T., Egarter, L., Manck, F., et al., 2018. Indigenous livestock breeds as indicators for cultural ecosystem services : A spatial analysis within the Alpine Space. Ecol. Ind. 94, 55–63. https://doi.org/10.1016/j.ecolind.2017.06.046.

Martín-Forés, I., Guerin, G.R., Lowe, A.J., 2017. Weed abundance is positively correlated with native plant diversity in grasslands of southern Australia. PLoS ONE 12, 1–13. https://doi.org/10.1371/journal.pone.0178681.

Martín-López, B., Gómez-Baggethun, E., González, J.A., et al., 2009. The assessment of ecosystem services provided by biodiversity: re-thinking concepts and research needs. In: Aronoff, J.B. (Ed.), Handbook of Nature Conservation. Nova Publisher, Hauppauge, NY, pp. 1–22.

Maseyk, F.J.F., Demeter, L., Csergő, A.M., Buckley, Y.M., 2017. Effect of management on natural capital stocks underlying ecosystem service provision: a 'provider group' approach. Biodivers. Conserv. 26, 3289–3305. https://doi.org/10.1007/s10531-017-1406-9.

Meehan, T.D., Werling, B.P., Landis, D.A., Gratton, C., 2012. Pest-suppression potential of midwestern landscapes under contrasting bioenergy scenarios. PLoS ONE 7, 1–7. https://doi.org/10.1371/journal.pone.0041728.

Mehring, M., Ott, E., Hummel, D., 2018. Ecosystem services supply and demand assessment: Why social-ecological dynamics matter. Ecosyst. Serv. 30, 124–125. https://doi.org/10.1016/j.ecoser.2018.02.009.

Merbold, L., Eugster, W., Stieger, J., et al., 2014. Greenhouse gas budget (CO2, CH4 and N2O) of intensively managed grassland following restoration. Glob Chang Biol 20, 1913–1928. https://doi.org/10.1111/gcb.12518.

Merz, A., Alewell, C., Hiltbrunner, E., Bänninger, D., 2009. Plant-compositional effects on surface runoff and sediment yield in subalpine grassland. J. Plant Nutr. Soil Sci. 172, 777–788. https://doi.org/10.1002/jpln.200800231.

Metzger, M.J., Rounsevell, M.D.A., Acosta-Michlik, L., et al., 2006. The vulnerability of ecosystem services to land use change. Agric. Ecosyst. Environ. 114, 69–85. https://doi.org/10.1016/j.agee.2005.11.025.

Meyer, S.T., Koch, C., Weisser, W.W., 2015. Towards a standardized Rapid Ecosystem Function Assessment (REFA). Trends Ecol. Evol. 30, 390–397. https://doi.org/10.1016/j.tree.2015.04.006.

Meyer, S.T., Ptacnik, R., Hillebrand, H., et al., 2018. Biodiversity-multifunctionality relationships depend on identity and number of measured functions. Nat. Ecol. Evol. 2, 44–49. https://doi.org/10.1038/s41559-017-0391-4.

Mishra, S.K., Negri, M.C., Kozak, J., et al., 2019. Valuation of ecosystem services in alternative bioenergy landscape scenarios. GCB Bioenergy 11, 748–762. https://doi.org/10.1111/gcbb.12602.

Mooney, H., Larigauderie, A., Cesario, M., et al., 2009. Biodiversity, climate change, and ecosystem services. Curr Opin Environ Sustain 1, 46–54. https://doi.org/10.1016/j.cosust.2009.07.006.

Morrison, M., Bennett, J., 2004. Valuing New South Wales rivers for use in benefit transfer. Aust. J. Agric. Resour. Econ. 48, 591–611. https://doi.org/10.1111/j.1467-8489.2004.00263.x.

Morse-Jones, S., Luisetti, T., Turner, R.K., Fisher, B., 2011. Ecosystem valuation: some principles and a partial application. Environmetrics 22, 675–685. https://doi.org/10.1002/env.1073.

Müller, S.M., Peisker, J., Bieling, C., et al., 2019. The importance of cultural ecosystem services and biodiversity for landscape visitors in the biosphere reserve Swabian Alb (Germany). Sustainability 11, 2650. https://doi.org/10.3390/su11092650.

Murphy, S., Lodge, G., 2002. Ground cover in temperate native perennial grass I. A comparison of four estimation methods. Rangel J 24, 288–300.

Naeth, M.A., Chanasyk, D.S., Rothwell, R.L., Bailey, A.W., 1991. Grazing impacts on soil water in mixed prairie and fescue grassland ecosystems of Alberta. Can. J. Soil Sci. 70, 313–325. https://doi.org/10.4141/cjss91-031.

Nelson DW, Sommers LE (1996) Total carbon, organic carbon, and organic matter. In: Sparks DL, Page AL, Helmke PA, Loeppert RH (eds) Methods of Soil Analysis. Part 3. Chemical Methods. Soil Science Society of America an dAmerica Society of Agronomy, Madison, WI, p 1424.

Newell-Price P (2020) Quantifying ecosystem services on permanent grassland - A short list of agri-environmental indicators. Deliverable 2.2b of the H2020 project SUPER-G – Developing SUstainable PERmanent Grassland systems and policies.

Ni, J., 2004. Estimating net primary productivity of grasslands from field biomass measurements in temperate northern China. Plant Ecol. 174, 217–234. https://doi.org/10.1016/j.physletb.2009.12.059.

O'Mara, F.P., 2012. The role of grasslands in food security and climate change. Ann. Bot. 110, 1263–1270. https://doi.org/10.1093/aob/mcs209.

O'Rourke, S.M., Holden, N.M., 2011. Optical sensing and chemometric analysis of soil organic carbon - a cost effective alternative to conventional laboratory methods? Soil Use Manag. 27, 143–155. https://doi.org/10.1111/j.1475-2743.2011.00337.x.

Ojea, E., Pascual, M., March, D., 2017. Socioeconomic impacts of networks of marine protected areas. In: Goriup, P.D. (Ed.), Management of marine protected areas: A network perspective, 1st ed. John Wiley & Sons Ltd., pp. 103–124
Orford, K.A., Murray, P.J., Vaughan, I.P., Memmott, J., 2016. Modest enhancements to conventional grassland diversity improve the provision of pollination services. J. Appl. Ecol. 53, 906–915. https://doi.org/10.1111/1365-2664.12608.
Paletto, A., Geitner, C., Grilli, G., et al., 2015. Mapping the value of ecosystem services: A case study from the Austrian Alps. Ann For Res 58, Issue 1.
Pascual, U., Balvanera, P., Díaz, S., et al., 2017. Valuing nature's contributions to people: the IPBES approach. Curr Opin Environ Sustain 26–27, 7–16. https://doi.org/10.1016/j.cosust.2016.12.006.
Pascual, U., Muradian, R., Brander, L., et al., 2012. The economics of valuing ecosystem services and biodiversity. In: TEEB, The Economics of Ecosystems and Biodiversity. Ecological and economic foundations. Routledge, Abingdon and New York, pp. 183–255.
Pascual, U., Termansen, M., Hedlund, K., et al., 2015. On the value of soil biodiversity and ecosystem services. Ecosyst. Serv. 15, 11–18. https://doi.org/10.1016/j.ecoser.2015.06.002.
Patrignani, A., Ochsner, T.E., 2015. Canopeo: A powerful new tool for measuring fractional green canopy cover. Agron. J. 107, 2312–2320. https://doi.org/10.2134/agronj15.0150.
C. Paul K. Helming Handbook of Soil-Related Impact Assessment BonaRes Ser 4 93 2019 10.20387/BonaRes-6DJM-E22M.
Pedrono, M., Locatelli, B., Ezzine-de-blas, D., Pesche, D., 2016. Impact of climate change on ecosystem services. In: In: Torquebiau (ed) Climate change and agriculture worldwide. Éditions Quae, pp. 251–261.
Pelosi, C., Bertrand, M., Capowiez, Y., et al., 2009. Earthworm collection from agricultural fields: Comparisons of selected expellants in presence/absence of hand-sorting. Eur. J. Soil Biol. 45, 176–183. https://doi.org/10.1016/j.ejsobi.2008.09.013.
Peoples, M.B., a.W. Faizah, Rerkasem B, Herridge DF,, 1989. Methods for evaluating nitrogen fixation by nodulated legumes in the field. Aust Cent Int Agric Res 11, 76.
Petrich, L., Lohrmann, G., Neumann, M., et al., 2020. Detection of Colchicum autumnale in drone images, using a machine-learning approach. Precis. Agric. https://doi.org/10.1007/s11119-020-09721-7.
Plummer, M.L., 2009. Assessing benefit transfer for the valuation of ecosystem services. Front. Ecol. Environ. 7, 38–45. https://doi.org/10.1890/080091.
Post, W.M., Kwon, K.C., 2000. Soil carbon sequestration and land-use change: Processes and potential. Glob Chang Biol 6, 317–327. https://doi.org/10.1046/j.1365-2486.2000.00308.x.
Prescott, C.E., 2010. Litter decomposition: What controls it and how can we alter it to sequester more carbon in forest soils? Biogeochemistry 101, 133–149. https://doi.org/10.1007/s10533-010-9439-0.
Pulley, S., Collins, A.L., 2019. Field-based determination of controls on runoff and fine sediment generation from lowland grazing livestock fields. J. Environ. Manage. 249, 109365 https://doi.org/10.1016/j.jenvman.2019.109365.
Pumpanen, J., Longdoz, B., Kutsch, W.L., 2009. Field measurements of soil respiration: principles and constraints, potentials and limitations of different methods. In: Kutsch, W.L., Bahn, M., Heinemeyer, A. (Eds.), Soil carbon dynamics: An integrated methodology. Cambridge University Press, Cambridge, p. 286.
Pywell, R.F., Hayes, M.J., Tallowin, J.B., et al., 2010. Minimizing environmental impacts of grassland weed management: Can Cirsium arvense be controlled without herbicides? Grass Forage Sci. 65, 159–174. https://doi.org/10.1111/j.1365-2494.2010.00735.x.
Qi, Y., Hung, J.B., Sen, Zhao Y, Wang, B., 2015. Research on infiltration rate of topsoil in combination with steady infiltration model and penetration resistance test. Appl Mech Mater 744–746, 1113–1119. https://doi.org/10.4028/www.scientific.net/amm.744-746.1113.
Qian, P., Schoenau, J.J., 2005. Use of ion-exchange membrane to assess nitrogen-supply power of soils. J. Plant Nutr. 28, 2193–2200. https://doi.org/10.1080/01904160500324717.
Razquin Lizarraga MM, Aranguren Ibañes E, Taull Taull M, et al (2012) Las facerías internacionales en el Pirineo: historia, actualidad y futuro. In: Canals Tresserras RM, San Emeterio Garciandía L (eds) Nuevos retos de la ganadería extensiva: un agente de conservación en peligro de extinción, 1st edn. Sociedad Española para el Estudio de los Pastos, pp 3–28.
Remme, R.P., Schröter, M., Hein, L., 2014. Developing spatial biophysical accounting for multiple ecosystem services. Ecosyst. Serv. 10, 6–18. https://doi.org/10.1016/j.ecoser.2014.07.006.
Reyers, B., Bidoglio, G., Dhar, U., et al., 2010. Measuring biophysical quantities and the use of indicators. In: The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, London, pp. 113–148.
Ricou, C., Schneller, C., Amiaud, B., et al., 2014. A vegetation-based indicator to assess the pollination value of field margin flora. Ecol. Ind. 45, 320–331. https://doi.org/10.1016/j.ecolind.2014.03.022.
Risch, A.C., Zimmermann, S., Ochoa-Hueso, R., et al., 2019. Soil net nitrogen mineralisation across global grasslands. Nat. Commun. 10, 4981. https://doi.org/10.1038/s41467-019-12948-2.
Robinson-Boyer, L., Grzyb, I., Jeffries, P., 2009. Shifting the balance from qualitative to quantitative analysis of arbuscular mycorrhizal communities in field soils. Fungal Ecol 2, 1–9. https://doi.org/10.1016/j.funeco.2008.11.001.
Root-Bernstein, M., Armesto, J., 2013. Selection and implementation of a flagship fleet in a locally undervalued region of high endemicity. Ambio 42, 776–787. https://doi.org/10.1007/s13280-013-0385-7.
Root-Bernstein, M., Jaksic, F.M., 2017. Making research relevant? Ecological methods and the ecosystem services framework. Earth's Futur 5, 664–678. https://doi.org/10.1002/2016EF000501.
Rosenberger, R.S., Loomis, J.B., 2000. Using meta-analysis for benefit transfer: In-sample convergent validity tests of an outdoor recreation database. Water Resour. Res. 36, 1097–1107. https://doi.org/10.1029/2000WR900006.
Rottstock, T., Joshi, J., Kummer, V., Fischer, M., 2014. Higher plant diversity promotes higher diversity of fungal pathogens, while it decreases pathogen infection per plant. Ecology 95, 1907–1917. https://doi.org/10.1890/13-2317.1.
Rounsevell, M.D.A., Ewert, F., Reginster, I., et al., 2005. Future scenarios of European agricultural land use: II. Projecting changes in cropland and grassland. Agric. Ecosyst. Environ. 107, 117–135. https://doi.org/10.1016/j.agee.2004.12.002.
Santos Oleques, S., Overbeck, G.E., de Avia, R.S., 2017. Flowering phenology and plant-pollinator interactions in a grassland community of Southern Brazil. Flora Morphol Distrib Funct Ecol Plants 229, 141–146. https://doi.org/10.1016/j.flora.2017.02.024.
Schaub, S., Buchmann, N., Lüscher, A., Finger, R., 2020a. Economic benefits from plant species diversity in intensively managed grasslands. Ecol. Econ. 168, 106488 https://doi.org/10.1016/j.ecolecon.2019.106488.
Schaub, S., Finger, R., Leiber, F., et al., 2020b. Plant diversity effects on forage quality, yield and revenues of semi-natural grasslands. Nat. Commun. 11, 768. https://doi.org/10.1038/s41467-020-14541-4.
Scherber, C., Mwangi, P.N., Temperton, V.M., et al., 2006. Effects of plant diversity on invertebrate herbivory in experimental grassland. Oecologia 147, 489–500. https://doi.org/10.1007/s00442-005-0281-3.
Schirpke, U., Meisch, C., Tappeiner, U., 2018. Symbolic species as a cultural ecosystem service in the European Alps: insights and open issues. Landsc Ecol 33, 711–730. https://doi.org/10.1007/s10980-018-0628-x.
Schloter, M., Nannipieri, P., Sørensen, S.J., Van, Elsas JD, 2018. Microbial indicators of soil quality. Biol. Fertil. Soils 54, 1–10.
Schmidt, O., 2001. Time-limited soil sorting for long-term monitoring of earthworm populations. Pedobiologia (Jena) 45, 69–83.
Schubiger, F.X., Lehmann, J., Daccord, R., et al., 2001. Die Bestimmung der Verdaulichkeit von Futterpflanzen. Agrar Schweiz 8, 360–363.
Schulp, C.J.E., Thuiller, W., Verburg, P.H., 2014. Wild food in Europe: A synthesis of knowledge and data of terrestrial wild food as an ecosystem service. Ecol. Econ. 105, 292–305. https://doi.org/10.1016/j.ecolecon.2014.06.018.
Sekercioglu, C.H., 2010. Ecosystem functions and services. In: Sodhi, N.S., Ehrlich, P.R. (Eds.), Conservation biology for all. Oxford University Press, New York, USA, pp. 45–72.
Shrestha, P.M., Kammann, C., Lenhart, K., et al., 2012. Linking activity, composition and seasonal dynamics of atmospheric methane oxidizers in a meadow soil. ISME J. 6, 1115–1126. https://doi.org/10.1038/ismej.2011.179.
Singh, J., Singh, S., Vig, A.P., 2016. Extraction of earthworm from soil by different sampling methods: a review. Environ. Dev. Sustain. 18, 1521–1539. https://doi.org/10.1007/s10668-015-9703-5.
Singh, J.S., Lauenroth, W.K., Steinhorst, R.K., 1975. Review and assessment of various techniques for estimating net aerial primary production in grasslands from harvest data. Bot. Rev. 41, 181–232.
Socher, S.A., Prati, D., Boch, S., et al., 2013. Interacting effects of fertilization, mowing and grazing on plant species diversity of 1500 grasslands in Germany differ between regions. Basic Appl. Ecol. 14, 126–136. https://doi.org/10.1016/j.baae.2012.12.003.
Southon, G.E., Jorgensen, A., Dunnett, N., et al., 2017. Biodiverse perennial meadows have aesthetic value and increase residents' perceptions of site quality in urban green-space. Landsc Urban Plan 158, 105–118. https://doi.org/10.1016/j.landurbplan.2016.08.003.
Špulerová, J., Piscová, V., Gerhátová, K., et al., 2015. Orchards as traces of traditional agricultural landscape in Slovakia. Agric. Ecosyst. Environ. 199, 67–76. https://doi.org/10.1016/j.agee.2014.08.021.
Staudinger, M.D., Grimm, N.B., Staudt, A., et al., 2012. Impacts of climate change on biodiversity, ecosystems. and ecosystem services: technical input to the 2013 National Climate Assessment.
Stern, N., 2007. The economics of climate change: the Stern review. Cambridge University Press, Cambridge.
Stevens, A., Nocita, M., Tóth, G., et al., 2013. Prediction of soil organic carbon at the european scale by visible and near infrared reflectance spectroscopy. PLoS ONE 8, 1–13. https://doi.org/10.1371/journal.pone.0066409.
Suter, M., Siegrist-Maag, S., Connolly, J., Lüscher, A., 2007. Can the occurrence of Senecio jacobaea be influenced by management practice? Weed Res. 47, 262–269. https://doi.org/10.1111/j.1365-3180.2007.00566.x.
Tardío, J., Pardo-De-Santayana, M., Morales, R., 2006. Ethnobotanical review of wild edible plants in Spain. Bot. J. Linn. Soc. 152, 27–71. https://doi.org/10.5586/asbp.2012.030.
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. Ecosyst. Serv. 42, 101082 https://doi.org/10.1016/j.ecoser.2020.101082.
Thiele, J., Albert, C., Hermes, J., Von, Haaren C, 2020. Assessing and quantifying offered cultural ecosystem services of German river landscapes. Ecosyst. Serv. 42, 101080 https://doi.org/10.1016/j.ecoser.2020.101080.
Thierfelder, C., Amézquita, C.E., Stahr, K., 2005. Effects of intensifying organic manuring and tillage practices on penetration resistance and infiltration rate. Soil Tillage Res. 82, 211–226. https://doi.org/10.1016/j.still.2004.07.018.
Tieskens, K.F., Schulp, C.J.E., Levers, C., et al., 2017. Characterizing European cultural landscapes : Accounting for structure, management intensity and value of

agricultural and forest landscapes. Land use policy 62, 29–39. https://doi.org/10.1016/j.landusepol.2016.12.001.
Tilley, J.M.A., Terry, R.A., 1963. A two-stage technique for the in vitro digestion of forage crops. Grass Forage Sci. 18, 104–111. https://doi.org/10.1111/j.1365-2494.1963.tb00335.x.
Tracy, B.F., Renne, I.J., Gerrish, J., Sanderson, M.A., 2004. Effects of plant diversity on invasion of weed species in experimental pasture communities. Basic Appl. Ecol. 5, 543–550. https://doi.org/10.1016/j.baae.2004.08.007.
Trogisch, S., Schuldt, A., Bauhus, J., et al., 2017. Toward a methodical framework for comprehensively assessing forest multifunctionality. Ecol. Evol. 7, 10652–10674. https://doi.org/10.1002/ece3.3488.
Tscharntke, T., Clough, Y., Wanger, T.C., et al., 2012. Global food security, biodiversity conservation and the future of agricultural intensification. Biol. Conserv. 151, 53–59. https://doi.org/10.1016/j.biocon.2012.01.068.
Valente, J., Doldersum, M., Roers, C., Kooistra, L., 2019. Detecting Rumex obtusifolius weed plants in grasslands from uav rgb imagery using deep learning. ISPRS Ann Photogramm Remote Sens Spat Inf Sci 4, 179–185. https://doi.org/10.5194/isprs-annals-IV-2-W5-179-2019.
Van Vooren, L., Reubens, B., Broekx, S., et al., 2018. Assessing the impact of grassland management extensification in temperate areas on multiple ecosystem services and biodiversity. Agric. Ecosyst. Environ. 267, 201–212. https://doi.org/10.1016/j.agee.2018.08.016.
Veen, P., Jefferson, R., de Smidt, J., van der Straaten, J., 2009. Grasslands in Europe of high nature value. KNNV Publishing, Zeist.
Villoslada Peciña, M., Ward, R.D., Bunce, R.G.H., et al., 2019. Country-scale mapping of ecosystem services provided by semi-natural grasslands. Sci. Total Environ. 661, 212–225. https://doi.org/10.1016/j.scitotenv.2019.01.174.
Vitalini, S., Puricelli, C., Mikerezi, I., Iriti, M., 2015. Plants, people and traditions: Ethnobotanical survey in the Lombard Stelvio National Park and neighbouring areas (Central Alps, Italy). J. Ethnopharmacol. 173, 435–458. https://doi.org/10.1016/j.jep.2015.05.036.
Wachendorf, M., Fricke, T., Möckel, T., 2018. Remote sensing as a tool to assess botanical composition, structure, quantity and quality of temperate grasslands. Grass Forage Sci. 73, 1–14. https://doi.org/10.1111/gfs.12312.
Walkley, A., Black, I.A., 1934. An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 37, 29–38. https://doi.org/10.1097/00010694-193401000-00003.
Webster, R., Oliver, M.A., 1990. Statistical Methods in Soil and Land Resource Survey. Oxford University Press, Oxford.
Wei, H., Fan, W., Wang, X., et al., 2017. Integrating supply and social demand in ecosystem services assessment: A review. Ecosyst. Serv. 25, 15–27. https://doi.org/10.1016/j.ecoser.2017.03.017.
Weiner, C.N., Werner, M., Linsenmair, K.E., Blüthgen, N., 2011. Land use intensity in grasslands: Changes in biodiversity, species composition and specialisation in flower visitor networks. Basic Appl. Ecol. 12, 292–299. https://doi.org/10.1016/j.baae.2010.08.006.
Werling, B.P., Dickson, T.L., Isaacs, R., et al., 2014. Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. Proc Natl Acad Sci U S A 111, 1652–1657. https://doi.org/10.1073/pnas.1309492111.
Werling, B.P., Meehan, T.D., Robertson, B.A., et al., 2011. Biocontrol potential varies with changes in biofuel-crop plant communities and landscape perenniality. GCB Bioenergy 3, 347–359. https://doi.org/10.1111/j.1757-1707.2011.01092.x.
Westphal, C., Bommarco, R., Carré, G., et al., 2008. Measuring bee diversity in different European habitats and biogeographic regions. Ecol. Monogr. 78, 653–671.
Williams, S.T., Maree, N., Taylor, P., et al., 2018. Predation by small mammalian carnivores in rural agro-ecosystems: An undervalued ecosystem service? Ecosyst. Serv. 30, 362–371. https://doi.org/10.1016/j.ecoser.2017.12.006.
Winding, A., Hund-Rinke, K., Rutgers, M., 2005. The use of microorganisms in ecological soil classification and assessment concepts. Ecotoxicol. Environ. Saf. 62, 230–248. https://doi.org/10.1016/j.ecoenv.2005.03.026.
Woodcock, B.A., Pywell, R.F., 2010. Effects of vegetation structure and floristic diversity on detritivore, herbivore and predatory invertebrates within calcareous grasslands. Biodivers. Conserv. 19, 81–95. https://doi.org/10.1007/s10531-009-9703-6.
World Bank, Ecofys (2017) Carbon pricing watch 2017.
Wright, C.K., Wimberly, M.C., 2013. Recent land use change in the Western Corn Belt threatens grasslands and wetlands. Proc. Natl. Acad. Sci. USA 110, 4134–4139. https://doi.org/10.1073/pnas.1215404110.
Xu, S., Rowntree, J., Borrelli, P., et al., 2019. Ecological health index: A short term monitoring method for land managers to assess grazing lands ecological health. Environ - MDPI 67, 1–18. https://doi.org/10.3390/environments6060067.
Zavaleta, E.S., Pasari, J.R., Hulvey, K.B., Tilman, G.D., 2010. Sustaining multiple ecosystem functions in grassland communities requires higher biodiversity. Proc. Natl. Acad. Sci. USA 107, 1443–1446. https://doi.org/10.1073/pnas.0906829107.
Zhang, Q., Yang, G., Song, Y., et al., 2019. Magnitude and drivers of potential methane oxidation and production across the Tibetan alpine permafrost region. Environ. Sci. Technol. 53, 14243–14252. https://doi.org/10.1021/acs.est.9b03490.
Zoderer, B.M., Tasser, E., Erb, K.H., et al., 2016. Identifying and mapping the tourists' perception of cultural ecosystem services: A case study from an Alpine region. Land Use Policy 56, 251–261. https://doi.org/10.1016/j.landusepol.2016.05.004.