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Methods

A multitiered approach for grassland ecosystem services mapping and assessment: The Viva Grass tool

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Abstract

Throughout the second half of the 20th Century, the area of semi-natural grasslands in the Baltic States decreased substantially, due to agricultural abandonment in some areas and intensification in more productive soil types. In order to halt the loss of biodiversity and ecosystem services provided by grasslands, the LIFE+ programme funded project, LIFE Viva Grass, aims at developing an integrated planning tool that will support ecosystem-based planning and sustainable grassland management. LIFE Viva Grass integrated planning tool is spatially explicit and allows the user to assess the provision and trade-offs of grassland ecosystem services within eight project case study areas in Estonia, Latvia and Lithuania.

In order to ensure methodological adaptability, the structure of the LIFE Viva Grass integrated planning tool follows the framework of the tiered approach. In a multi-tier system, each consecutive tier entails an increase in data requirements, methodological complexity or both. The present paper outlines the adaptation of the tiered approach for mapping and assessing ecosystem services provided by grasslands in the Baltic States. The first tier corresponds to a deliberative decision process: The matrix approach is used to assess the potential supply of grassland ecosystem services based on expert estimations. Expert values are subsequently transferred to grassland units and therefore made spatially explicit. The data collected in the first tier was further enhanced through a Principal Components Analysis (PCA) in order to explore ES bundles in tier 2. In the third tier, Multi-Criteria Decision Analysis is used to target specific policy questions.

Keywords

Ecosystem services, grasslands, tiered approach, integrated planning

Introduction

Semi-natural grasslands represent complex ecosystems that provide a variety of different ecosystem functions and services, essential for maintenance of biodiversity as well as for survival and well-being of human society (Bullock et al. 2011). According to the ecosystem services (ES) categories defined by the Millennium Ecosystem Assessment (Sarukhan et al. 2005) and TEEB - The Economics of Ecosystems and Biodiversity (TEEB 2010), grasslands contribute to provisioning services – e.g. hay for animal feeding, biomass for energy production, herbs for medical treatment, genetic resources; regulating services – e.g. water regulation, soil retention, nutrient regulation, pollination; cultural services – rural and urban landscape and its aesthetic qualities and cultural heritage, providing the basis for recreation and tourism, as well as quality of life for living in that area; and supporting services – biomass production, nutrient cycling and soil formation amongst others. Loss of grassland biodiversity leads to degradation or even destruction of the ecosystem functions and services, which would require substantial financial investments to maintain or provide these services artificially.

In the Baltic States, as in many parts of Europe, rural areas are undergoing the process of marginalisation and related social and economic decline, that is resulting in depopulation, departure from the labour force and consequent abandonment of grasslands (Järv et al. 2016; Kliimask et al. 2015; Nikodemus et al. 2005; Ruskule et al. 2013; Strijker 2005). In addition, the former rural lifestyle and traditional farming practices for maintaining high ecological value grasslands are vanishing (Antrop 2005; Ruskule et al. 2013). Due to the depopulation of rural areas as well as lack of economic motivation for the maintenance of grasslands, they are often transformed into forests or intensive agricultural lands (Vanwambeke et al. 2012). With the accession to the EU and the availability of agricultural subsidies, the share of managed agricultural land has increased (Nikodemus et al. 2010). However, this has not prevented the decline of the semi-natural grasslands area, since the subsidies, in general, provide more favourable conditions for the promotion of intensive farming practices and agriculture production (Vinogradovs et al. 2016) rather than maintaining semi-natural grassland habitats (Halada et al. 2017, Zariņa et al. 2017). The unfavourable conservation status of the semi-natural habitats in the Baltic States has also been proven by the recent reporting of the Member States to European Commission under Article 17 requirements of the Habitats Directive (European Commission 2015).

The EU Common Agricultural Policy (CAP) is recognised as a major driver of agricultural land use, influencing rural development, landscape change as well as determining the grassland management practices (Lüker-Jans et al. 2016; Strijker 2005). This is also the case in the Baltic States, where the EU and national agriculture policies, along with nature conservation and, to some extent, the climate change mitigation and energy efficiency policy, promoting the use of biomass as a renewable energy source, were identified as the most important influencing factors on grassland management and thus impacting the status of grassland ecosystems and services they provide (Ruskule et al. 2015). The protection of semi-natural grasslands is indirectly set as one of the environmental objectives of the CAP and is supported through the Rural Development Programmes (RDP) by the agro-environmental measures, targeted to maintain grasslands and related biodiversity by "restoring, preserving and enhancing ecosystems related to agriculture". However, due to insufficient coordination between agriculture and nature conservation authorities, the environmental ambitions of the RDPs measures in the Baltic States are rather low (Ruskule et al. 2015). Additionally, the inconsistencies amongst the policy targets of different sectors lead to conflicts in land use and a decrease of semi-natural grassland area and quality (Rūsiņa 2017). This calls for a more integrated approach to policy-making and land use governance, which would address the trade-offs between different policy objective and management practices. The concept of ES can contribute to balanced and integrative resource management by facilitating cross-scale and cross-sectoral planning (Fürst et al. 2017).

The project “Integrated planning tool to ensure viability of grasslands – LIFE Viva Grass” aims to support the maintenance of biodiversity and ES provided by grasslands, through encouraging ecosystem-based planning and economically viable grassland management. The major task of the project is implementing the aims and objectives through an Integrated Planning Tool (hereinafter the Viva Grass tool) that will help to make decisions for sustainable grassland management by strengthening linkages between social, economic, environmental, agricultural fields and policies, emphasising the ES approach. The Viva Grass tool, developed within the project, provides spatially explicit decision support for landscape and spatial planning that sustains biodiversity, fortifies the provision of ES in agroecosystems, aims to prevent loss of High Nature Value Grasslands and increases the efficiency of semi-natural grassland management. The tool is integrated into an online GIS working environment which allows users to assess the provision and trade-offs of grassland ES in user-defined areas. The tool is divided into two sections: a general information platform freely available for the general public and a planning-orientated platform available only for registered users. LIFE Viva Grass encompasses nine case study areas (two farms, four municipalities, two protected areas and one county) across the three Baltic States (Estonia, Latvia and Lithuania).

Recent literature shows a wide array of integrated modelling systems aimed at supporting environmental decision-making, with an increased integration of the ES framework (Grêt-

Regamey et al. 2017; Jakeman et al. 2011). Malinga et al. (2015) show that the ES concept is best implemented into decision-making when the scale of assessment is local or regional, although the implementation of the concept has generally focused on a narrow selection of ES at those scales. Moreover, most of the approaches are mono-disciplinary, using either biophysical, social or economic valuations (Schägner et al. 2013). These shortcomings may be due to the difficulties of integrating multiple ES and multiple disciplines into easily manageable modelling systems. The Viva Grass tool is structured as a tiered system that provides methodological adaptability and helps overcome the aforementioned problems. As defined by Grêt-Regamey et al. 2015, each consecutive tier entails an increase in data requirements, methodological complexity or both.

The aim of this paper is to describe a methodology for the adaptation of the tiered approach to map and assess the supply of ES by grassland in the Baltic States. Furthermore, the paper outlines the implementation of the tiered approach into an integrated planning tool aimed at informing and supporting decisions related to sustainable grassland management. Beyond the methodological description, the advantages and shortcomings of such an approach are discussed.

Methods

Data availability: Towards a typology for grassland ES assessment

The spatial scale of the project posed a challenge in terms of data availability and data homogenisation. European-scale maps such as CORINE land cover (Soukup et al. 2016) do not offer the level of spatial and thematic detail required to link, in a spatially explicit way, grassland classes with the ES they provide. On the other hand, the basic national LULC maps differ substantially from one country to the other in terms of their thematic scales. A key requirement of the study was to develop an ES mapping and assessment based on a common classification of grassland types. A transnational basemap allows for comparisons between countries and the development of a shared methodology.

The potential delivery of ES is determined by the interaction of natural capital attributes, comprising both biotic and abiotic component and human inputs and management strategies (Smith et al. 2017). Based on these notions, the grassland classes that constitute the Viva Grass basemap were defined according to two main factors:

1. The underlying natural conditions: Two factors were selected as descriptors of the environmental conditions that underpin the provision of ES in the grasslands of the Baltic States: Land quality and slope. The concept of land quality is an integrated evaluation of fertility of soils used in the Baltic States' land evaluation systems and is composed of several factors, e.g. soil texture, soil type, topography, stoniness and level of cultivation (pH, A horizon dip, amount of organic matter). Land quality is expressed in points per hectare with 100 points being maximum (Boruks 2001; Vinogradovs et al. 2018). The land quality layer was divided into three classes: (1) less than 25 points, (2) 26-50 points, (3) above 50 points; additionally, hydromorphic soils (organogenic deposits) were extracted to create class 4. Soils have previously been identified as a crucial component of ES delivery (Greiner et al. 2017). Moreover, soil structure has been repeatedly used as an indicator of soil functions (Rabot et al. 2018). Low quality soils (1) are associated with poor soils with sandy soil texture, high risk of erosion, low capacity of nutrients supply and exchangeable elements and biological activity and very low estimated yields. Medium land quality soils (2) are associated with loamy sand soil texture, relatively low organic matter, low fertility, moderate capacity to accumulate nutrients and exchangeable elements. High land quality soils (3) are associated with loam and clay soil texture, moderate soil fertility, a high percentage of organic matter and capacity to accumulate nutrients and exchangeable elements. Hydromorphic soils are soils developed on organogenic deposits, characterised by various soil fertility and a relatively high rate of biological activity (Dube et al. 2001; Keesstra et al. 2012; Shaheen et al. 2013).

The slope has little or no direct influence on the yield of crops, but steeper slopes are associated with shallower soils with less water retention capacity due to gravity and with a higher risk for soil erosion (Van Orshoven et al. 2012), thus impacting ES supply potential. The slope layer was subdivided into three categories according to the gradient of steepness:

1. plain surface ($0^o – 4^o$),
2. gentle steepness ($5^o – 10^o$) and
3. steep slope (>10^o).

The categories were created during expert assessment and designated as erosion potentiality where: the first category represented no soil erosion, second category – minimal soil erosion and third category - noteworthy soil erosion potential. The slope dataset was generated from DEMs (10 m cell) (Fig. 1).

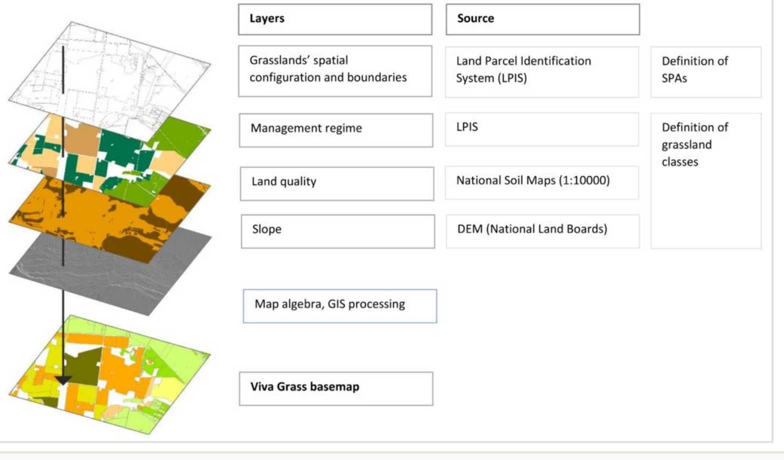

Figure 1.

LIFE Viva Grass basemap workflow.

2. The management regime of the grasslands: Three types of grassland management regimes and one type of cropland were considered in the analysis as the foundation for creating the ES supply potential basemap, namely: cultivated, permanent, semi-natural grasslands and arable/cropland. One of the main driving factors for different supply potential of ES in grasslands is the intensity of management or level of interference in topsoil. Cultivated grasslands are seeded (often a monoculture – *Festuca sp., Phleum sp., Dactylis sp.*) and ploughed, usually included in crop rotation and less than five years of age. Cutting of grass is undertaken several (up to four) times a season. Fertilisation is also a common practice to maintain high yields. Cultivated grasslands are associated with intensive farming systems. Permanent grasslands are generally defined as land used to grow grasses naturally or through cultivation which is older than five years. This type of grasslands is rarely seeded, contain both natural vegetation and cultivated species. Permanent grasslands are excluded from crop rotation, mostly used as hay fields and cut not more than two times a season or used as pastures. Permanent grasslands are associated with low input farming systems. Semi-natural grasslands are the result of decades or centuries of low-intensity management and are currently not seeded or ploughed. Semi-natural grasslands contain high levels of biodiversity (Bullock et al. 2011; Dengler and Rūsiņa 2012) and are used as low-intensity pastures or hay fields (one late cut per season) or solely managed to receive agri-environmental payments (Vinogradovs et al. 2018). Arable/cropland is defined as intensively managed farmland used for crop production, ploughed at least one time in the season and usually fertilised.

The grassland classes alone do not account for the spatial dimension of ES. As pointed out by Walz et al. (2017), Service Providing Areas (SPAs) constitute the best way to spatially capture the complex ecological systems that underlie the delivery of ES. Service Providing Areas can be defined as spatially delineated units that encompass entire ecosystems, their integral populations and the underlying natural capital attributes. The unit used to define SPAs and map the potential delivery of grassland ES was the "basic agro-ecological unit" or field, which comprises the grasslands spatial configuration and boundaries. The basic agro-ecological unit is the smallest relevant unit to apply a management decision, defined as a continuous area with identical land-use.

The national Integrated Administration and Control Systems (IACS) were selected as the source of information for grassland management regime and map's basic spatial unit or SPAs. IACS databases are the most important system for the management and control of payments to farmers in the EU and contain a system for the identification of all agricultural parcels and their management regime. IACS have the same structure throughout EU, consequently simplifying the process of data integration within a transnational basemap.

Each of the above-mentioned factors is represented by one spatial layer and were combined in a GIS environment through map algebra and GIS processing operations. Fig. 1 shows the classification of input variables and the data sources. As a result of this process, 30 grassland classes were obtained (Fig. 2). Additionally, 10 arable land classes and 10 abandoned land classes were included in order to allow for the assessment of different LULC change scenarios. The SPAs generated in this process were used in the assessment of *provisioning* and *regulating and maintenance* ES. In the case of cultural ES, the evaluation does not follow the grasslands classification and the SPAs are solely defined based on the spatial configuration and boundaries of the grassland parcels.

	Provisioning					Regulation & Maintenance							
Grassland classes	Cultivated crops	Reared animals and their outputs	Fodder	Biomass-based energy sources	Herbs for medicine	Bio-remediation by micro-organisms, plants and animals	Filtration/storage/accumulation by ecosystems	Control of (water) erosion rates	Pollination and seed dispersal	Maintaining habitats for plant and animal nursery and reproduction	Weathering processes/soil fertility	Chemical condition of freshwaters	Global climate regulation
21. Semi-natural grassland on plain relief, low soil fertility	0	1	1	1	5	4	2	0	5	5	2	3	4
22. Semi-natural grassland on plain relief, medium soil fertilty	0	2	2	2	4	5	3	0	5	4	3	4	4
23. Semi-natural grassland on plain relief, high soil fertility	0	3	3	3	3	5	4	0	5	3	4	5	4
24. Semi-natural grassland on plain relief, organic soils	0	3	3	3	4	5	4	0	5	4	0	3	5
25. Semi-natural grassland on gentle slope, low soil fertility	0	1	1	1	5	4	2	4	5	5	2	3	4
26. Semi-natural grassland on gentle slope, medium soil fertilty	0	2	2	2	4	5	3	4	5	4	3	4	4
27. Semi-natural grassland on gentle slope, high soil fertilty	0	3	3	3	3	5	4	4	5	3	4	5	4
28. Semi-natural grassland on gentle slope, organic soils	0	3	3	3	4	5	4	0	5	4	0	3	5
29. Semi-natural grassland on steep slope , low soil fertility	0	1	1	1	5	4	2	5	5	5	2	3	4
30. Semi-natural grassland on steep slope , medium soil fertility	0	2	2	2	4	5	3	5	5	4	2	4	4

Figure 2.

Extract of the expert-based scores matrix including grassland classes 21 to 30, corresponding to semi-natural grasslands. A total of 30 grassland classes plus 10 arable land classes were evaluated. The full version of the expert-based scores matrix is included as a supplementary file (Suppl. material 1).

The tiered approach

One of the main aims of the Viva Grass project is offering integrated, ecosystem-based planning solutions based on economically viable grassland management scenarios. Additionally, the implementation of economically viable grassland management models targets areas of different natural and socio-economic contexts. Given the spatially explicit nature of the processes being addressed in the project, there is a need to establish links between spatial data on ES, agricultural, natural and socio-economic contexts in order to achieve the above-mentioned goals. The multi-scale nature of Viva Grass case studies, as well as the differences in data availability and spatial and thematic scales across the three Baltic States, require a consistent but flexible approach. As it has been pointed by Dunford et al. (2017), individual ecosystem service tools rarely meet the needs of multi-stakeholder processes and the complexity of land management scenarios. A structured combination of tools and methods offers the flexibility required to meet a wide range of needs. In order to ensure methodological adaptability and overcome the aforementioned problems, the structure of the Viva Grass tool follows the framework of the tiered approach. In a multi-tier system, each consecutive tier entails an increase in data requirements, methodological complexity or both (Grêt-Regamey et al. 2015). In the framework developed within Viva Grass, the tiers are not only defined by the methods used within each tier, but also by the policy questions to be answered by each tier (Fig. 3).

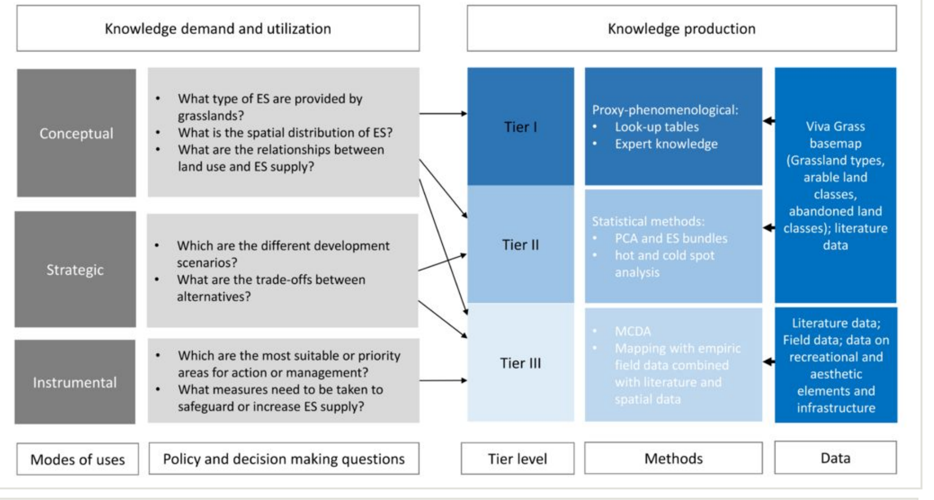

Figure 3.

The tiered approach for grassland ES mapping and assessment in the Baltic States.

Policy- and decision-makers face different challenges, thus their demand for knowledge on ES varies depending on their specific management needs (Dick et al. 2017). In Viva Grass, regular contacts and engagement with stakeholders in designing the tool brought up a range of issues that can be grouped as proposed by several authors studying the use of ES information and knowledge in decision-making (Klein et al. 2015; McKenzie et al. 2014; Wright et al. 2017). For many local, regional and sectoral stakeholders, the concept of ES is still new, therefore the tool provides *conceptual* information on ES that helps to understand the ES approach, the spatial distribution of ES and the links between land use and ES supply. The tool also aims at supporting *strategic* planning by evaluating trade-offs between different development alternatives or scenarios, therefore helping users in identifying new types of policies and policy options based on the ES approach. Finally, the tool aims at answering an *instrumental* group of questions, e.g. setting priorities or spatially identifying the most suitable management measures for sustainability of grasslands.

Tier 1

At tier 1, the potential supply of grassland ES is assessed through the matrix approach based on multiple datasets.This type of tools often uses landuse or landcover data to map ES supply and demand (Burkhard et al. 2010). The information contained in LULC maps is generally combined or "enriched" with vegetation and habitat maps in order to obtain a more precise definition of SPAs. As outlined in the previous section, the grassland classes used in the Viva Grass ES matrix are the result of the combination of several datasets. The SPAs obtained in the process constitute the basis for the ES matrix evaluation, but also allow for a spatial representation of the ES matrix scores. The level of detail of the grassland classes reflects a deeper biophysical complexity than the national LULC maps. Complex grassland classes provide experts with a proxy-phenomenological model to score the supply of ES. Phenomenological models include an additional understanding of the underlying biophysical variables that underpin ecosystem functions (Dunford et al. 2017). Ultimately, proxy-phenomenological models lead to a better understanding and quantification of more intangible ES, specifically those under the *regulation and maintenance* category. Previous studies have used the matrix approach to assess ES supply and vulnerability in combination with scenario-based assessments in alpine grasslands and agro-sylvo-pastoral systems (Dechazal et al. 2008). Lavorel et al. (2010) also used a matrix-based approach to link ecosystem properties to ES in a subalpine grassland landscape based on stakeholders perceptions and expert opinions. The impacts of nature conservation on the delivery of ES in river, coastal and chalk grasslands were assessed by Eastwood et al. (2016) using expert ranks.

Within Viva Grass, the tiered approach with expert-based scores was used exclusively to assess the supply of ES belonging to the *provisioning* and *regulating and maintenance* categories (CICES 2015). This is due to the fact that cultural ES were not directly linked to grassland classes. Instead, cultural ES were assessed based on SPAs and on the context of each grassland's surrounding landscape and its features.

Five experts per country (Estonia, Latvia and Lithuania) were selected for the grassland ES supply valuation. The selection was based on the experts' knowledge of grassland ecology, agricultural management, agri-environmental policy and the study areas. The valuation of ES potential supply was structured as a three-step process: in the first step, the international experts panel selected a relevant set of ES provided by grasslands and one indicator per ES. The selection of ES was based on the experts' knowledge on grasslands' ecosystem and recent literature (Bullock et al. 2011; Frélichová et al. 2014; Lamarque et al. 2011). In the second step, experts individually scored the provision of ES by the grassland classes whereas in the third step, experts came to an agreement on the ES supply values in a series of focus group discussions (FGDs). In the second step, respondents were asked to score the potential provision of ES based on a qualitative scale ranging from 0 (no relevant supply of the selected ES) to 5 (very high supply of the selected ES). In order to ease the process, individual matrices were provided instead of the aggregated final ES matrix. In each individual matrix, only one ecosystem service is represented, reducing this way the amount of information experts handle in their first ES assessment. The third step consisted of several rounds of FGDs in which each expert contrasted his answers with the rest of the group and had the opportunity to re-score the ES. This iterative process helps achieve a certain degree of stabilisation of the final scores (Jacobs et al. 2015). The FGDs ultimately aim at obtaining one single score per ecosystem service through a consensus-building process. Additionally, FGDs help incorporate different forms of knowledge and expertise into the ES assessment process. It is important to note that the experts were asked to value only the potential provision of ES instead of the realised flow. In semi-natural systems, influenced by human management actions, it is necessary to distinguish between ES potential and actual ES flow. Provisioning ES may show large differences between potential supply and actual flow, depending on management strategies and policy frameworks. The matrix, provided to the experts for the valuation, included not only the grassland types and ES, but also one biophysical indicator per ecosystem service (Table 1). Biophysical indicators were included in order to help build a common understanding of the ES under assessment.

Table 1.

ES indicators and factors determining ES potential. The list of indicators was provided in order to build a common understanding of the ES under assessment.

**in case of drained soils the value shall be lowered by 1 unit*.

Ecosystem service	**Indicator**	**Factors determining ES potential**
Provisioning services		
Cultivated crops	yield (t/ha per year)	Only arable land + soil fertility
Reared animals and their outputs	Number of Livestock Unit (LU/ha)	Land use + soil fertility
Fodder	dry weight of grass biomass	Land use + soil fertility
Biomass-based energy sources	dry weight of grass biomass	Land use + soil fertility
Herbs for medicine	Number of species and abundance	Land use + soil fertility
Regulating services		
Bio-remediation	-	Land use + soil fertility
Filtration/storage/ accumulation	Soil capacity to store/accumulate nutrients (Kg ha-1) *	Land use + soil fertility
Control of (water) erosion rates	Amount of soil retained (kg/ha per year)	Land use + soil fertility + relief
Pollination and seed dispersal	Diversity and occurrence of insects- pollinators (number of species and number of individuals/ha)	Land use
Maintaining habitats	Number of species per 1 m2 (except invasive species)	Land use + soil fertility
Weathering processes/ soil fertility	Nutrients available for plant uptake by most important soil texture classes	Land use + soil fertility + relief

Ecosystem service	**Indicator**	**Factors determining ES potential**
Chemical condition of freshwaters	Absorption of nutrients	Land use + soil fertility
Global climate regulation	Carbon sequestration in vegetation and soils	Land use + soil fertility

Tier 2

The qualitative nature of expert-based assessments is not an obstacle for deeper, statistics-based analysis. The data collected in the first tier was further enhanced through a Principal Components Analysis (PCA) in order to explore ES bundles in tier 2. Focusing on single ES in mapping and assessment processes may lead to an unbalanced use or overexploitation of ecosystems (Ingram et al. 2012; Raudsepp-Hearne et al. 2010). Bundles analysis offer a deeper understanding of how ES are associated across heterogeneous landscapes (Spake et al. 2017) and the underlying drivers of such associations. The characterisation of ES bundles is especially relevant when it is used as a tool to evaluate the impacts of management decisions and policies. An analysis of bundles of grassland ES was carried out on the basis of the expert-based assessment matrix produced in the previous step. However, cultural ES were excluded from this analysis due to differences in the evaluation methodology.

A **Principal Components Analysis** was carried out using the qualitative scores for grassland plots (observations) and ES (variables) based on the matrix as input data.

Cultural ecosystem services

Tier 2 also includes the assessment of cultural ES. The nature of cultural ecosystem services provided by grasslands is context-specific and the factors that determine the provision of this set of services often show local-scale differences. In this regard, experts knowledge may not fully account for the local landscape attributes related to cultural ecosystem services. Consequently, the Viva Grass methodology evaluates cultural ES in the context of each grassland's surrounding landscape and its features. This approach has been identified by van Zanten et al. (2016) as attribute-based, using regionally relevant landscape features that are commonly identified in public preference studies. Therefore, cultural ES are not included in the ES matrix valuation method and they are evaluated separately.

The selection of evaluation criteria for *aesthetic value* and *cultural heritage* was undertaken based on the assessment of preferences for agricultural landscapes by van Zanten et al. (2014), van Zanten et al. (2016) and van Berkel and Verburg (2014) and the review on environmental heterogeneity by Dronova 2017. The landscape features used to measure each cultural ES, along with their buffering distances, are shown in Table 2. For each ES, a composite indicator is calculated by aggregating landscape features based on presence/absence criteria. A landscape feature is included in the aggregation if a particular grassland plot falls within the buffering distance of that specific feature. The results of the aggregation are then re-scaled to a zero-to-five qualitative scale. Similarly, *physical and experiential interactions* and *educational value* were analysed based on the presence of recreation and education-related elements, which are aggregated and re-scaled into a composite indicator. Fig. 4 shows the supply potential of four cultural ES in Vaive parish, within the pilot area of Cēsis Municipality (Latvia).

Table 2.

List of cultural ES and their evaluation criteria.

Ecosystem services	Landscape features	Buffering distance
1. Physical and experiential interactions (recreational)	Rural recreational enterprises	3 km
	Watching towers	300 m
	Tourist trails	100 m
	Area of hunting clubs	0 m
	Camping sites	300 m
	Social gathering sites	300 m
2. Educational	Educational trails	100 m
	Educational sites	100 m
3. Cultural heritage	Monuments	100 m
	Farmsteads before and in 19th century	100 m
	Traditional land use (Wooded meadow)	300 m
4. Aesthetics	Water bodies, streams	300 m
	Naturalness of surroundings	100 m
	Naturalness of grassland itself	from attributes of base map
	Linear elements	300 m / from 1:10000 map hedgerows, stone walls.
	Relief	STD of topography=10 as threshold in 5x5 km cells
	Openness	country specific density of forest in 5x5 km

Tier 3

The nature of the analyses carried on the third tier are driven by the policy questions addressed. Similarly, the variables used are directly related to the questions and stakeholders targeted at this level of the multitier framework (see Fig. 3). At the third tier, the SPAs are further enriched with additional information (e.g. annex I habitat type and conservation status). Depending on the policy question being targeted, other sources of data are used, such as the risk of abandonment, grass bioenergy potential or risk of giant hogweed invasion. The results obtained in Tiers 1 and 2 are combined with additional data through Multi-Criteria Decision Analysis.

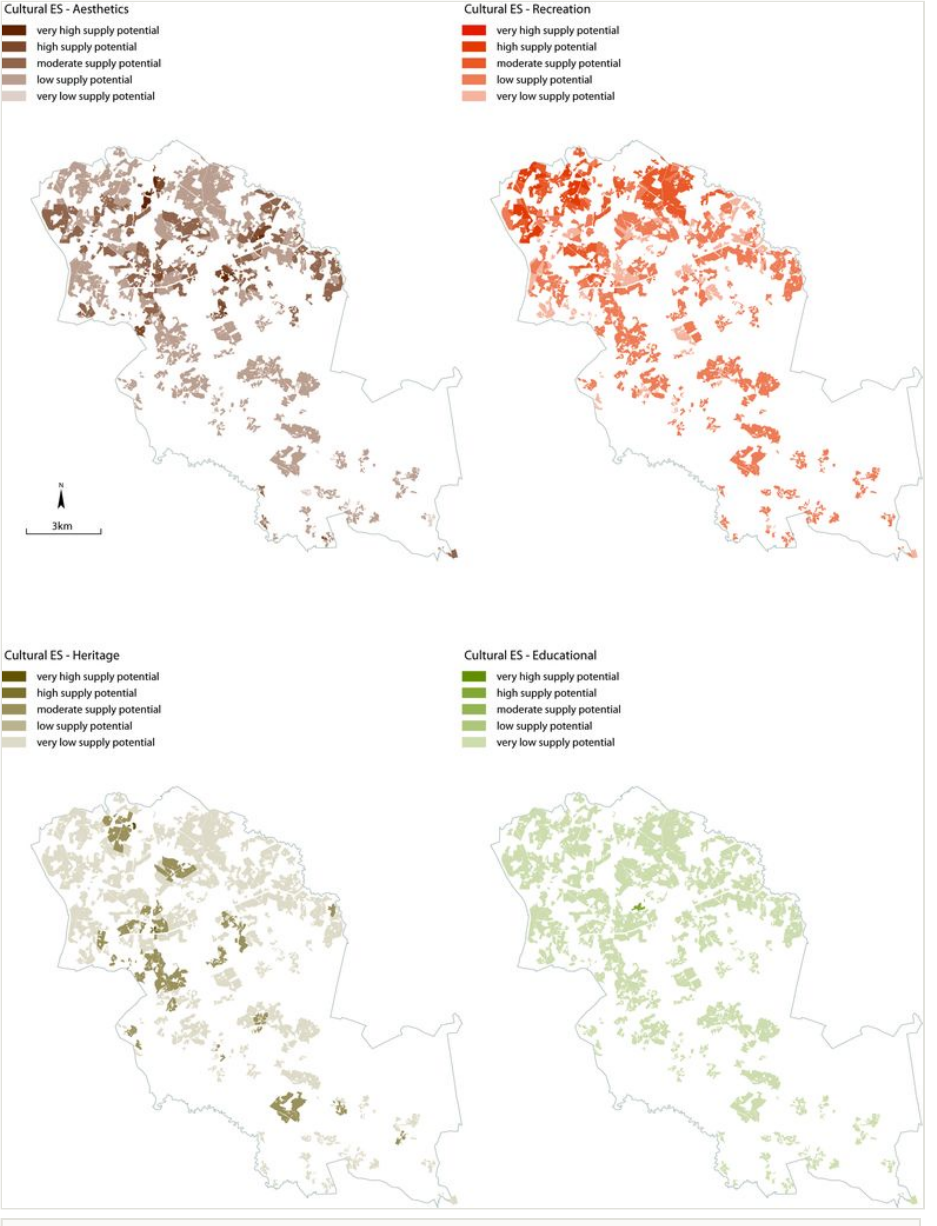

Figure 4.

Supply potential of four cultural ES in Vaive parish, Cēsis municipality (Latvia).

Multi-Criteria Decision Analysis (MCDA) has been described as a framework that assists decision-making processes with multiple objectives and stakeholders, taking into consideration multiple criteria (Belton and Stewart 2002). Koschke et al. (2012) highlight the application-orientated facet of MCDA and its ability to integrate different sources of data. Other ES assessment tools and methodologies may be too scientifically focused and fail in providing easily applicable solutions for planning and management. Moreover, the planning or management goals are of a complex nature and cannot be undertaken with a single indicator or dataset. MCDA offers a structured scheme that combines data in a meaningful way. Ideally, a MCDA design should offer a certain degree of flexibility, so that the same target could be tackled with the same tool in different biophysical or socio-economic contexts.

As stated by Esmail and Geneletti (2018), there is no unique approach to MCDA. Instead, several variations exist, which differ from each other in terms of data needs, level of stakeholder involvement or computational complexity. The MCDA development process within Viva Grass is based on the three stages identified by Geneletti and Ferretti (2015). In the first stage, the objectives of the analysis are defined in FGDs between stakeholders and the experts in charge of developing the MCDA. In the second stage, experts identify the relevant analysis criteria and available data. Based on these, weighting scores and aggregation rules are defined and the MCDA constructed. In this second stage, stakeholders are further consulted on the MCDA structure logic and the weights of criteria. In the third stage, the model is run and the outputs are evaluated. Outputs are translated into recommendations, e.g. grassland restoration guidelines. Through this process, the tool users are able to explore different planning alternatives and their outputs in terms of ES supply. These alternatives are constructed based on the choice of evaluation criteria and the definition of weighting scores.

Within the framework of the Viva Grass project, MCDA has been used, not only to evaluate the potential supply of certain ES, but also to spatially locate the demand forsuch services. MCDA models were used to develop three Decision Management Systems (DMSs). Each DMS is constructed based on a distinct MCDA structure and targets one or more specific policy questions. The expert scores obtained in the first tier are used as input data in the MCDA models and further enhanced with the results from the bundles analysis in tier 2 and additional information relevant to the policy question or management problem being addressed. Some of the data used in the MCDA are included as causal relationships, used to link the grassland categories to data collected from literature or national statistics. In other cases, MCDA uses data specific to the particular grassland polygon. All MCDA models are constructed on a GIS-based environment in order to obtain spatially explicit outcomes and to facilitate the integration of results in different local and regional planning processes.

In addition to the methods described above, the online tool allows users to update ES values on specific areas by uploading direct data acquired by field measurements. Primary data can be used to estimate ES stock or flow values but are restricted at the site level. However, if the sampling technique has been designed on the basis of statistical representativeness, primary data can be used as an input to different ES modelling approaches.

Results

The outputs of each tier answer different policy- and decision-making questions (Fig. 3). Moreover, the results of each tier feed into the next tier level as source data.

At tier 1, the outputs of the three-step expert-based assessment were gathered in a grassland ES matrix. Fig. 2 displays the qualitative expert-based scores for 30 grassland classes, 10 arable land classes, 10 abandoned land classes and 13 ES. These scores correspond to the final stage of assessment, at which experts have reached a definitive consensus. The ES scores were subsequently linked to the grasslands classes and represented in the basic map contained in the Viva Grass tool (Fig. 5), where users can consult the spatial distribution of ES supplied by grasslands.

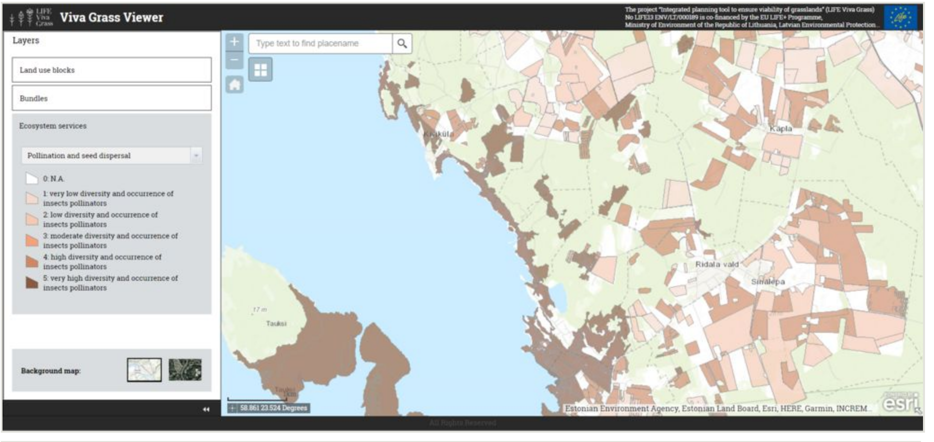

Figure 5.

Interface of the Viva Grass tool viewer. The viewer displays the ES maps corresponding to Tiers 1 and 2.

At tier 2, the PCA revealed 3 main components which correspond to three bundles accounting for 90.53% of the total variance (Table 3). The first component accounts for 48.18% of the total variance and is positively correlated with *herbs for medicine, maintaining habitats, global climate regulation*, pollination *and seed dispersal* and negatively correlated with *reared animals and their outputs*, *fodder* and *biomass based energy sources* . This component represents a trade-off between provisioning ES related with intensified grasslands and ES characteristic of semi-natural habitats. The second component accounts for 28.1% of the total variance in the dataset and is positively correlated with *filtration/storage/accumulation by ecosystems, bio-remediation by micro-organisms* and *chemical condition of fresh waters.* The third component explains 14.25% of the total variance and is positively correlated with *control of erosion rates* and *weathering processes/soil fertility*. The factor loadings in show how the ES bundles, revealed by the PCA, correspond with synergies (following the definitions by Mouchet et al. 2014 and

Spake et al. 2017) due to the high correlation between the ES in the bundle. The bundles are named after the ES they contain.

Table 3.

Factor loadings showing the correlation between the original variables (ES) and the components extracted by the PCA. An ES was retained in a bundle if the factor loading was higher than 0.5.

	Ecosystem Services	**1st Component**	**2nd Component**	**3rd Component**
Provisioning	Reared animals and their outputs	-0.958		
	Fodder	-0.807		
	Biomass-based energy sources	-0.808		
	Herbs for medicine	0.921		
Regulation & Maintenance	Pollination and seed dispersal	0.846		
	Maintaining habitats for plant and animal nursery and reproduction	0.953		
	Global climate regulation	0.726		
	Bio-remediation by micro-organisms, plants and animals		0.839	
	Filtration/storage/accumulation by ecosystems		0.845	
	Chemical condition of freshwaters		0.766	
	Control of (water) erosion rates			0.608
	Weathering processes/soil fertility			0.902

Habitats bundle: Herbs for medicine, maintaining habitats, global climate regulation, pollination and seed dispersal.

Production bundle: Reared animals and their outputs, fodder, biomass based energy sources, cultivated crops.

Soils bundle: Control of erosion rates, chemical condition of fresh waters, bio-remediation, filtration/storage/accumulation by ecosystems and weathering processes-soil fertility. The soils bundle includes both the second and the third component.

Naming the bundles helps communicate relevant information about the effects of different management strategies. In the context of ES, PCA has been used on qualitative matrix-based evaluations by Depellegrin et al. (2016), Nikolaidou et al. (2017) and Zhang et al. (2017) amongst others.

Visualising the spatial configuration of ES bundles is an essential step in order to incorporate the concept into planning processes. A grassland was mapped as belonging to a certain bundle if all ES in the bundle in that particular grassland scored above average (2.5) (Fig. 6). The *production bundle* includes cultivated and permanent grasslands in plains or gentle slopes and fertile soils. Permanent grasslands in low soil fertility and all semi-natural grasslands, regardless of the soils type, are included in the *habitats bundle*. The soils bundle includes all grasslands in medium and high fertility soils and organic soils. The ES bundles revealed with this method are not mutually exclusive and overlaps may occur.

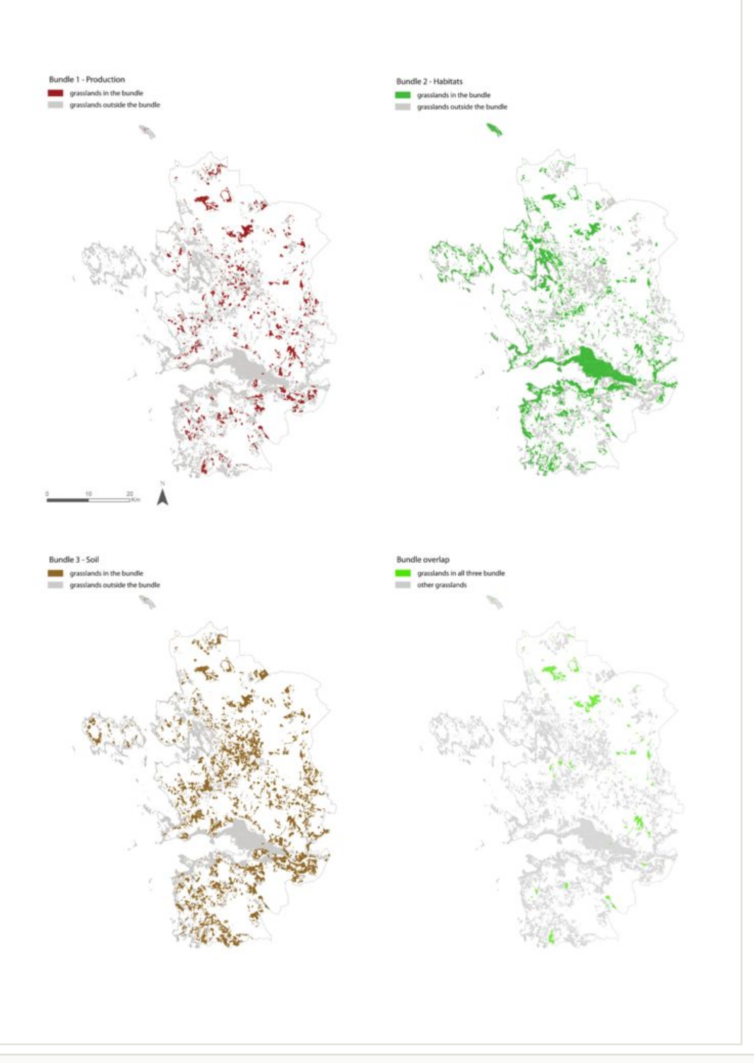

Figure 6.

Grassland ES bundles in a Viva Grass pilot area: Lääne County (West Estonia).

Two examples are provided for the results of tier 3. As part of the Viva Grass tool, the MCDA approach has been used in Estonia to guide local and regional planners in the implementation of the Green Network. The Green Network of Estonia complements the network of protected areas, combining them with natural and semi-natural areas into a coherent network at various geographical levels (Raet et al. 2010). Semi-natural grasslands, amongst other ecosystems, are one of the key components of the green network. The Green Network acts as guidance for the development of general and comprehensive plans, in order to ensure ecological coherence and connectivity throughout the country. One of the MCDA modules developed helps planners define Green Network corridors and core areas, as well as detect conflict between conservation and urban development priorities by combining grassland ES expert scores and ES synergies maps together with data on habitats conservation status, biodiversity, current spatial plans and transportation network data.

In one of the Latvian case study areas, the Viva Grass Integrated Planning tool was tested to support the landscape management planning at the municipality level. The MCDA approach was applied to prioritise sites for landscape maintenance or restoration measures. The criteria for prioritisation included the value of the four cultural services (recreational, educational, cultural heritage and aesthetic) as well as ecological value (based on the habitats bundle – herbs for medicine, maintaining habitats, global climate regulation, pollination and seed dispersal). A local stakeholder group was involved in the weighting of the selected five criteria. The results of the prioritisation were used to determine site specific management measures for maintenance or improvement of landscape quality, which can serve as input to the municipality land-use policy documents.

Discussion

In recent years, several authors have undertaken the analysis of grasslands' value and multi-functionality from the ES perspective (Bullock et al. 2011), addressing a wide variety of scales, from regional (Maes et al. 2011) to landscape (Lamarque et al. 2011; Tscharntke et al. 2005) and local (Grigulis et al. 2012; Öckinger and Smith 2006). The choice of ES mapping and assessment methodologies used is frequently directly correlated with the scale of study. Biophysical methods based on direct field measurements have been commonly used at the local scale (Kohler et al. 2017) whereas expert-based assessments or spatial proxies based on statistical data have been applied at the landscape or regional scales (Maes et al. 2011). Although there are studies addressing multiple scales assessments of ES (Rabe et al. 2016), very few focus on particular ecosystems or habitat types. The analysis of ES at different spatial scales is, in theory, viable, but there are a number of challenges that must be adequately identified and tackled in order to obtain relevant results. In this regard, matching datasets and methods with the expected level of detail of results is an essential step to achieve efficiency. However, disentangling the complex association of spatial scales, data and methods is a challenging process that may hinder the quality of results.

Data and maps availability has been identified as a main constraint in ES supply and demand assessments (Palomo et al. 2018). This problem becomes more complex when the geographical scope of the analysis encompasses several countries: data varies greatly in terms of content quality and spatial and temporal scales between agencies and institutions. As a consequence, two main processes of the ES analysis are affected: the definition of a basemap containing the SPAs and the evaluation of ES supply and demand. Some studies (Koschke et al. 2012, Larondelle and Haase 2013) have used regional scale maps such as CORINE to overcome the lack of detailed basemaps at the national or local level. However, downscaling regional maps entails high levels of uncertainty that should be accounted for. Considering the loss of quality associated with broad-scale maps, the Viva Grass methodology uses map algebraic tools to combine a number of datasets that correspond to the environmental and management factors that underpin the provision of ES.

The lack of accurate biophysical data also affects the evaluation of ES supply and demand, reducing the choice of available ES mapping and assessment methods. In this regard, expert knowledge has been widely used as a substitute for biophysical methods in data-scarce environments (Jacobs et al. 2015). Although expert-scoring tools provide a fast and efficient way to evaluate the provision and demand of ES, they may show limitations when used as input to more complex ES modelling tools. Within Viva Grass, the expert scoring system used in tier one allows for an assessment of the spatial distribution of ES in the pilot areas. Subsequently, tier 2 encompasses a bundles analysis that helps understand the likely outputs of grassland management options. However, the output of the matrix approach lacks the detail needed when addressing some of the specific grassland management issues. In this regard, the tiered approach used in the Viva Grass project offers the flexibility required to match the complexity of methods with the accuracy of outputs driven by management and policy questions. Ascribing variables and datasets to different tier levels, depending on the level of detail required, increases the overall efficiency of the ES mapping and assessment process. Regarding the level of acceptance of the expert-based evaluation by stakeholders, a transparent communication of the evaluation process ensures that methodologies are credible and trusted. Within the Viva Grass project, clear communication through regular national discussion round-tables contributed to the acceptance of the proposed methodologies by stakeholders.

In the cases when data was available, MCDA models were developed and integrated into tier 3 in order to answer specific grassland-related policy questions. The MCDA models, developed in Viva Grass, use the results of the matrix model as input data, which is later enhanced with supplementary data. However, there are some risks associated with the use of MCDA. Stirling 2006 claims that in MCDA processes, the decisions about data, criteria and weightings used are taken by a small group of experts, therefore limiting public discussion. This may, in turn, overlook the collective character of ES. Amongst the methods proposed to overcome this risk, deliberative multi-criteria evaluation (DMCE) has been used to incorporate a broader community understanding (Mavrommati et al. 2017). DMCE uses processes of dialogue and deliberation in order to achieve a common understanding on ecosystem services and related scenarios. DMCE methods have previously been integrated into MCDA frameworks in order to enhance community involvement and knowledge building (Mavrommati et al. 2017; Proctor and Drechsler 2006). However, the resources required to set the appropriate framework for DMCE may hinder the overall performance of MCDA, especially in time-constrained projects.

Regarding cultural ES, the aesthetic and recreational values are often regionally specific, depending upon the preferences stated by population (van Zanten et al. 2016). It is therefore recommended to assess aesthetic and recreational preferences based on local or regional perception whenever feasible. Cultural ES still present methodological challenges, despite the wide array of methods available (Gosal et al. 2018; Hermes et al. 2018). Linking cultural ES with ecological functions would not account for the perceptual and non-material nature of these services (Stålhammar and Pedersen 2017) and therefore a separate set of methodologies is needed. This, in turn, presents an obstacle when a wide set of cultural, provisioning and regulating ES is considered for analysis. In this regard, consolidating methodologies and results into meaningful and applicable outputs requires frameworks providing a high degree of integration of knowledge systems. On this subject, the H2020 project ESMERALDA has compiled a flexible methodology, including a "method finder" online tool (Santos-Martin et al. 2018) and a conceptual framework for integrated ecosystem assessment (Brown et al., in this volume).

Conclusions

The methodology developed within Viva Grass represents a cost-efficient and flexible way of evaluating the supply of grasslands ES at different spatial scales, in different regional contexts, addressing a wide range of grassland-related management, planning and policy issues. The multi-tier structure of the Viva Grass tool allows users to select the method that best adapts to their knowledge demands. In this regard, the conservation of grasslands in the Baltic States is influenced by different sectoral policies and strategies. It is therefore essential to develop tools that are able to target a wide range of stakeholders. The Viva Grass methodology puts the ES framework into practice through a set of interrelated tools. Using expert-based scores and the Viva Grass basemap, users are able to assess the spatial distribution of grassland ES and the relations between landuse and ES supply. At a strategic and planning level, ES bundles analysis allows evaluating grassland development scenarios. Finally, users can employ a set of MCDA tools to spatially locate the most suitable grasslands for action or management and prioritise measures to safeguard or increase the supply of ES.

The transition of the ES framework from the academic sphere into practical planning applications is expected to grow in the upcoming years, therefore similar tools will be needed to bridge the gap between science, policy and practice. However, methodologies, tools, data and maps alone are not sufficient for a successful implementation of the ES framework (Rosenthal et al. 2014). Regular stakeholder engagement and capacity building throughout the process of methodology design, evaluation and implementation is essential for successful assimilation of the ES concept into policy and management.

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Supplementary material

Suppl. material 1: Expert-based scores matrix including 30 grassland classes plus 10 arable land classes doi

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