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ECOSYSTEM SERVICE APPROACH FOR LAND USE MANAGEMENT IN AGROECOSYSTEMS IN THE MOSAIC-TYPE LANDSCAPE

Doctoral Thesis

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The doctoral thesis was carried out at the Chair of Physical Geography, Faculty of Geography and Earth Sciences, University of Latvia, from 2013 to 2019.

The thesis consists of the introduction, 2 chapters, conclusion, and reference list.
Form of the thesis: collection of articles/research papers in physical geography, regional and environmental geography

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The defense of doctoral thesis will be held on June 17, 2020 at 13:00 in a public session of the Doctoral Committee at the Faculty of Geography and Earth Sciences of the University of Latvia, Jelgavas iela 1, Riga.

The thesis is available at the Library of the University of Latvia, Raiņa bulvāris 19, Riga, Latvia.

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ANNOTATION

The thesis consists of a consecutive set of research articles aimed at developing a multi-criteria decision support system for the improvement of land use management in agroecosystems in mosaic-type landscapes. The autologistic binary regression model for the assessment of the driving forces of land use change in mosaic-type landscape in Vidzeme uplands was developed within the framework of research. The results showed that land quality, distance to farms, distance to paved roads and distance to forest edges were the main factors underlying land use change. The method for ecosystem service assessment and mapping in agroecosystems was developed for the area of study and approbated in Baltic states. The interaction analysis was performed to identify trade-offs and synergies among ecosystem services and to reveal "cold/hot" spots of ecosystem service supply. The achieved results were incorporated into a multi-criteria decision support tool for the integral planning of rural landscapes and improvement of land management. The multi-criteria decision support tool was tested for prioritisation of land use management in Cēsis municipality. The results of the thesis can be employed for analysing agricultural policies, territorial planning and the modelling of land use change and management.

LIST OF ABBREVIATIONS

ABR – autologistic binary regression

ALU – agricultural land use

ES – ecosystem services

IACS – integrated administration and control system

MCDS – multi-criteria decision support

CONTENTS

INTRODUCTION

Land use has changed almost 75 % of the ice-free Earth surface (Ellis and Ramankutty 2008). Land use affects alterations in landscape structure, functions and ecosystem service supply. Global demand for food and bioenergy will continue to rise (Schneider et al. 2011), thus exposing agricultural land to further intensification (Tilman et al. 2011). The opposite process of intensification is marginalization, which can be found in geographical locations less suitable for intensive agriculture, leading to landscape polarization. The aforementioned process is present both on continental and national scales. In the south and east of Europe, the abandonment and subsequent afforestation of agricultural land is more evident, whereas the agricultural intensification is more present in western and northern Europe (Rienks et al. 2008). On a national scale, i.e. in Latvia's fertile soil regions, all farmland is returned to agricultural use, but in unfavourable agro-ecological conditions the farmland abandonment and natural, or deliberate, afforestation takes place (Nikodemus et al. 2005; Nikodemus et al. 2010; Vanwambeke et al. 2012; Vinogradovs et al. 2018).

In order to understand the ongoing changes in ecosystems and society, it is essential to use a composite approach to landscape research – to study the relationships of humans and their environment in the landscape, landscape structure and land use intensity, as well as landscape history, values, meaning and management (Plieninger et al. 2015).

Topicality of the study

Agricultural land use is the greatest human impact on the environment (Balmford et al. 2012). It discloses a loss of ecosystem and biological variety (Newbold et al. 2015), increased greenhouse gas emissions and changes in nitrogen and phosphorus cycles (Burney et al. 2010), which, in turn, lead to increased eutrophication of inland waters and the sea. Both intensification and marginalisation of agriculture lead to the homogenisation of the landscape – the simplification of the landscape structure and the consequent reduction in the availability of suitable habitats – the loss of diversity for small landscape elements and land use types in heavily managed areas (Nikodemus et al. 2018), natural and/or deliberate afforestation of agricultural lands in marginal locations (Nikodemus et al. 2005; Vinogradovs et al. 2018). The mosaic-type landscape, whose spatial structure is defined by very complex agroecological conditions, particulary those exposed to the marginalisation and homogenisation processes.

The solution to management of these processes, which would ensure sustainable land use, is targeted land management. The EU's Common Agricultural Policy (CAP) guidelines on the environment (European Commission 2019) set the main objectives of ensuring sustainable land management by eliminating agricultural activity that is harmful to the environment and stimulating the production of environmentally friendly goods and services. The agri-environmental schemes developed under the CAP directly aim at reducing the environmental impacts of agricultural activities, such as the loss of habitats and biodiversity, major landscape transformation and reduction of pollution caused by fertilizers and pesticides. The effectiveness of these measures is observed in the areas where they deliver more benefits (Betary et al. 2015). One of the solutions for achieving these objectives is the introduction of the concept of ecosystem services in land policy and management (Van Zanten et al. 2014).

The ecosystem service approach is often implemented under land management, particularly in land use policy, spatial planning and environmental impact assessment (Rozas-Vásquez et al. 2019), as it is able to ensure a holistic pretext while providing the necessary basic information on the state and quality of the environment, the functioning of ecosystems and the potential of these functions, taking into account the economic interests of society (Hansen et al. 2014).

There are a number of approaches to the assessment (evaluation and mapping) of the ES: biophysical assessment methods are based on the assessment of biotic and abiotic factors determining the structures or functions of the ecosystems (Burkhard and Maes 2017), methods of economic assessment when the benefit of society is calculated in monetary terms (Farber et al. 2012) and social assessment methods when EP values are obtained by social anthropological methods (Plieninger et al. 2013). As a part of the thesis, a novel biophysical assessment method was developed to evaluate ES in agroecosystems, based on the criteria of land quality, soil texture, as well as terrain and farming intensity. The method is effectively applied in the Baltic states because it is based on data layers available in the countries: digital maps of soils and land assessment, terrain models and integrated administration and control system (IACS) data, which cover the whole area equally.

For land management, it is important to provide a framework where the decision-makers – politicians, municipal officials, landowners and land managers – are able to assess the impact of the type of agricultural use of land and its change on the provided ES, as well as to anticipate the security of ES supply in the future. There are many systems for integrating the ES into spatial planning (Grêt-Regamey et al. 2017), however, none of them have been adapted for the assessment of ES supply and land management in agroecosystems. They are based on either limited data (e.g. ground cover only (Dailey et al. 2009), or complex output data (Grêt-Regamey et al. 2017) and they often require specific knowledge and skills (Bagstad et al. 2011; Jackson et al. 2013; Fürst et al. 2010; Peh et al. 2013; Pickard et al. 2015). Therefore, their availability to the general public is not ensured and their application would not be effective, since the existing national geographic databases could not be used for ES assessment. The integrated planning tool developed by *LIFE Viva Grass* project, in which the author has taken active involvement is presented in the thesis.

Scientific novelty

The thesis consists of three parts containing the following innovative elements:

1. Assessment of drivers or land use change in mosaic-type landscape:
   a) an extensive geospatial data collection has been carried out using remote sensing, geospatial analysis and field survey methods;
   b) development and approbation of method to employ autologistic binary regression (ABR) into modelling agricultural land use abandonment in mosaic-type landscape;
2. Assessment and mapping of ecosystem services in agroecosystems:
   a) development of novel ES assessment method based on land quality, soil texture, terrain and IACS data and based on existing national geospatial data sets; the method is applicable in the Baltic states;
   b) statistical analysis of interaction among ES to reveal spatial bundles, trade-offs and synergies – crucial to operationalize ES into land use management and planning;
3. Developing an underlying set of algorithms for multi-criteria decision support and integrated planning tool – the *Viva Grass Tool*:
   a) development cartographic representation of ES supply potential and interaction values;
   b) integration of drivers of land use change, ES supply potential and ES interaction values into weighted sum models of integrated planning tool's decision support systems;
   c) approbation of integrated planning system in mosaic-type landscape.

Hypothesis of the thesis

A multi-criteria decision-making support tool based on the ecosystem services approach is applicable to land use management and planning, thereby ensuring the sustainability of agroecosystems systems.

Aim of the thesis

Developing and approbating ecosystem service approach for land management in agroecosystems in mosaic-type landscapes.

Tasks of the thesis

1. Create a geospatial database to assess the drivers of landscape change and ES.
2. Develop ABR model to detect probability of ALU abandonment in mosaic-type landscapes.
3. Develop method for ES assessment in agroecosystems in mosaic-type landscapes.
4. Allocate ES bundles, trade-offs and synergies by statistical analysis of the matrix of ES assessment values.
5. Develop cartographic solutions to represent ES and interaction values for integrated planning support tool.
6. Integrate ES, interaction and driving force of land use change values into weighted sum models.

Publications

The thesis is arranged into three consecutive articles that implement the tasks of the thesis. Tasks are grouped into four task-groups that overlap thematically, but do not duplicate (Fig. 1). Publications have been published or accepted for publication in internationally listed journals during the last 2 years (2018–2019).

Paper I. **Vinogradovs, I.,** Nikodemus, O., Elferts, D., & Brūmelis, G. (2018). Assessment of site-specific drivers of farmland abandonment in mosaic-type landscapes: A case study in Vidzeme, Latvia. *Agriculture, Ecosystems & Environment*, 253, 113–121, (listed in *Web of Science* and *Scopus*).

The article describes the methodology for identifying and evaluating the drivers of landscape change in the mosaic-type landscape. The methodology sets out methods for obtaining, processing, statistical analysis and modelling spatial data of land use change, as well as interpretation of the results. As a part of the publication, the author of the thesis has developed a method for collecting geospatial data, conducted field surveys and data verification, co-operated in the development of ABR model and performed interpretation of the results.

Paper II. Villoslada, M., **Vinogradovs, I.**, Ruskule, A., Veidemane, K., Nikodemus, O., Kasparinskis, R., Sepp, K., Gulbinas, J. (2018). A multitiered approach for grassland ecosystem services mapping and assessment: The *Viva Grass Tool*. *One Ecosystem*, 3, e25380, (listed in *Scopus*).

The article discloses the development of methodology to assess ES based on the assessment of the land quality, soil, slope and land use data. The publication provides a statistical analysis of the interaction among ES. The developed methodology is the result of team work. The author's contribution is a statistical analysis of the interaction of the ES, as well as participation in the preparation and publication of the article.

Paper III. **Vinogradovs, I.**, Nikodemus, O., Villoslada, M., Ruskule, A., Veidemane, K., Gulbinas, J., Morkvenas, Ž., Kasparinskis, R., Sepp, K., Järv, H., Kliimask, J., Zariņa, A., Brūmelis, G. (accepted for publication) Integrating ecosystem services into decision support for management of agroecosystems: *Viva Grass Tool*. *One Ecosystem* (listed in *Scopus*).

The article describes the workflow for creating architecture for the multi-criteria decision support tool and describes the integration of ES values and ES interaction values into weighted-sum models into the integrated planning tool – *Viva Grass Tool*. The development of the integrated planning tool is the team work, in which the author was addressing the issue of cartographic representations and integration of ES values and land use change drivers into multi-criteria decision analysis and support modules.

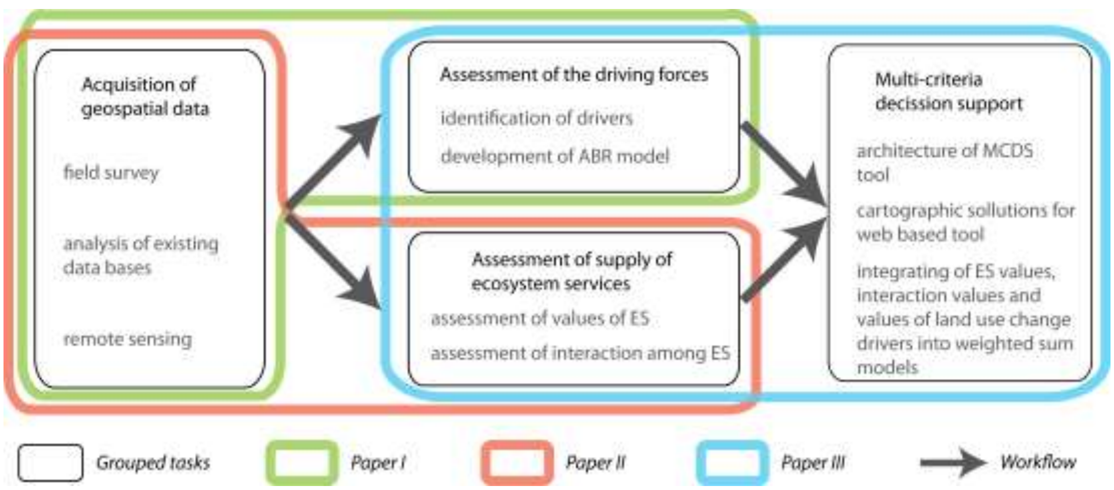

Figure 1. Workflow and tasks of the thesis

Related articles

Vinogradovs, I., Nikodemus, O., Tabors, G., Krūze, I., Elferts, D. (2016). Assessment of factors of landscape change in mosaic-type landscape: a case study of Vidzeme, Latvia. *Environmental protection engineering (N 19),* pp. 212–217.

Nikodemus, O., Penēze, Z., **Vinogradovs, I.**, Rendenieks, Z. (2018). Zemes izmantošanas izmaiņas un to ainavekoloģiskais vērtējums. Nikodemus, O., Kļaviņš, M., Krišjāne, Z., Zelčs, V. (zin. red.) Latvija. Zeme, daba, tauta, valsts. Rīga, LU Akadēmiskais apgāds, 604.-615.

Vološina, M., Zariņa, A., Nikodemus, O., **Vinogradovs, I.** (2018). Landscape planning as an asset for regional development. In: *Economic Science for Rural Development Conference Proceedings* (No. 48).

The guidebook on the introduction of ecosystem service framework in integrated planning. Kasparinskis, R., Ruskule, A., **Vinogradovs, I.**, Villoslada, M. (2018). Riga, University of Latvia, Faculty of Geography and Earth Sciences, p. 63.

Ušča, M., **Vinogradovs, I**., Reķe, A., Immurs, D. V., & Zariņa, A. (2019). Assessment of Ecosystem Services for Planning of Green Infrastructure at the Regional Level. In *Proceedings of the 12th International Scientific and Practical Conference. Volume I* (Vol. 315, p. 319), (listed in *Scopus*).

Zariņa, A., **Vinogradovs, I.**, & Šķiņķis, P. (2018). Towards (dis) continuity of agricultural wetlands: Latvia's polder landscapes after Soviet productivism. *Landscape research*, 43(3), pp. 455–469, (listed in *Scopus*).

Selected conference proceedings

Vinogradovs, I., Nikodemus, O., Krišjāne, Z. Land use change scenarios in marginal mosaic-type landscapes and their impact on ecosystem services. *IALE World Congress,* 1–5 July 2019, Milan, Italy.

Zariņa, A., **Vinogradovs, I.**, Ruskule, A., Ecosystem services as an integral support tool for green infrastructure and landscape planning: a case of agro-industrial landscapes in Latvia. *IALE World Congress,* 1–5 July 2019, Milan, Italy.

Ruskule, A., **Vinogradovs, I.**, Veidemane, K., Prožavoite, D., Nikodemus, O., Villoslada, M., Ādamsone, I. Applying ecosystem service approach and stakeholder engagement in landscape planning: LIFE Viva Grass example. *ESP Europe,* 15–19 September 2018, San Sebastian, Spain.

Vinogradovs, I., Nikodemus, O., Elferts, D., Brūmelis, G. Assessment of site-specific agro-ecological and location drivers of farmland abandonment in mosaic-type landscape: case study of Vidzeme, Latvia. *IALE Europe,* 12–15 September 2017, Ghent, Belgium.

Zariņa, A., **Vinogradovs, I.** Landscapes of agricultural appearance: non-productivist practices in Latvia's marginal farmlands. *IALE Europe,* 12–15 September 2017, Ghent, Belgium.

Ruskule, A., Morkvenas, Ž., Gulbinas, J., Kuris, M., Remmelgas, L., Indriksone, D., Veidemane, K., **Vinogradovs, I.**, Villoslada, M. Accommodating the ecosystem service concept for enhancing grassland viability in the Baltic states: the LIFE Viva Grass approach. *IALE Europe,* 12–15 September 2017, Ghent, Belgium.

Vinogradovs, I., Villoslada, M., Gulbinas, J., Ruskule, A., Sepp, K., Kasparinskis, R., Nikodemus, O. Mapping and identifying grassland ecosystem services and their trade-offs: study from Baltic states. *14th Eurasian Grassland Conference,* 4–8 July 2017, Riga, Latvia.

Vinogradovs, I., Nikodemus, O., Tabors, G., Krūze, I., Elferts, D. Assessment of factors of landscape change in mosaic-type landscape: a case study of Vidzeme, Latvia. *19th*

Conference for Junior Researchers "Science – Future of Lithuania", 6 May 2016, Vilnius, Lithuania.

Vinogradovs, I., Zariņa, A., Lūkins, M. Territorialisation of marginal lands: unfolding the post-productivist landscape potential. *Nordic Georgaphers Meeting,* 15–19 June 2015, Tallinn, Tartu, Estonia.

Vinogradovs, I. Application of LIDAR data for land overgrow assessment. *LU 73rd scientific conference*, 2–6 February 2015, Riga.

Vinogradovs, I. Application of remote sensing data to detect land use change in mosaic-type landscapes. *LU 72nd scientific conference*, 23–31 January 2014, Riga.

Projects during the doctoral thesis preparation

1. Integrated planning tool to ensure viability of grasslands LIFE Viva Grass (EU LIFE+ programme, project No. LIFE13 ENV/LT/000189), 2016–2019, researcher.
2. Sustainable management of natural resources during the climate change, scientific project of University of Latvia No. ZD2010/AZ03, 2016–2017, researcher.
3. Formation of marginal areas in Latvia. Causes and consequences (No. 514/2012), 2016, researcher.

The thesis consists of a summary in English and Latvian, and three consecutive articles – parts of the dissertation. The summary includes annotation, introduction, methods, results, conclusions and list of references.

1 DATA AND METHODS

1.1 Study area

The case study area is located in the western part of Vidzeme uplands (Fig. 2). Administratively it consists of Vaive parish of Cēsis municipality, Taurene, Vecpiebalga and Dzērbene parishes of Vecpiebalga municipality, Drusti parish of Rauna municipality and Zosēni parish of Jaunpiebalga municipality. Selected methods of the thesis were approbated on a national scale and on the scale of the Baltic states.

Figure 2. Case study area

1.2 Acquisition of geospatial data

Quality geospatial data is the foundation of sustainable land management. As a part of the thesis, a high-definition geospatial data set was created, which was used in modelling the drivers of land use change and assessment of ecosystem services. As a part of the study, the development of a land use database was carried out by remote sensing and field survey methods, as well as the collection, verification and augmenting of information from existing geospatial databases.

The first sub-task was the identification, quality assessment and matching of existing geospatial databases. The databases used in the study are summarised in Table 1.

The data sets were restructured according to the settings of the research. Where necessary, the data was categorised (e.g. quality of land, number of animals in farms) or used to generate derived data (e.g. distance to animal accommodation, forest edges, paved roads, etc.).

Table 1

Geospatial datasets used in the research

Geospatial data sets	*Owner*	*Availability, remarks*
IACS data	Rural Support Service	Open access (from 2018), separate agricultural fields' geometry and cultures grown and payments received available
Drainage systems	Ministry of Agriculture, Real Estate Department	Open access, contains thorough information on drainage systems.
Animal recordings	Agricultural Data Centre	No geospatial data available in open access
Cadastre data	State Land Service	Limited access, no personal information.
Digital soil maps	State Land Service	Open access, information on agricultural land
Land quality maps	State Land Service	Open access, information on agricultural land
SPA, biotopes	Nature Conservation Agency	Open access
Topographical map 1:10000	Geospatial Information Agency	Limited access, limited land use coverage
Digital elevation model (LIDAR)	Geospatial Information Agency	Open access, limited coverage, post processing needed
Digital elevation model (SRTM)	Geospatial Information Agency	Open access, limited resolution (20m)
State forest records	State Forest Service	Limited access
Monument of cultural and historical values	National Cultural Heritage Agency	No geospatial data available in open access

In order to supplement and partially verify the information contained in the aggregated geospatial databases, remote sensing methods were applied. The first of these methods was a visual assessment of several cycles of orthophotos. As a part of the thesis, the use of LIDAR cloud data for the recognition of agricultural land abandonment in Vaive parish was approbated. LIDAR data with a resolution of 8 pt/m^2 was obtained for the site. The classification and interpretation of the point cloud was made, and digital terrain and surface models were created. In ArcGIS software, a normalized surface pattern was constructed using the MapAlgebra module, which was used as a basis for creating a relative height model. In parallel, a LIDAR data intensity model was developed, allowing for an innovative approach to the separation of clearings and overgrown farmland. Due to the unavailability of high-quality, spatial-based data, the use of this method throughout the whole area of the study had to be abandoned.

In a situation where agricultural land is not in its entirety declared in the rural register data, i.e., the land is used for agricultural production, but it does not receive European Union aid payments or farmland is managed, for example, grass is being mown and mulched on site in order to maintain an open landscape around holiday farms, the development of a fully-fledged geospatial database required a survey of agricultural lands. The survey was conducted in the late summer of 2014 and 2015, delineating the nature and intensity of agricultural land management, and in particular focusing on the degree of abandonment in the targeted areas. Thus, three agricultural categories of land use intensity were distributed: agricultural land used in agricultural production; unused agricultural land subject to natural afforestation and partly abandoned agricultural land maintained but not used for agricultural production. In some areas (Vaive parish), mapping of the spread of Sosnovsky hogweed was also carried out for further integration into the decision-making support tool.

1.3 Assessment of driving forces of land use change

The identification of driving forces of land use change was carried out in three consecutive steps: identification of drivers, geospatial analysis and statistical analysis. Based on previous studies (Nikodemus et al. 2005; Nikodemus et al. 2010; Ruskule et al. 2012; Vanwambeke et al. 2012; Ruskule et al. 2013), abandonment of agricultural land was identified as the most important land use change process in the mosaic-type landscape. Factors reflecting site-specific properties were selected for the distribution of site-specific drivers, which spatially vary within one type of landscape and have been identified as relevant in previous studies. A summary of the underlying factors for driving forces is presented in Table 2.

Table 2

Factors used in analysis

Variable	*Unit*	*Description*
Land quality	Pt/ha (0-100)	Quality of agricultural land described as 100-point max grades
Soil texture	group	Groups of soil texture: sand, loamy sand, sandy loam, clay, peat.
Cadastre area	ha	Size (ha) of cadastre parcel in 2016
Drainage system	0/1	Presence of drainage system
Slope	0/1	Slope <10°/>10°
Previous land use patch	ha	Size (ha) of homogeneous land use type in 1990
Distance to rural centre	m	Distance
Distance to paved road	m	Distance
Distance to farm	m	Distance
Distance to forest edge	m	Distance

The data was collected in the grid type analysis model in the ArcMap program. The analytical grid size was selected at 100 x 100 m, corresponding to the detail of the land use patterns in the created spatial data sets. A centroid was created for each grid cell, thus covering the area under investigation with 220000 data collection points. The values of all the factors were read at each point, supplemented with X and Y coordinates in the LKS-92 system and stored for further statistical analysis in the form of a table.

To estimate the probability of farmland abandonment we constructed two autologistic binary regression (ABR) models as implemented in software R 3.4.0. (R Core Team 2017). One model was made to compare probabilities for semi-abandoned farmland versus farmland in active agricultural use. The second model was used to compare abandoned farmland versus farmland in active agricultural use. To account for spatial autocorrelation, in both models a distance-weighted autocovariate was included (calculated in R package spdep (Bivand et al. 2013)). Land quality, distance to roads, cadastre area, previous land use patch areas, soil texture (peat as reference level), erosion risk and drainage were used as independent variables in both models. There was no multicollinearity between independent variables, as generalized variance-inflation factor values were below 2 for all variables. All distance and area variables were scaled to unit variance before analysis as they had a high difference in amplitude. Log-odds were also expressed as odds ratio values for easier interpretation of results. Explained variance was calculated using the McFadden method of pseudo r-squared for generalized linear models as implemented in R library (pscl) (Jackmans 2017).

1.4 Assessment of ecosystem service supply potential

The geospatial data set for ES assessment was constructed based on the coverage of agro-ecological conditions of agricultural land (land quality, soil and terrain) and the type of land management. As a composite value of agro-ecological conditions, the land quality value and the reduction of soil texture were grouped into 2 categories: mineral soils and organic (peat) soils were applied. The qualitative value of the land was divided into 3 classes, using 25 and 50 points (LLU 2019) as threshold values, relatively indicating the fertility of agricultural lands and the potential for marginalisation. Slope values were divided into three classes depending on the impact of the slope on potential of soil erosion. The types of land management were divided into five classes depending on the intensity of the land management practice intervention on the soil's surface and the relevance of grassland species to a particular habitat. The grouping of determinants of ES assessment (Table 3) created ES assessment categories. A field, a spatial unit of continuous land use, whose borders were either determined by the data from the rural register (declared fields) or by the site survey and remote sensing data, was identified as an ES assessment and service providing area. Each ES providing area (field) was subjected to zonal statistical analysis and was assigned the dominant value of the basic determinant of ES. The type of management was determined according to the data from the rural register. Certain agricultural land uses (orchards, short rotation coppice) were excluded from the ES assessment due to their low presence in the area of study.

Table 3

Classification of determinants of ES assessment

	Determinants		
	Soils	*Slopes*	*Type of management*
Classes	Low quality	< 4°	Cultivated grasslands
	Medium quality	4° – 10°	Permanent grasslands
	High quality	> 10°	Semi-natural grasslands
	Organic soils		Cropland
			Abandoned agricultural land

The supply potential of ES was assessed using the matrix method approach (Burkhard et al. 2009) for five provisioning and nine regulating services (CICES 2015) related to agroecosystems. One indicator was defined for each service. An expert panel consisting of geography, biology, environmental science, agriculture and soil science experts, based on research of scientific articles, carried out a semi-quantitative assessment of each ES on a scale ranging from 0 (no service provided) to 5 (very high service provision). The assigned ES values are potentially replaceable by actual service values when such values will be available. The cultural ES were not evaluated using the matrix method, since the provision of services is linked to the landscape elements determining the provision of the service (Table 4).

Bundles of ES were revealed through the principal component analysis of semi-quantitative ES values for grassland plots (observations) and ES (variables) based on the matrix as input data (Queiroz et al. 2015) using SPSS software. The trade-offs and synergies were assessed using a correlation analysis for each pair of ES. Distribution of ES hotspots was done by counting ES to high values (4.5), cold points – counting ES with low values (1, 2).

Table 4

List of cultural ES and their evaluation criteria

Cultural ES	*Landscape feature*	*Buffering distance*
Physical and experiential interactions (recreational)	Rural recreational enterprises	3 km
	Watch towers	300 m
	Tourist trails	100 m
	Area of hunting clubs	0 m
	Camping sites	300 m
	Social gathering places	300 m
Educational	Educational trails	100 m
	Educational sites	100 m
Cultural heritage	Monuments	100 m
	Manor houses, old farmsteads	100 m
	Traditional land use	300 m
Aesthetics	Water bodies and streams	300 m
	Naturalness of surroundings	100 m
	Naturalness of land use	0 m
	Linear landscape elements	300 m
	Relief	standard deviation > 10 5x5 km grid
	Openness	forest cover < 50 % 5x5 km grid

1.5 Development of multi-criteria decision analysis tool

The multi-criteria decision support (MCDS) is a framework designed to guide the decision-making process, taking into account a number of criteria, in situations where a number of objectives need to be achieved and a number of stakeholders have to be involved (Belton & Stewart 2002). Territorial planning and management aims are of a complex structure that cannot be expressed by a single indicator or a single dataset (Koschke et al. 2012). The proposed MCDS frame provides a structured scheme that combines the results of ES values with biophysical and socio-economic data sets for an integrated use in the planning process.

Table 5.

Functionality and target audience of MCDS tool

Tool Modules	Agricultural land use	ES assessment	ES bundles, trade-offs, hotspots	Biomass potential	Energy potential	Management recommendations	Prioritisation, classification	Map export	Editing, uploading, downloading	*Target audience*
	Functionalities									
Viva Grass Viewer	X	X	X			X		X		General public
Viva Grass Bio-energy	X			X	X	X		X		Planners, researchers
Viva Grass Planner	X	X	X			X	X	X	X	Planners, researchers

The individual tool models are designed for different functionalities and different user groups (Table 5). The complete functional support of the MCDS process is provided by the *Viva Grass Planner* module, which requires an understanding of GIS data processing processes. *Viva Grass Viewer* is aimed at exploring the ES assessment and ES interaction, *Viva Grass Bio-Energy* is designed for planning the use of grass biomass as a fuel source.

The operationalizing of ES into the MCDS tool was based on a scheme adapted from Langemeyer et al. (2016) (Fig. 3). In the framework of the approbation of the MCDS tool, the development of each phase of the process focused on the involvement of stakeholders, which was carried out in the meetings of the working groups. The author of the thesis carried out the approbation of the MCDS tool within one administrative area (Cēsis municipality).

It was linked with the municipal development programme and territorial plan. Stakeholders' meetings included representatives of the municipal spatial planning specialists, employees of the administrative management of Cēsis municipality, rural consultants, tourism specialists, farmers, businessmen and residents.

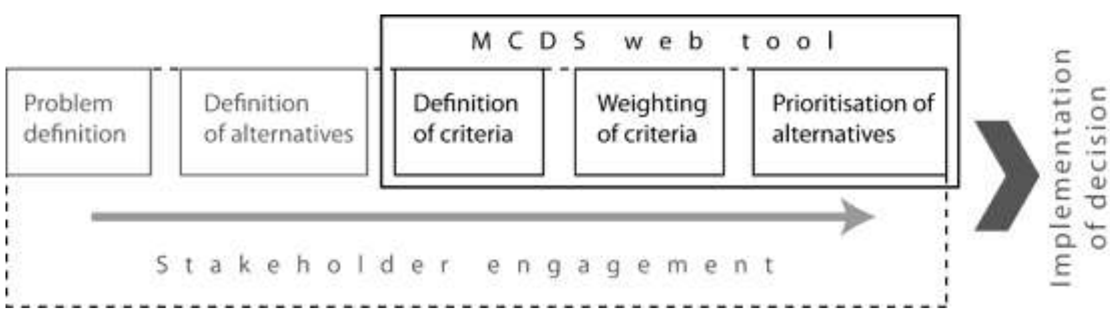

Figure 3. Multi-criteria decision support scheme (adapted from Langemeyer et al. 2016)

For the weighting and prioritisation of the MCDS criteria, a weighted sum model (Triantaphyllou 2000) was used, where separate ES were chosen as weighing criteria for which a user (a group of stakeholders) assigns certain values with a total value of 100, resulting in a prioritisation weight calculated on the basis of the formula

$$\sum_{i=0}^{n} \frac{Index_i}{\max(Index) * n} Weight/100$$

where Index – value of a particular index, max(Index) – maximum value of a selected index, and Weight – user-defined weight for the component. The total weight index is the sum of the selected components. Weighting scales can be saved and edited. Since the weighted-sum model requires values where all criteria are expressed in the same unit, the MCDS tool includes the possibility of classifying data which allows for the addition of data of different expression to prioritisation, such as the “cold spot” value or belonging to the trade-offs, as well as data created to deal with certain problems, i.e., as the “agricultural land abandonment risk” index. Additionally, required indicators in the MCDS tool are to be used as core data derivatives or as new composite indices formed as weighted-sum models according to this formula:

$$A_i^{SSM-value} = \sum_{j=1}^{n} w_j \, a_{ij}, \text{kur } i = 1, 2, 3, \dots \, m$$

where w_i – weight of criteria, a_{ij} – value of criteria and $A_i^{SSM\text{-}value}$ value of composite index.

In the municipality of Cēsis, the MCDS tool was approbated for the development of prioritization of agricultural land management in the context of maintaining and increasing tourism potential. The workflow of the MCDS (Fig. 4) was implemented in 5 successive stakeholder meetings, each marking a discussion of the results of the previous meeting and, if necessary, an adjustment; the first meeting was devoted to the presentation of the ES approach.

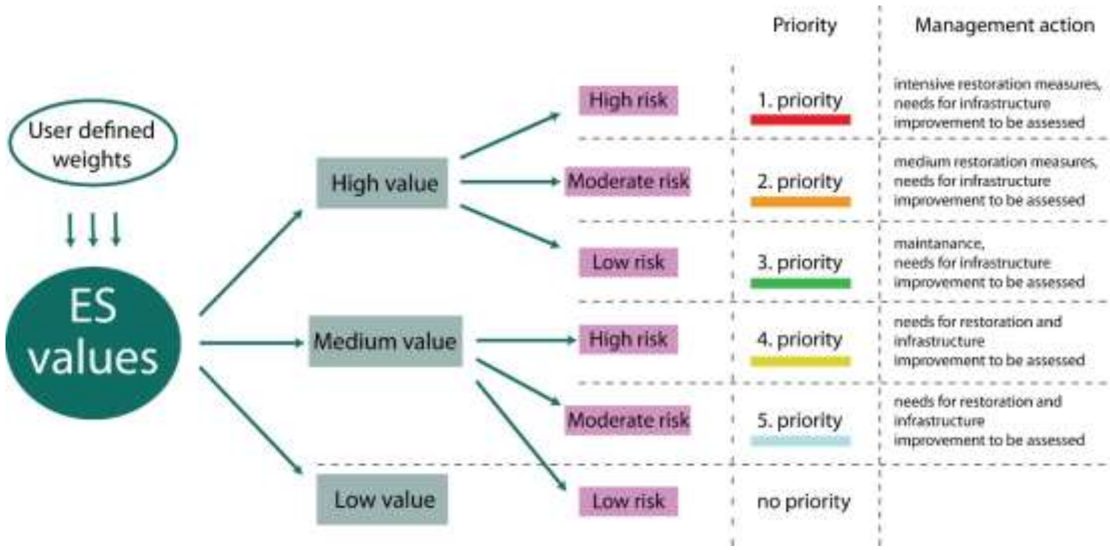

Figure 4. Workflow of MCDS for the prioritisation of management of agricultural land

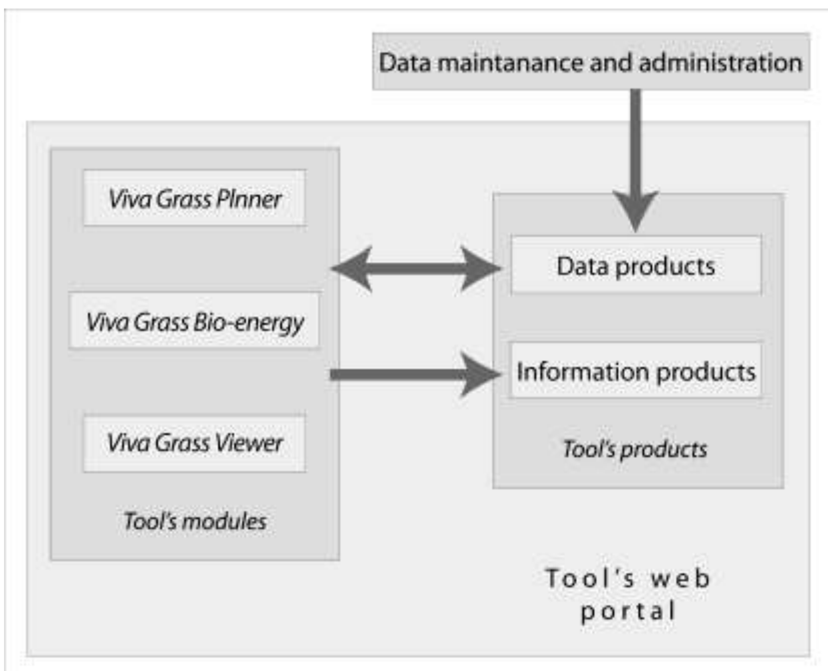

Figure 5. The structure of the web based MCDS tool

1.6 GIS and cartographic solutions for the web-based tool

The *Viva Grass Tool* is based on an ArcGIS Enterprise platform. Data is stored in a common spatial database (PostgreSQL) and published as GIS services (maps). The web-based tool modules/applications were constructed using the ArcGIS Web application builder. To fulfil custom requirements, additional application widgets were developed (Fig. 5). The *Viva Grass Tool* includes three main Tool modules: *Viva Grass Viewer*, *Viva Grass*

Bio-energy and *Viva Grass Planner* targeted to particular users and decision-making contexts. The three modules produce and use various data and information products, which can be linked with other information platforms.

The assessment maps of ES and calculation results are available as “data product” shape file archives. The assessment matrix and the algorithms that were used are available as “information products”.

2 RESULTS AND DISCUSSION

This section describes and discusses the main results of the thesis: the analysis of the drivers of land use change, the assessment of ecosystem services and an analysis of their interaction, the approbation of the multi-criteria decision support tool.

2.1 The results of the assessment of the drivers of land use change

The method implemented in the thesis identified the drivers of land use change and the probability (risk) of abandoning agricultural land. The changes in land use are linked to land reform following the collapse of the USSR and the restructuring of the agricultural sector after accession to the EU.

Table 5

Results of autologistic binary regression

Land maintenance type	*Variable*	*Estimate*	*Odds ratio*	*Std. error*	*t-value*	*p-value*
Semi-abandoned ALU	KVP	- 0.38	0.69	0.06	- 6.55	< 0.001
	KLI	- 0.32	0.72	0.05	7.09	< 0.001
	ALC	- 0.07	0.93	0.04	- 1.59	0.113
	ALF	0.23	1.27	0.04	5.97	< 0.001
	AMM	- 0.26	0.77	0.05	- 5.63	< 0.001
	ACS	0.17	1.19	0.04	4.18	< 0.001
	ZKV	- 0.32	0.73	0.05	- 6.36	< 0.001
	MSK	- 0.58	0.56	0.01	- 5.76	< 0.001
	NST	- 0.03	0.97	0.10	- 0.25	0.803
	Soil texture (peat reference)					
	C	- 0.55	0.58	0.21	- 2.68	0.007
	SL	- 0.40	0.67	0.14	- 2.85	0.004
	S	- 0.19	0.83	0.16	1.21	0.227
	LS	- 0.38	0.67	0.14	- 2.85	0.004
Abbandoned ALU	KVP	- 0.09	0.91	0.02	- 2.85	< 0.001
	KLI	- 0.22	0.80	0.02	- 2.85	< 0.001
	ALC	0.04	1.04	0.02	- 2.85	
	ALF	0.24	1.27	0.02	- 2.85	< 0.001
	AMM	- 0.59	0.55	0.03	- 2.85	< 0.001
	ACS	0.17	1.18	0.02	- 2.85	< 0.001
	ZKV	- 0.58	0.56	0.03	- 2.85	< 0.001
	MSK	- 0.40	0.67	0.05	- 2.85	< 0.001
	NST	- 0.33	0.72	0.05	- 2.85	< 0.001
	Soil texture (peat reference)					
	M	- 0.95	0.39	0.10	- 2.85	< 0.001
	SL	- 0.61	0.54	0.07	- 2.85	< 0.001
	S	- 0.40	0.67	0.09	- 2.85	< 0.001
	LS	- 0.72	0.49	0.06	- 2.85	< 0.001

KVP – size of cadastre parcel, KLI – size of previous land use patch, ALC – distance to rural centre, ALF – distance to farm, AMM – distance to forest edge, ACS – distance to road, ZKV – land quality, MSK – presence of drainage, NST – slope > 15°, C – clay, SL – sandy loam, S – sand, LS – loamy sand.

Regression models are commonly used to assess the drivers of land use changes in different regions and scales (Millington et al. 2007). The results of the autologistic binary regression (Table 6) indicate that higher land quality value in the Vidzeme mosaic-type landscape reduces the possibility that farmland will be transformed to semi-abandoned (unutilised) farmland (odds ratio 0.73, $p < 0.001$) or abandoned agricultural land (odds ratio 0.56, $p < 0.001$). The soil texture has no statistically significant impact on the probability that agricultural land will be transformed into partly abandoned land, while the probability of abandoning agricultural land decreased with all variations of soil texture calculated relative to peat.

The absence of steep slopes (odds ratio 0.72, $p < 0.001$) reduces the probability that farmland will be abandoned, while the presence of drainage systems reduced the possibility that farmland will be partially abandoned (odds ratio 0.56, $p < 0.001$) or abandoned (odds ratio 0.67, $p < 0.001$). Increased distance to farms (odds ratio 1.27, $p < 0.001$) and road paved with gravel or asphalt pavement (odds ratio 1.18, $p < 0.001$), as well as a decrease in distance to forest edges (odds ratio 0.55, $p < 0.001$) increased the probability that farmland would be abandoned. Greater distance to farms (odds ratio 1.27, $p < 0.001$) and shorter distance to the forest edge (odds ratio 0.78, $p < 0.001$) increased the probability that agricultural land would not be used for agricultural production.

The overall explained variance of the ABR model for farmland abandonment in the Vidzeme mosaic-type landscape is 29.21 %, while for partial abandonment it is 40.48 %. Although the explained variance within the area under investigation varied, in all parishes the land quality value and the distance to forest edges were important factors for increasing the risk of abandoning agricultural lands. In most of the areas increasing the distance to the farm also increased the abandonment risk of agricultural lands. The unexplained variance of the model is attributable to the effects of factors not included in the model, for instance, socioeconomic factors on the farm level, such as farm income and size, age and education level of the farmer, continuity and persistence of agricultural practices and the level of mechanisation (Baldock et al. 1996; Van Doorn and Bakker 2007; Kristensen et al. 2004; MacDonald et al. 2000, Terres et al. 2015). Socio-economic and demographic indicators at the regional level also play an important role (Kuemmerle et al. 2008; Prishchepov et al. 2013).

The obtained results allow the formation of a composite indicator to be used in a weighted-sum model from a number of variables which showed significant impact on land use change, such as the quality of land, the distance to a farm and the distance to a forest edge, and thus allows for the creation of an agricultural land abandonment risk index used in the multi-criteria decision-making support tool (Chapter 2.3).

2.2 Assessment of ecosystem services

As a part of the assessment of ecosystem services, a specific indicator value was applied to the expression of each service (for provisioning services in metric units, for regulating services – relative units) and later categorised in the ordinal scale of the ecosystem service assessment matrix (1-5). For instance, indicator for the ES "fodder" is t/ha/year, i.e. value "1" stands for <1 t/ha/year, "2" – 2-3 t/ha/year etc. An indicator for ES "habitat maintenance" is number of species of vascular plants per 1m^2, i.e. value "1" stands for "very low number of species", value "5" – very high number of species (Table 7, Fig.

6). The structure of the matrix allows for the substitution of ordinal data with actual values when they are available.

The developed ES assessment method identifies the potential for the provision of the service under the given agro-ecological conditions, taking into account the land management intensity. For example, cultivated grassland – ploughed at least once every five years, a reseeded, fertilised agroecosystem, will provide a higher value for provisioning services than permanent grasslands under any early ecological conditions. On the other hand, semi-natural grasslands, a non-intensively managed, species-rich agroecosystem will provide a higher value for regulating services under any agro-ecological conditions.

Table 7

Extract of the expert-based scores matrix

	Provisioning ES					Regulating ES							
ALU class	Cultivated crops	reared animals	Fodder	Biomass for energy	Medical herbs	Bioremediation	Filtration / accumulation	Erosion control	Pollination	Habitat maintenance	Weathering	Chem. con. of freshwaters	Global climate regulation
11. Permanent grasslands on plain relief, low land quality	0	2	1	1	3	3	2	0	4	4	2	3	3
12. Permanent grasslands on plain relief, medium land quality	0	3	2	2	2	4	3	0	4	3	3	4	3
13. Permanent grasslands on plain relief, high land quality	0	4	3	3	2	4	4	0	4	3	4	5	3
14. Permanent grasslands on plain relief, on organic soils	0	3	2	2	2	5	4	0	4	3	0	3	4
15. Permanent grasslands on gentle slope, low land quality	0	2	1	1	3	3	2	4	4	4	2	3	3
16. Permanent grasslands on gentle slope, medium land quality	0	3	2	2	2	4	3	3	4	3	3	4	3
17. Permanent grasslands on gentle slope, high land quality	0	4	3	3	2	4	4	3	4	3	4	5	3
18. Permanent grasslands on gentle slope, on organic soils	0	3	2	2	2	5	4	0	4	3	0	3	4
19. Permanent grasslands on steep slope, low land quality	0	2	1	1	3	3	2	5	4	4	2	3	3
20. Permanent grasslands on steep slope, medium land quality	0	3	2	2	2	4	3	5	4	3	2	4	3

The principal component analysis revealed 3 main components (Table 8), which correspond to three bundles accounting for 90.53 % of the total variance. The first component accounts for 48.18 % of the total variance and is positively correlated with "herbs for medicine", "maintaining habitats", "global climate regulation" and "pollination" ES and negatively correlated with "reared animals", "fodder" and "biomass-based energy sources" ES. This component represents a trade-off between provisioning ES related with cultivated grasslands and the 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/ accumulation by ecosystems", "bio-remediation" and "chemical condition of fresh waters” ES. The third component explains 14.25 % of the total variance and is positively correlated with the “control of erosion” and “weathering processes” ES.

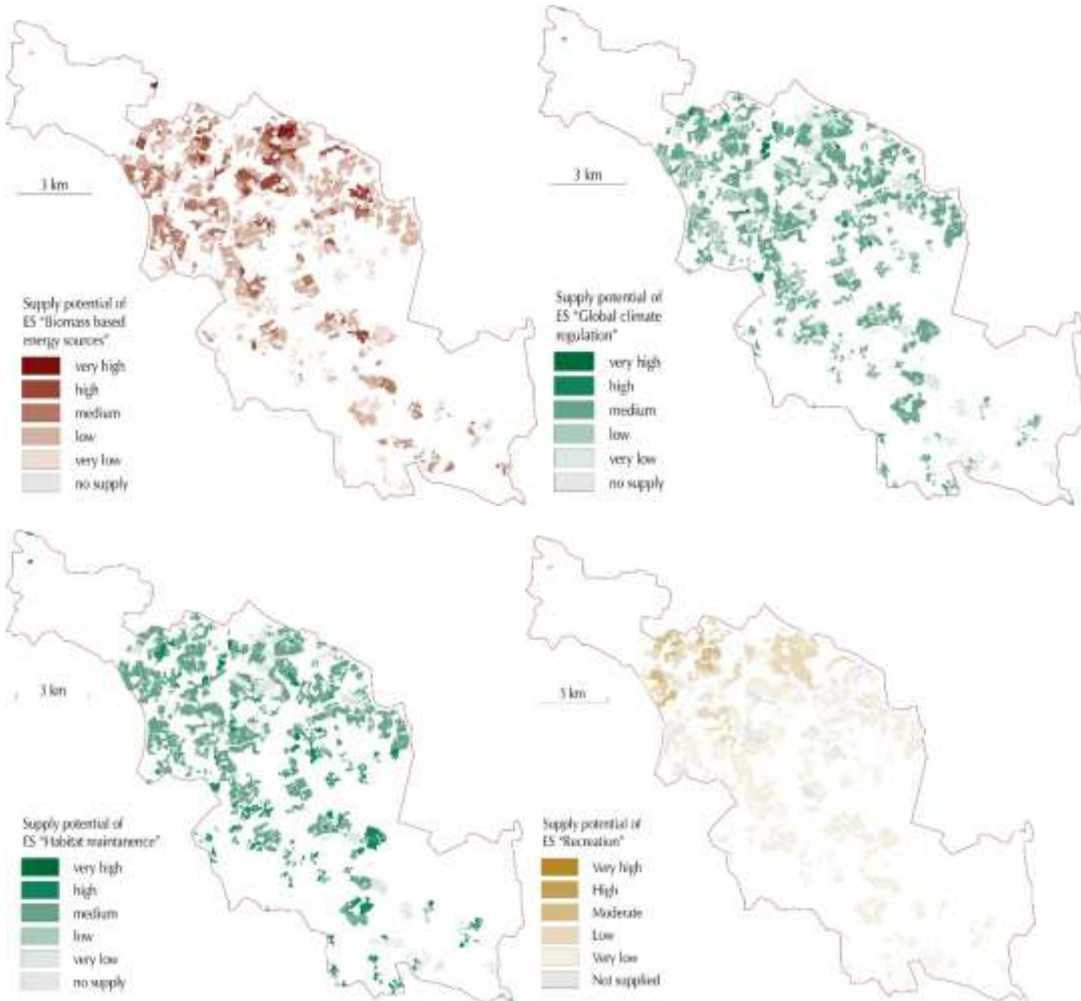

Figure 6. Results of ES assessment in Cēsis municipality.

Table 8

Factor loadings showing the correlation between the original variables (ES) and the components extracted by the PCA

Ecosystem services	1st component	2nd component	3rd component
reared animals	- 0,958		
Fodder	- 0,807		
Biomass-based energy sources	- 0,808		
Medical herbs	0,921		
Pollination	0,846		
Habitat maintenance	0,953		
Global climate regulation	0,726		
Bioremediation		0,839	
Filtration / accumulation		0,845	
Chem. cond. of freshwaters		0,766	
Erosion control			0,608
Weathering			0,902

Based on the results of the principal components analysis, it is possible to distinguish bundles of ecosystem services, a kind of ES grouping where synergies between services appear, i.e. the value of one service increases the value of all other services in the bundle, or trade-off, when the value of one service increases and thus the value of other services will reduce in the bundle (Mochet et al. 2014; Spake et al. 2017). As the first component revealed two distinct polarities, two distinct bundles where identified, thus providing that inside the bundle only a synergetic relationship appears and the trade-off is located in the relationship between bundles. Bundles were given names that reflect their functionality and more clearly disclose their nature:

- Habitats bundle. Synergetic relationships among “herbs for medicine”, “maintaining habitats”, “global climate regulation”, “pollination” ES;
- Productivity bundle. Synergetic relationships among “reared animals”, “fodder” and “biomass-based energy sources” ES
- Soil bundle. Synergetic relationships among “filtration/ accumulation by ecosystems”, “bio-remediation”, “chemical condition of fresh waters”, “control of erosion” and “weathering processes” ES.

The belonging of a given field to a particular ES bundle was determined if their average value of ES in the bundle exceeded the threshold value 3, i.e., the potential of the services was provided above the average value (Fig. 7).

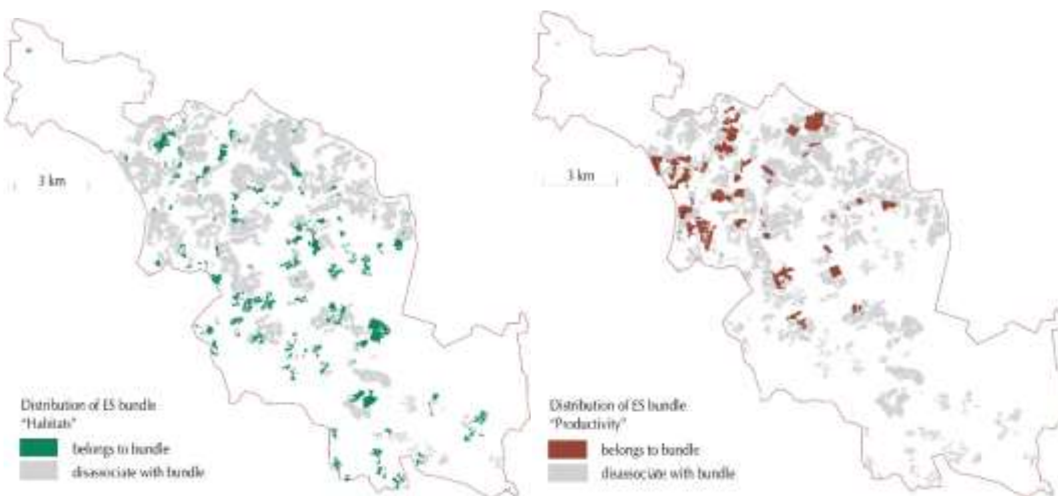

Figure 7. Distribution of ES bundles “Habitats” and “Productivity” in Cēsis municipality

The mapping of ES bundles provides base information for spatial character of interaction among ES, thus disclosing a decisive foundation for decision making on most suitable agricultural land use of the given field. In a situation where services in the “habitats” bundle provide above average values, but services in the “production” bundle provide below average values, is called a “trade-off in benefit of habitats bundle”. In a situation where services in the “habitats” bundle provide below average values, but services in “production” bundle provide above average values, is called a “trade-off in benefit of production bundle” (Fig. 8). Nevertheless, in a study area where such exceptional situations were present when ES values in both bundles displayed low and very low values, or in the opposite situation, where ES values in both bundles displayed high and very high values. The former is called “cold spots of ES supply potential”, the latter – “hot spots of ES supply potential”.

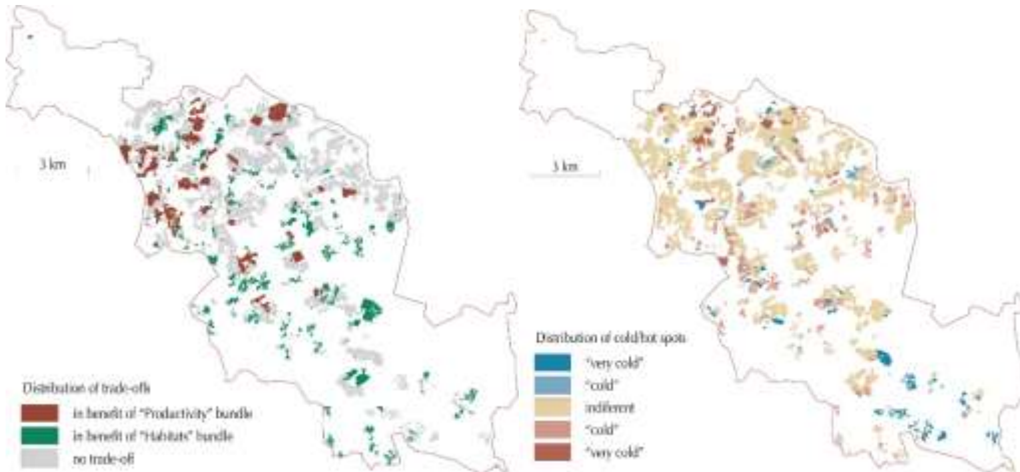

Figure 8. Trade-offs among ES bundles and hot/cold spots of ES supply potential in Cēsis municipality

The research on ecosystem service trade-offs have brought on the agenda of the landscape ecological studies serious issues: agroecosystems to a large extent depend on the provisioning of ES (e.g., pollination, pest and disease control, soil fertility maintenance), while agroecosystems are also important suppliers of ecosystem services (firstly, provisioning services, but also certain regulatory and cultural services) (Garbach et al. 2014; Willemen et al. 2017). However, in the context of intensification of agriculture, the focus is on the accession of provisioning services, which is linked to serious trade-offs (Kirchner et at. 2015). The scientific literature provides a detailed description of the trade-off between agricultural production and regulating ES (Haines-Young et al. 2012; Maes et al. 2012) e.g., carbon sequestration (Schulze et al. 2005; Glendell & Brazier 2014), pollination (Power, 2010; Cole et al. 2017, maintaining of habitats (McLaughlin & Mineau 1995; Tscharntke et al. 2005). The presented study supports the opinion that under the same agro-ecological conditions, increasing the intensity of agricultural activity will increase in the value of the “productivity” bundle and will lead to a decrease in the value of the “habitats” bundle services.

2.3 Multi-criteria decision support

The application of the multi-criteria decision support tool is implemented through the framework of the decision-making systems, which are designed for addressing specific problems. Within the framework of the thesis, the prioritization of the territory management within the context of landscape maintenance in the Cēsis municipality.

The discussion of experts and stakeholders identified criteria for the selection of high value landscapes and tourist-relevant areas. The chosen criteria are cultural ecosystem services (aesthetic value, recreational value, educational value, heritage value) and ecological value (average value of ecosystem services for the "habitats" bundle). Two composite indices were identified and used for the selection of risk areas: "risk of hogweed invasion" represented by the location of territories in relation to areas contaminated with Sosnovsky hogweed and "risk of abandonment of farmland", represented by a weighted sum of a land quality (50 %) distance from a farm (30 %)) and distance to a road (20 %).

The weighing of the criteria resulted in the weights of the criteria matrix based on ES linked to the aims of a sustainable development strategy of the Cēsis municipality for 2030: quality of life and environment, employment opportunities, health; safety, cultural accessibility, educational and lifelong learning, social infrastructure, security and care. The average priorities for each criterion, when calculated as a percentage, was expressed as the "weight" used in the prioritization calculations of the MCDS tool (Table 9).

Table 9

Decided weights of criteria by experts and stakeholders

Criteria	Weight (%)
Aesthetic value	25
Recreation value	18
Education value	12
Heritage value	22
Ecological value	23

The MCDS tool prioritisation is performed by assigning a sequential number to each territorial unit. By default, this set is divided in five categories using natural brakes as threshold values. The categorisation by quantiles or same size groups can be employed if needed. This division is categorised into three categories of landscape values – high, medium and low. When applying risk categories to value categories, site management priorities are created (Fig. 9).

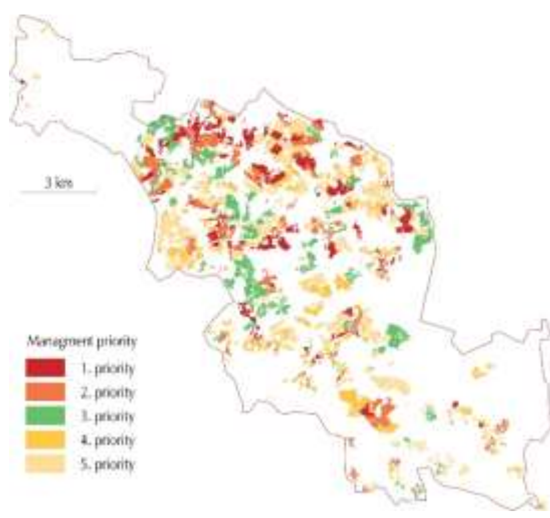

Figure 9. The results of the prioritisation of farmland management in Cēsis municipality

In the described multi-criteria decision support process, in order to avoid risks that a small group of stakeholders may have a significant influence on certain values or weights

(Stirling 2006), the deliberative multi-criteria evaluation (Mavrommati et al. 2017) was applied, enabling greater awareness and public involvement in the planning process.

2.4 GIS and cartographical solutions for web-based tool

Viva Grass Viewer is the basic module of the MCDS tool available for the general public. It is designed as an explorer of thematic maps (contextual layers) (Fig. 10) with limited possibilities to edit maps – the user can modify agricultural land use to a chosen field and explore the changes in supply potential of ES, belonging to the ES bundles, trade-offs and cold/hot spots, as well as to obtain the recommendations for agricultural land use intensity for the given agro-ecological conditions.

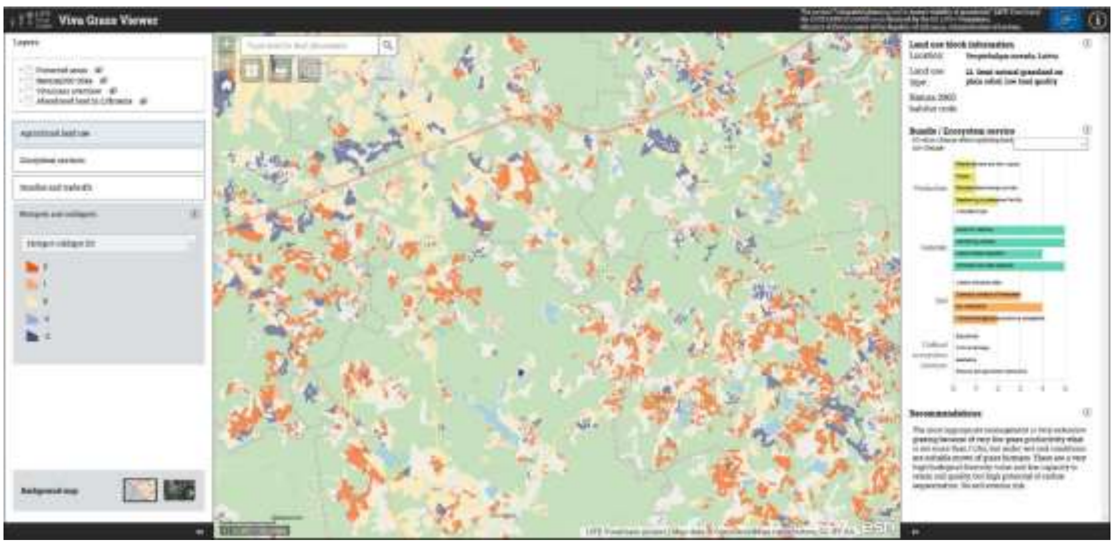

Figure 10. *Viva Grass Viewer*, screenshot

Viva Grass Planner is the main module of MCDS tool and is accessible for registered users. Basic knowledge of GIS is required to use this module. *Viva Grass Planner* contains all contextual layers of ES assessment and interaction analysis (Fig. 11), as well as possibility to upload any additional data required for specific analysis. This module operates as an online GIS software able to perform basic spatial analytics, display and to export the results.

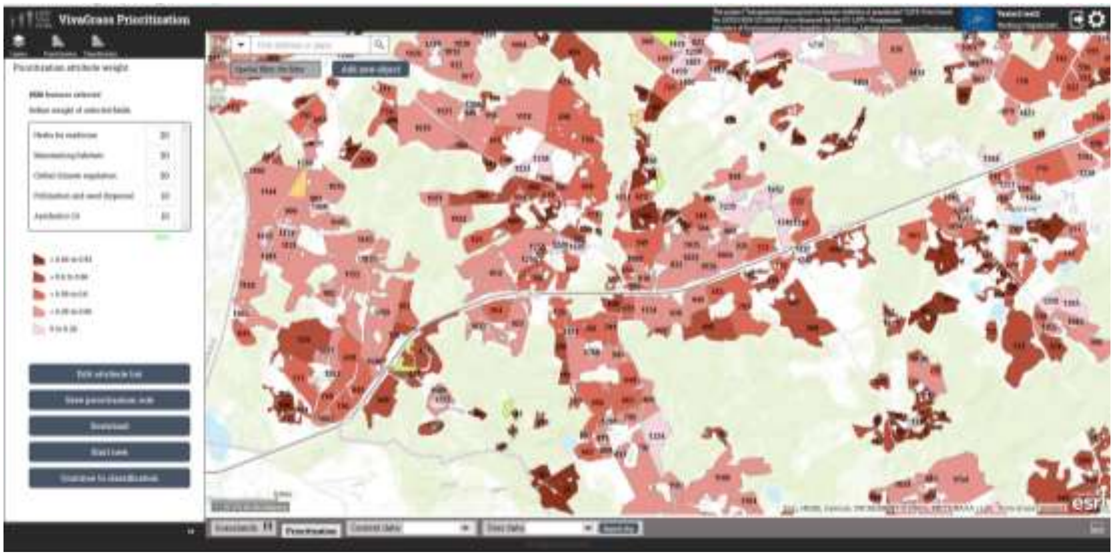

Figure 11. *Viva Grass Planner*, screenshot

CONCLUSIONS

Three consecutive studies were carried out with the aim to develop and approbate ecosystem service approach for land management in agroecosystems in mosaic-type landscapes:

- assessment of drivers or land use change in mosaic-type landscape;
- development of biophysical method of ecosystem service assessment for agro-ecosystems;
- integration of ecosystem services and drivers of land use change in multi-criteria decision support tool for planning and management of agro-ecosystems.

The effectiveness of autologistic regression models in assessing the drivers of landscape change has been demonstrated. The study has shown that the most important biophysical and locational factors are the land quality, the distance to farms, roads and forest edges, which function as the strongest drivers for the abandonment of agricultural land in the mosaic-type landscape in Vidzeme. The study demonstrated that for the development of more accurate land use scenarios, the ABR model should be complemented with farm-level socio-economic data.

As a part of the thesis, the assessment and mapping method of ecosystem services for agricultural land has been developed and analysis of the interaction among ecosystem services has been carried out. The study shows that, under similar agro-ecological conditions, the intensification of land management increases the value of provisioning services and reduces the value of regulatory services, thereby leading to a trade-off situation. On the other hand, under unfavourable agro-ecological conditions, such as poor soils or steep slopes, intensification does not lead to an increase of provisioning services and creates “cold points” of ecosystem service supply. The method presented in the thesis has been used to map ecosystem services in agroecosystems in the Baltic states.

The drivers of land use change and the assessment of ecosystem services were used in the multi-criteria decision support as weighted criteria for improving land management in marginal territories. An integrated planning scheme for the prioritisation of agricultural land management for the maintenance and enhancement of landscape aesthetic and tourism values has been developed and approbated in the framework of the current thesis. The newly elaborated approach is included in the integrated planning tool *Viva Grass Tool*.

The results of the thesis can be applied in forecasting changes in the use of agricultural land and provision of ecosystem services, and also in analysing the impact of the agricultural policies. The assessment of ecosystem services should be used as an integral part of the MAES (Mapping and Assessment of Ecosystem Services) process.

For a further advancement of the results of the thesis, the developed models should be supplemented with forest land data, thereby obtaining an effective instrument to support decisions in the planning and management of rural areas.

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Latvijas Universitāte
Ģeogrāfijas un Zemes zinātņu fakultāte

Ivo Vinogradovs

EKOSISTĒMU PAKALPOJUMU PIEEJA ZEMES IZMANTOŠANAS PĀRVALDĪBĀ MOZAĪKVEIDA AINAVU AGROEKOSISTĒMĀS

Promocijas darbs

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Rīga, 2020

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Promocijas darbs ir secīgu pētījumu kopa, kuras ietvaros ir izstrādāta daudzkritēriju lēmumu pieņemšanas atbalsta shēma zemes izmantošanas pārvaldības uzlabošanai mozaīkveida ainavu agroekosistēmās. Darba ietvaros tika aprobēts autoloģistiskās binārās regresijas modelis zemes izmantošanas maiņas virzītājspēku novērtēšanai Vidzemes augstienes mozaīkveida ainavā. Kā svarīgākie lauksaimniecības zemju izmantošanas izmaiņu faktori tika identificēti zemes kvalitatīvā vērtība, attālums līdz lopu novietnei, attālums līdz ceļam un meža malai. Darba tapšanas laikā tika izstrādāta ekosistēmu pakalpojumu novērtēšanas un kartēšanas metode agroekosistēmām Vidzemes augstienē, un tālāk tā tika aprobēta visās Baltijas valstīs. Promocijas darba ietvaros tika veikta ekosistēmu pakalpojumu mijiedarbības analīze, identificējot pakalpojumu nodrošinājuma kompromisus un "aukstos" un "karstos" punktus. Iegūtie rezultāti tika iestrādāti daudzkritēriju lēmumu pieņemšanas atbalsta rīkā un ir izmantojami teritoriju plānošanā un zemes pārvaldībā. Daudzkritēriju lēmumu pieņemšanas atbalsta rīks tika aprobēts teritoriju apsaimniekošanas prioritāšu noteikšanas modelī Cēsu novadā. Promocijas darba rezultāti ir izmantojami lauksaimniecības politikas, teritorijas attīstības un zemes pārvaldības modelēšanā un analīzē.

SAĪSINĀJUMI

ABR – autoloģistiskā binārā regresija

DKLA – daudzkritēriju lēmumu atbalsts

ĢIS – ģeogrāfiskās informācijas sistēmas

ĪADT – īpaši aizsargājamās dabas teritorijas

LIDAR – aerolāzerskenēšanas metode *(Light Detection and Ranging)*

LIZ – lauksaimniecībā izmantojamā zeme

SATURS

IEVADS

Cilvēku darbība ir tieši mainījusi teju 75% no ledājiem brīvās sauszemes teritorijas (Ellis un Ramankutty 2008). Tas izpaužas ainavas struktūru, funkciju un sniegto ekosistēmu pakalpojumu izmaiņās. Globālais pieprasījums pēc pārtikas un bioenerģijas 21. gadsimtā turpinās pieaugt (Schneider et al. 2011), tādējādi pakļaujot arvien lielākai intensifikācijai auglīgās lauksaimniecības zemes (Tilman et al. 2011). Savukārt zemes, kas ģeogrāfiskā novietojuma ziņā ir mazāk piemērotas lauksaimniecībai, skar marginalizācijas process. Tas kopumā veicina ainavas polarizāciju. Šo procesu izpausmes novērojamas kā kontinentālā, tā nacionālā mērogā. Eiropas dienvidos un austrumos vairāk izteikta lauksaimniecības zemes pamešana un aizaugšana ar krūmiem, bet Eiropas centrālajā un ziemeļu daļā ir raksturīgāka lauksaimniecības intensifikācija (Rienks et al. 2008). Nacionālā mērogā, piemēram, Latvijā, zemes denacionalizācijas rezultātā pamestās lauksaimniecības zemes auglīgajos reģionos šobrīd ir pilnībā no jauna atgrieztas lauksaimnieciskā ražošanā, savukārt nomaļā novietojumā un lauksaimniecībai nelabvēlīgos agroekoloģiskos apstākļos norit to pamešana un dabiska vai apzināta apmežošana (Nikodemus et al. 2005; Nikodemus et al. 2010; Vanwambeke et al. 2012; Vinogradovs et al. 2018, Zariņa et al., 2018).

Lai izprastu ekosistēmās un sabiedrībā notiekošās izmaiņas, ir nepieciešams izmantot kompleksu pieeju ainavu izpētei, proti, pētīt cilvēku un vides attiecības ainavā, ainavas struktūru un zemes lietojuma intensitāti, ainavu vēsturi, ainavu vērtības un nozīmi, un to pārvaldību (Plieninger et al. 2015).

Pētījuma aktualitāte

Lauksaimniecība ir tā cilvēka darbības joma, kas atstāj visplašāko ietekmi uz vidi (Balmford et al. 2012). Šī ietekme izpaužas ekosistēmu un bioloģiskās daudzveidības samazināšanā (Newbold et al. 2015), siltumnīcas efektu izraisošo gāzu emisijā un izmaiņās slāpekļa un fosfora aprites ciklos (Burney et al. 2010), kas savukārt izraisa iekšējo ūdeņu un jūras pastiprinātu eitrofikāciju. Gan lauksaimniecības intensifikācija, gan marginalizācija veicina ainavas homogenizāciju – ainavas struktūras vienkāršošanos – un tālab daudzām sugām piemērotu dzīvotņu samazināšanos, tai skaitā mazo ainavas elementu un atsevišķu zemes lietojuma veidu izzušanu intensīvi apsaimniekotās teritorijās (Nikodemus et al. 2018), dabisku un apzinātu lauksaimniecības zemju apmežošanu marginālā novietojumā (Nikodemus et al. 2005; Vinogradovs et al. 2018). Mozaīkveida ainavas, kuru telpisko struktūru nosaka komplicēti agroekoloģiskie apstākļi, ir sevišķi pakļautas marginalizācijas un homogenizācijas procesiem.

Zemes pārvaldība, nodrošinot ilgtspējīgu zemes izmantošanu, ietver minēto procesu mērķtiecīgu vadīšanu. Eiropas Savienības (turpmāk ES) kopējās lauksaimniecības politikas nozīmīgākie mērķi pamatnostādņu vides jautājumos (European Commission, 2019) ir nodrošināt ilgtspējīgu zemes apsaimniekošanu, novēršot videi kaitīgu lauksaimniecisko darbību, un stimulēt videi draudzīgu preču ražošanu un pakalpojumu nodrošināšanu. Kopējās lauksaimniecības politikas izstrādātā agrovides pasākumu kopa ir vērsta uz lauksaimnieciskās darbības ietekmes uz vidi mazināšanu – novērst dzīvotņu un bioloģiskās daudzveidības samazināšanos, nepieļaut būtisku ainavas transformāciju, mazināt mēslojuma un pesticīdu izraisīto piesārņojumu. Šo pasākumu lielākā efektivitāte ir teritorijās, kur tie sniedz vislielākos ieguvumus (Betary et al. 2015). Viens no risinājumiem minēto mērķu sasniegšanā un teritoriju izvēlē ir ekosistēmu pakalpojumu koncepta ieviešana zemes politikā un pārvaldībā (Van Zanten et al. 2014).

Ekosistēmu pakalpojumu pieeja ir īstenojama zemes pārvaldībā, sevišķi zemes izmantošanas politikā, teritorijas plānošanā un ietekmes uz vidi novērtēšanā (Rozas-Vásquez et al. 2019), jo tā spēj sniegt holistisku priekšstatu, vienlaikus nodrošinot nepieciešamo pamatinformāciju par vides stāvokli un kvalitāti, ekosistēmu funkcionēšanu un šo funkciju potenciāla izmaiņām, ņemot vērā arī sabiedrības ekonomiskās intereses (Hansen et al. 2014).

Pastāv vairākas pieejas ekosistēmu pakalpojumu novērtēšanai, proti, to apzināšanai un kartēšanai (*assessment,* angl.). Tiek izmantotas biofizikālā novērtējuma metodes, kurās ekosistēmu pakalpojumu novērtējums tiek balstīts uz ekosistēmu struktūru vai funkciju noteicošiem biotiskiem un abiotiskiem faktoriem (Burkhard and Maes, 2017); ekonomiskā novērtējuma metodes, kurās sabiedrības ieguvums tiek aprēķināts naudas izteiksmē (Farber et al. 2012), un sociālā novērtējuma metodes, kurās ekosistēmu pakalpojumu vērtības tiek iegūtas sociālantropoloģisku izziņas metožu ceļā (Plieninger et al. 2013).

Promocijas darba laikā tika izstrādāta jauna biofizikālā novērtējuma pieeja ekosistēmu pakalpojumu nodrošinājuma potenciāla apzināšanai agroekosistēmās. Pieejas pamatā ir zemes kvalitatīvās vērtības, augsnes, reljefa un saimniekošanas intensitātes datu izmantošana ekosistēmu pakalpojumu aprēķināšanai konkrētā platībā. Lauks ir teritoriālā pamatvienība, kuru izmanto integrētās administrācijas un kontroles sistēmas maksājumu aprēķināšanā zemniekiem. Metode ir efektīvi lietojama Baltijas valstīs, jo tā ir balstīta šajās valstīs pieejamos datu slāņos – augsnes un zemes vērtējuma digitālajās kartēs, reljefa modeļos un integrētās administrācijas un kontroles sistēmas datos, kas vienlīdz pārklāj visu teritoriju.

Zemes pārvaldības īstenošanai svarīgi ir izveidot sistēmu, ar kuras palīdzību lēmumu pieņēmēji – politiķi un ierēdņi, zemes īpašnieki vai tās lietotāji – spētu novērtēt zemes izmantošanas veidu un to maiņas ietekmi uz sniegtajiem ekosistēmu pakalpojumiem, kā arī prognozēt iespējamās izmaiņas nākotnē. Šobrīd pastāv atšķirīgas pieejas ekosistēmu pakalpojumu integrēšanai telpiskajā plānošanā (Grêt-Regamey et al. 2017), tomēr neviena no tām nav pielāgota šo pakalpojumu novērtēšanai un izmantošanai zemes pārvaldībā agroekosistēmās. To pamatā ir vai nu ierobežoti dati (piem., tikai zemes segums (Dailey et al., 2009)), vai sarežģīti iegūstami sākotnējie dati (Grêt-Regamey et al. 2017), kā arī bieži vien to lietošanai ir nepieciešamas specifiskas priekšzināšanas un iemaņas (Bagstad et al. 2011; Jackson et al. 2013; Fürst et al. 2010; Peh et al. 2013; Pickard et al. 2015). Tādējādi šīs pieejas nevar plaši un efektīvi izmantot, jo sniegto ekosistēmu pakalpojumu novērtēšanā nevar izmantot esošās nacionālās ģeotelpiskās datubāzes.

Promocijas darbā tiek aprakstīts un analizēts *LIFE Viva Grass* projektā izstrādātais integrētās plānošanas rīks, kura izveidē autors ir aktīvi līdzdarbojies.

Zinātniskā novitāte

Promocijas darba pamatā ir trīs izvirzītie pamatuzdevumi un to novatoriski risinājumi:

1. Zemes izmantošanas izmaiņu virzītājspēku apzināšana mozaīkveida ainavā:
   a) veikta plaša ģeotelpisko datu apkopošana, izmantojot tālizpētes, ģeotelpiskās analīzes un lauka apsekošanas metodes;
   b) pirmo reizi izstrādāta un aprobēta metodika autoloģistiskās binārās regresijas (ABR) modeļa izstrādei lauksaimniecībā izmantojamās zemes (LIZ) pamešanas modelēšanai mozaīkveida ainavā.
2. Ekosistēmu pakalpojumu apzināšana un kartēšana agroekosistēmās:
   a) izstrādāta jauna ekosistēmu pakalpojumu novērtēšanas metode, kuras pamatā ir zemes kvalitatīvās vērtības, augsnes, nogāžu slīpuma un integrētās administrācijas kontroles sistēmas dati; izstrādātajā metodē tiek izmantotas jau eksistējošas visaptverošas nacionālā līmeņa ģeotelpiskās datubāzēs, kas ir pieejamas Baltijas valstīs;
   b) veikta ekosistēmu pakalpojumu vērtību mijiedarbības statistiskā analīze, kas ļāva izdalīt ekosistēmu pakalpojumu telpiskās kopas, kompromisu un sinerģijas situācijas, tādējādi tādējādi nodrošinotekosistēmu pakalpojumu novērtēšanas integrēšanu zemes pārvaldības plānošanā tādējādi nodrošinotekosistēmu pakalpojumu novērtēšanas integrēšanu zemes pārvaldības plānošanā.
3. Daudzkritēriju lēmumu pieņemšanas atbalsta rīka jeb integrētā plānošanas rīka *Viva Grass Tool* pamatā esošās algoritmu kopas izstrāde:
   a) ekosistēmu pakalpojumu vērtību un ekosistēmu pakalpojumu mijiedarbības vērtību kartogrāfiskā attēlojuma izstrāde;
   b) ainavu izmaiņu virzītājspēku, ekosistēmu pakalpojumu vērtību un to mijiedarbības vērtību iestrāde svērtās summas modeļos integrētās plānošanas rīka lēmuma pieņemšanas atbalsta sistēmas ietvaros;
   c) veikta integrētās plānošanas sistēmas aprobācija mozaīkveida ainavā.

Hipotēze

Ekosistēmu pakalpojumu pieejā balstīts daudzkritēriju lēmumu pieņemšanas atbalsta rīks ir lietojams zemes izmantošanas pārvaldībā un plānošanā, tādējādi palīdzot nodrošināt agroekosistēmu ilgtspēju.

Darba mērķis:

izstrādāt un aprobēt ekosistēmu pakalpojumu pieejā balstītus agroekosistēmu pārvaldības risinājumus mozaīkveida ainavā.

Uzdevumi mērķa sasniegšanai:

1. izveidot ģeotelpisko datubāzi ainavu izmaiņu virzītājspēku un ekosistēmu pakalpojumu vērtību apzināšanai;
2. izstrādāt ABR modeli LIZ pamešanas varbūtības noteikšanai mozaīkveida ainavās;
3. izstrādāt metodiku ekosistēmu pakalpojumu vērtību apzināšanai mozaīkveida ainavu agroekosistēmās;
4. izdalīt ekosistēmu pakalpojumu kopas, kompromisus un sinerģijas, veicot ekosistēmu pakalpojumu novērtēšanas matricas statistisko analīzi;
5. izstrādāt kartogrāfiskus risinājumus ekosistēmu pakalpojumu vērtību un ekosistēmu pakalpojumu mijiedarbības vērtību attēlošanai integrētajā plānošanas rīkā;
6. iestrādāt ekosistēmu pakalpojumu vērtību, mijiedarbības un zemes izmantošanas maiņas virzītājspēku vērtības svērtās summas modeļos.

Publikācijas

Promocijas darbs ietver trīs secīgus rakstus, kuros īstenoti darba izstrādāšanā izvirzītie uzdevumi. Promocijas darba uzdevumi ir grupēti četrās grupās, kas publikācijās tematiski pārklājas, bet neatkārtojas (1. attēls). Publikācijas pēdējo divu gadu laikā ir publicētas vai pieņemtas publicēšanai starptautiski citējamos žurnālos.

1. publikācija. **Vinogradovs, I.,** Nikodemus, O., Elferts, D., & Brūmelis, G. (2018). Assessment of site-specific drivers of farmland abandonment in mosaic-type landscapes: A case study in Vidzeme, Latvia. *Agriculture, Ecosystems & Environment*, 253, 113-121 (citēts *Web of Science* un *Scopus* datubāzēs).

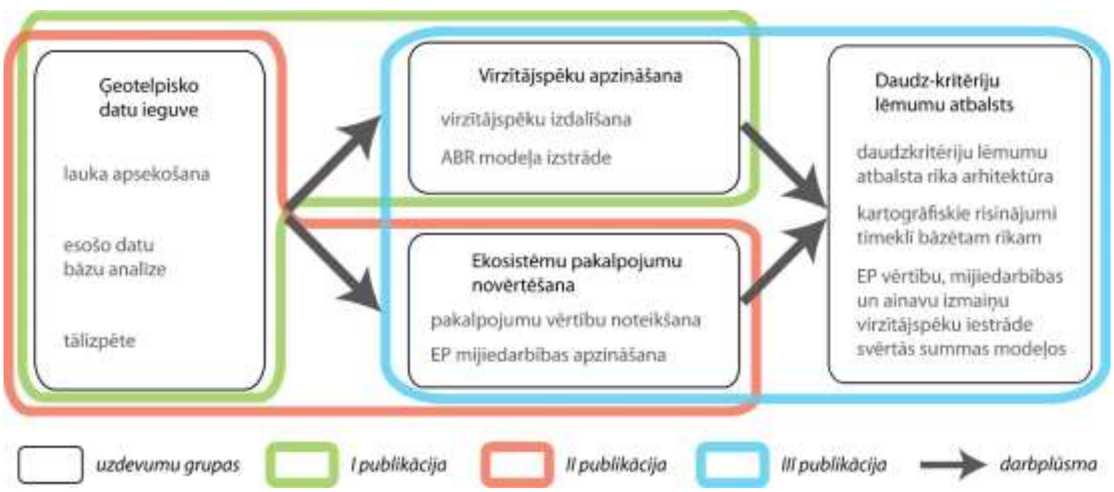
Publikācijā ir aprakstīta metodoloģija ainavu izmaiņu virzītājspēku apzināšanai un novērtēšanai mozaīkveida ainavā. Metodoloģijā ir izklāstītas datu iegūšanas, apstrādes, statistiskās analīzes un modelēšanas metodes. Publikācija satur rezultātu izklāstu un interpretāciju. Promocijas darba autors publikācijas sagatavošanas procesā ir izstrādājis ģeotelpisko datu ievākšanas metodi, ievācis un verificējis empīriskus datus, kā arī līdzdarbojies ABR modeļa izstrādē un interpretējis iegūtos rezultātus.

2. publikācija. Villoslada, M., **Vinogradovs, I.,** Ruskule, A., Veidemane, K., Nikodemus, O., Kasparinskis, R., Sepp, K., Gulbinas, J. (2018). A multitiered approach for grassland ecosystem services mapping and assessment: The Viva Grass tool. *One Ecosystem*, 3, e25380, (citēts *Scopus* datubāzē).

Publikācijā ir atspoguļota metodika, kas balstīta zemes kvalitatīvās vērtības, augšņu, nogāžu slīpuma un zemes izmantošanas datu izmantošanā ekosistēmu pakalpojumu novērtēšanai. Publikācijā veikta ekosistēmu pakalpojumu vērtību un mijiedarbības statistiskā analīze. Izstrādātā metodika ir komandas darba rezultāts. Autora darbs ir ekosistēmu pakalpojumu mijiedarbības statistiskā analīze, kā arī līdzdalība raksta sagatavošanā un publicēšanā.

3. publikācija. **Vinogradovs, I.**, Nikodemus, O., Villoslada, M., Ruskule, A., Veidemane, K., Gulbinas, J., Morknenas, Ž., Kasparinskis, R., Sepp, K., Järv, H., Kliimask, J., Zariņa, A., Brūmelis, G. (pieņemts publicēšanā) Integrating ecosystem services into decision support for management of agroecosystems: Viva Grass tool. *One Ecosystem* (citēts *Scopus* datubāzē).

Publikācijā aprakstīta daudzkritēriju lēmumu pieņemšanas atbalsta rīka arhitektūras izveides darbplūsma, kā arī ekosistēmu pakalpojumu vērtību un to mijiedarbības vērtību integrācija svērtās summas modeļos integrētās plānošanas rīkā *Viva Grass Tool*. Integrētās plānošanas rīka izstrāde ir komandas darbs, kurā promocijas darba autors ir risinājis kartogrāfiskā attēlojuma problemātiku vadījis kartogrāfiskā attēlojuma problemātikas risināšanu un ekosistēmu pakalpojumu nodrošinājuma, mijiedarbības un agroekoloģisko un novietojuma faktoru integrēšanu daudzkritēriju lēmumu analīzes un atbalsta moduļos.



1. attēls. Promocijas darba uzdevumu sasaiste publikācijās un to saistošā darbplūsma.

Saistītās publikācijas

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Kasparinskis, R., Ruskule, A., **Vinogradovs, I.**, Villoslada, M. (2018).The guidebook on the introduction of ecosystem service framework in integrated planning. Riga, University of Latvia, Faculty of Geography and Earth Sciences, p. 63.

Ušča, M., **Vinogradovs, I**., Reķe, A., Immurs, D. V., & Zariņa, A. (2019). Assessment of Ecosystem Services for Planning of Green Infrastructure at the Regional Level. In *Proceedings of the 12th International Scientific and Practical Conference. Volume I* (Vol. 315, p. 319) (citēts *Scopus* datubāzē).

Zariņa, A., **Vinogradovs, I.**, & Šķiņķis, P. (2018). Towards (dis) continuity of agricultural wetlands: Latvia's polder landscapes after Soviet productivism. *Landscape research*, *43*(3), pp. 455–469 (citēts *Scopus* datubāzē).

Saistītās zinātniskās konferences

Vinogradovs, I., Nikodemus, O., Krišjāne, Z. Land use change scenarios in marginal mosaic-type landscapes and their impact on ecosystem services. *IALE Wourld congress* 1–5 July 2019, Milan, Italy.

Zariņa, A., **Vinogradovs, I.,** Ruskule, A., Ecosystem services as an integral support tool for green infrastructure and landscape planning: a case of agro-industrial landscapes in Latvia. *IALE Wourld congress* 1–5 July 2019, Milan, Italy.

Ruskule, A., **Vinogradovs, I.**, Veidemane, K., Prožavoite, D., Nikodemus, O., Villoslada, M., Ādamsone, I. Applying ecosystem service approach and stakeholder engagement in landscape planning: LIFE Viva Grass example. *ESP Europe* 15–19 September 2018, San Sebastian, Spain.

Vinogradovs, I., Nikodemus, O., Elferts, D., Brūmelis, G. Assessment of site-specific agro-ecological and location drivers of farmland abandonment in mosaic-type landscape: case study of Vidzeme, Latvia. *IALE Europe* 12–15 September 2017, Ghent, Belgium.

Zariņa, A., **Vinogradovs, I.** Landscapes of agricultural appearance: non-productivist practices in Latvia's marginal farmlands. *IALE Europe* 12–15 September 2017, Ghent, Belgium.

Ruskule, A., Morkvenas, Ž., Gulbinas, J., Kuris, M., Remmelgas, L., Indriksone, D., Veidemane, K., **Vinogradovs, I.,** Villoslada, M. Accommodating the ecosystem service concept for enhancing grassland viability in the Baltic States: the LIFE Viva Grass approach. *IALE Europe* 12–15 September 2017, Ghent, Belgium.

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Vinogradovs, I. Tālizpētes datu izmantošana zemes seguma izmaiņu izpētei mozaīkveida ainavās: iespējas un ierobežojumi. *LU 72. zinātniskā konference*. 23.–31. janvāris, 2014, Rīga.

Autora darbība projektos promocijas darba izstrādes laikā

4. Integrētās plānošanas rīks pļavu dzīvotspējas nodrošināšanai *LIFE Viva Grass* (EU LIFE+ program, project No. LIFE13 ENV/LT/000189), 2016–2019, pētnieks.
5. Dabas resursu ilgtspējīga izmantošana klimata pārmaiņu kontekstā, Latvijas Universitātes pētniecības projekts Nr. ZD2010/AZ03, 2016–2017, pētnieks.
6. Marginālo teritoriju veidošanās cēloņi un sekas Latvijā, valsts zinātniskā granta projekts (Nr. 514/2012), 2016, pētnieks.

Promocijas darbs sastāv no kopsavilkuma angļu un latviešu valodā un trīs secīgiem rakstiem – promocijas darba daļām. Kopsavilkums ietver anotāciju, ievadu, metožu un rezultātu daļu, secinājumus un izmantotās literatūras sarakstu.

1. DATI UN PĒTĪJUMA METODOLOĢIJA

1.1. Pētījuma teritorija

Pētāmā teritorija (2. att.) atrodas Vidzemes augstienes rietumu daļā. Tā ietver Cēsu novada Vaives pagastu, Vecpiebalgas novada Taurenes, Vecpiebalgas un Dzērbenes pagastu, Raunas novada Drustu pagastu un Jaunpiebalgas novada Zosēnu pagastu. Promocijas darba laikā izstrādātā pieeja tika aprobēta arī Latvijas un Baltijas mērogā.

2. attēls. Pētījuma teritorija

1.2. Ģeotelpisko datu ieguve

Kvalitatīvi ģeotelpiskie dati ir ilgtspējīgas zemes pārvaldības pamatā. Promocijas darbā tika izveidota augstas izšķirtspējas ģeotelpisko datu kopa, kura bija par pamatu ainavas izmaiņu virzītājspēku modelēšanai un ekosistēmu pakalpojumu novērtēšanai. Pētījuma laikā, izmantojot tālizpētes un lauku apsekošanas metodes, kā arī apkopojot, verificējot un papildinot ģeotelpisko datubāzu informāciju, tika izstrādāta zemes lietošanas ģeotelpiskā datubāze.

Pirmais apakšuzdevums bija esošo ģeotelpisko datubāzu apzināšana, to kvalitātes novērtēšana un savietošana. Izmantotās datubāzes ir apkopotas 1. tabulā.

Darba izstrādāšanas laikā datubāzes tika pārstrukturētas atbilstoši pētījuma vajadzībām. Nepieciešamības gadījumā dati tika kategorizēti (piemēram, zemes kvalitatīvā vērtība, dzīvnieku skaits novietnēs) vai izmantoti atvasinātu datu ģenerēšanai (piemēram, attālums līdz dzīvnieku novietnei, mežmalai, ceļam ar segumu).

1. tabula

Pētījumā izmantotās ģeotelpiskās informācijas datubāzes

Ģeotelpiskās informācijas datubāze	*Turētājs*	*Pieejamība, piezīmes*
Lauku reģistra dati	Lauku atbalsta dienests	Brīvpieejas (no 2018. gada), pieejami gan lauku bloki, gan atsevišķu lauku dati, kas ietver audzētās kultūras, saņemtos maksājumus u. c.
Meliorācijas dati	Zemkopības ministrijas nekustamie īpašumi	Brīvpieejas, satur plašu informāciju par meliorācijas sistēmām, to veidu un ierīkošanas (atjaunošanas) laiku.
Dzīvnieku reģistrs	Lauksaimniecības datu centrs	Brīvpieejā nav pieejami ģeotelpiski dati.
Kadastra dati	Valsts zemes dienests	Ierobežotas pieejamības, nav pieejami dati par zemes īpašnieku.
Digitālās augšņu kartes	Valsts zemes dienests	Brīvpieejas, pārsvarā sedz lauksaimniecībā izmantojamās zemes
Zemes kvalitatīvās vērtības dati	Valsts zemes dienests	Brīvpieejas, pārsvarā sedz lauksaimniecībā izmantojamās zemes
ĪADT, biotopu dati	Dabas aizsardzības pārvalde	Brīvpieejas
Topogrāfiskie dati 1:10000	Latvijas Ģeotelpiskās informācijas aģentūra	Ierobežotas pieejamības, nepilnīgs zemes seguma datu pārklājums
Digitālā augstuma modeļa pamatdati	Latvijas Ģeotelpiskās informācijas aģentūra	Brīvpieejas, nepilnīgs pārklājums, nepieciešama pēcapstrāde
Digitālais reljefa modelis	Latvijas Ģeotelpiskās informācijas aģentūra	Brīvpieejas, zema izšķirtspēja (20 m)
Meža valsts reģistrs	Valsts meža dienests	Ierobežotas pieejamības
Valsts nozīmes kultūras pieminekļu dati	Nacionālā kultūras mantojuma pārvalde	Brīvpieejā nav pieejami ģeotelpiskie dati

Lai papildinātu un daļēji arī verificētu apkopotajās ģeotelpiskajās datubāzēs ietverto informāciju, tika lietotas tālizpētes metodes. Pirmkārt, tas bija vizuāls vienlaikus veikts vairāku ciklu ortofoto novērtējums, tādējādi tika fiksētas pamestās lauksaimniecībā izmantojamās zemes. Promocijas darba laikā tika aprobēta LIDAR punktu mākoņa (punktu kopas) datu izmantošana zemes apauguma noteikšanai lauksaimniecības zemē Vaives pagastā. Par teritoriju tika iegūti LIDAR dati ar izšķirtspēju 8 pt/m^2. Pēc tam tika veikta punktu mākoņa klasifikācija un interpretācija, kā arī tika izveidots reljefa un virsmas digitālais modelis. *ArcGIS* programmatūrā, izmantojot *MapAlgebra* moduli, tika konstruēts normalizēts virsmas modelis, un uz tā pamata – apauguma augstuma modelis. Paralēli tika izstrādāts arī LIDAR datu intensitātes modelis, kas ļāva aprobēt inovatīvu pieeju izcirtumu un aizaugušas lauksaimniecībā izmantojamās zemes nošķiršanai. Kvalitatīvu, telpiski plašu datu nepieejamības dēļ bija jāatsakās no šīs metodes lietošanas visā pētījuma teritorijā.

Situācijā, ka ne visa lauksaimniecībā izmantojamā zeme ir deklarēta lauku reģistra datos (proti, zeme tiek izmantota lauksaimnieciskai ražošanai, bet par to netiek saņemti Eiropas Savienības atbalsta maksājumi, vai arī lauksaimniecībā potenciāli izmantojamā zeme tiek apsaimniekota – zāle tiek pļauta un uz vietas mulčēta –, tikai lai, piemēram, saglabātu atvērtu ainavu ap brīvdienu lauku mājām), pilnvērtīgas ģeotelpiskās datubāzes sastādīšanai bija nepieciešama lauksaimniecības zemju apsekošana. Teritorijas apsekošana tika veikta 2014. un 2015. gada vasaras beigās un rudens sākumā. Tās laikā tika noteikts lauksaimniecības zemes apsaimniekošanas veids un intensitāte un sevišķa uzmanība tika pievērsta lauksaimniecības zemes aizaugšanas pakāpei un mērķtiecīgi apmežotām teritorijām. Tādējādi tika izdalītas trīs lauksaimniecībā izmantojamās zemes kategorijas: lauksaimniecības zeme, kas tiek izmantota lauksaimnieciskā ražošanā; neizmantotā lauksaimniecības zeme, kas pakļauta dabiskai apmežošanai; un daļēji pamestā lauksaimniecības zeme, kas tiek uzturēta, bet netiek izmantota lauksaimnieciskai ražošanai. Atsevišķās teritorijās (Vaives pagastā) tika veikta arī Sosnovska latvāņa izplatības kartēšana, lai vēlāk šo informāciju varētu iekļaut lēmumu pieņemšanas atbalsta rīkā.

1.3. Zemes izmantošanas virzītājspēku novērtēšana

Ainavu virzītājspēku apzināšana tika veikta trīs secīgos soļos: virzītājspēku identifikācija, ģeotelpiskā analīze un statistiskā analīze. Balstoties iepriekš veiktajos pētījumos (Nikodemus et al. 2005; Nikodemus et al. 2010; Ruskule et al. 2012; Vanwambeke et al. 2012; Ruskule et al. 2013), tika identificēts nozīmīgākais mozaīkveida ainavas izmaiņu process – lauksaimniecībā izmantojamās zemes pamešana. Pētījuma teritorijai atbilstošu virzītājspēku izdalīšanai tika izvēlēti faktori, kas atspoguļo vietai specifiskās īpašības, telpiski variē vienā ainavas tipā un ir atzīti par nozīmīgiem arī iepriekš veiktos pētījumos. Virzītājspēku pamatā esošo faktoru apkopojums ir attēlots 2. tabulā.

2. tabula

Zemes izmantošanas virzītājspēku apzināšanas ģeotelpiskai analīzei izmantotie faktori

Mainīgais	*Mērvienība*	*Apraksts*
Zemes vērtība	balles/ha (0–100)	Lauksaimniecības zemes vērtība, izteikta ballēs
Augsnes granulometriskais sastāvs	grupa	Augšņu granulometriskā sastāva grupa: smilts, mālsmilts, smilšmāls, māls, kūdra
Kadastra vienības izmērs	ha	Kadastra vienības izmērs (ha) 2016. gadā
Meliorācijas sistēmas	0/1	Meliorācijas sistēmu klātbūtne
Reljefa slīpums	0/1	Nogāze <10°/>10°
Kādreizējā lauka izmērs	ha	Masivizētā lauka izmērs vai lauka izmērs
Attālums līdz lauku centram	m	Attālums metros
Attālums līdz ceļam ar grants vai asfalta segumu	m	Attālums metros
Attālums līdz dzīvnieku novietnei	m	Attālums metros
Attālums līdz meža malai	m	Attālums metros

Dati tika apkopoti režģa veida analīzes modelī *ArcMap* programmā. Analītiskā režģa izmērs tika izvēlēts 100 ×100 m, un tas atbilst zemes lietojuma veidu plankumu detalizētībai izveidotajos telpiskajos zemes lietojuma datos. Katram datu režģa poligonam tika izveidots centroīds, tādējādi pētāmā teritorija tika noklāta ar 220 000 datu ievākšanas punktiem. Katrā punktā tika nolasītas visu apzināto faktoru vērtības, tās tika papildinātas ar X un Y koordinātām LKS-92 sistēmā un saglabātas tālākai statistiskai analīzei tabulas formā.

Statistiskā analīze tika veikta programmā R (R Core Team, 2017). Lai atbilstošāk izvēlētos analīzes modeli, tika veikta datu aprakstošā statistiskā analīze, grafiski attēloti un aprakstīti mainīgo biežumu sadalījumi. Lai novērtētu lauksaimniecības zemes pamešanas varbūtību, tika izveidoti divi autoloģistiskās bināras regresijas modeļi programmatūrā R 3.4.0. (R Core Team, 2017). Viens modelis tika izveidots, lai salīdzinātu varbūtības attiecībā uz daļēji pamestu lauksaimniecības zemi salīdzinājumā ar lauksaimniecības zemi, ko izmanto lauksaimnieciskā ražošanā, un otrs modelis –, lai salīdzinātu pamesto lauksaimniecības zemi ar lauksaimniecības zemi, ko izmanto lauksaimnieciskajā ražošanā. Lai ņemtu vērā telpisko autokorelāciju, abos modeļos tika iekļauta attāluma svērtā autokovariante (aprēķināta R paketē spdep (Bivand et al. 2013)). Zemes kvalitatīvā vērtība, attālums līdz ceļam, kadastra vienības platība, iepriekšējā zemes izmantošanas veida lauka platība, augsnes granulometriskais sastāvs, nogāzes slīpums un meliorācijas sistēmu klātbūtne abos modeļos tika izmantoti kā neatkarīgi mainīgie. Neatkarīgajiem mainīgajiem netika novērota multikolinearitāte, jo vispārināto variances ietekmes faktoru vērtības bija mazākas par 2 visiem mainīgajiem. Visi attāluma un laukuma mainīgie tika mērogoti atbilstoši vienības novirzei pirms analīzes, jo tiem bija liela amplitūdu atšķirība. Izskaidrotā novirze tika aprēķināta, lietojot *McFadden* metodi ar pseido r^2, kas tiek izmantota vispārinātiem lineāriem modeļiem R paketē pscl (Jackmans, 2017).

1.4. Ekosistēmu pakalpojumu novērtēšana

Ģeotelpiskā pamatne ekosistēmu pakalpojumu novērtēšanai tika veidota no lauksaimniecībā izmantojamās zemes agroekoloģisko apstākļu (zemes kvalitāte, augsne un reljefs) un zemes apsaimniekošanas veida pārklājuma. Kā agroekoloģisko apstākļu kompozītvērtība tika izmantota zemes kvalitatīvā vērtība un augsnes granulometriskā sastāva grupu redukcija divās kategorijās – minerālaugsnēs un organiskajās augsnēs (kūdraugsnēs). Zemes kvalitatīvā vērtība tika iedalīta trīs klasēs, par sliekšņa vērtībām izmantojot pētījumos (LLU, 2019) izvirzītās 25 un 50 balles, kas relatīvi norāda uz lauksaimniecības zemes auglību un marginalizācijas potencialitāti. Nogāzes slīpuma vērtības tika iedalītas trīs klasēs atkarībā no nogāzes slīpuma ietekmes uz potenciālo augsnes eroziju. Zemes apsaimniekošanas veids tika iedalīts piecās klasēs atkarībā no intensitātes, ar kādu zemes apsaimniekošana ietekmē augsnes virskārtu, un no zālaugu sugu atbilstības noteiktam biotopam. Sagrupējot ekosistēmu pakalpojumu novērtēšanas pamatdeterminantus, tika izšķirtas ekosistēmu pakalpojumu novērtēšanas novērtēšanas kategorijas (3. tabula). Par ekosistēmu pakalpojumu novērtēšanas un vienlaikus arī par to sniegšanas vienību tika noteikts “lauks” – vienlaidus zemes lietojuma teritoriālā vienība, kuras robežas tika noteiktas vai nu pēc lauku reģistra datiem (deklarētie lauki), vai teritorijas apsekojuma un tālizpētes datiem ārpus deklarētājām lauksaimniecības zemēm. Katrai teritorijai (laukam), kas nodrošina ekosistēmu pakalpojumus, tika veikta zonālā statistikā analīze un piešķirta dominējošā ekosistēmu pakalpojumu pamatdeterminanta vērtība. Apsaimniekošanas veids tika noteikts pēc lauku reģistra datiem. Atsevišķi zemes lietojuma veidi, kuru īpatsvars pētījuma teritorijā nebija liels, tika izslēgti no ekosistēmu pakalpojumu novērtējuma (piemēram, augļudārzi, ogulāji, īscirtmeta audzes).

3. tabula

Ekosistēmu pakalpojumu pamatdeterminantu klasifikācija

	Ekosistēmu pakalpojumu novērtēšanas pamatdeterminanti		
	Augsnes	*Nogāzes*	*Apsaimniekošanas veids*
Klases	Zema kvalitāte	< 4°	Kultivētie zālāji
	Vidēja kvalitāte	4–10°	Ilggadīgie zālāji
	Augsta kvalitāte	> 10°	Daļēji dabiskie zālāji
	Organiskās augsnes		Aramzemes
			Neizmantotās lauksaimniecības zemes

Ekosistēmu pakalpojumu nodrošinājuma potenciāls tika novērtēts ar matricas metodi (Burkhard et al., 2009) pieciem apgādes un deviņiem regulējošiem (CICES, 2015) ar agroekosistēmām saistītiem pakalpojumiem. Katram pakalpojumam tika noteikts viens indikators. Eksperti – ģeogrāfijas, bioloģijas, vides zinātnes, lauksaimniecības un augsnes zinātnes speciālisti –, balstoties uz zinātnisko literatūru, katrai ekosistēmu pakalpojuma kategorijai veica daļēji kvantitatīvu vērtējumu skalā no 0 (pakalpojums netiek sniegts) līdz 5 (ļoti augsts pakalpojuma nodrošinājums). Piešķirtās ekosistēmu pakalpojumu vērtības ir potenciāli aizvietojamas ar faktiskām pakalpojumu vērtībām, kad šādas vērtības būs pieejamas. Kultūras ekosistēmu pakalpojumi netika vērtēti ar matricas metodi, jo šie pakalpojumi ir atkarīgi no konkrētās teritorijas ģeogrāfiskā stāvokļa saistībā ar tiem ainavas elementiem, kas nodrošina šo pakalpojumu (4. tabula).

4. tabula

Kultūras ekosistēmas pakalpojumu novērtēšanas kritēriji

Kultūras ekosistēmu pakalpojumi	*Indikators / ainavas elements*	*Attālums (vai cits kritērijs)*
Tieša un netieša, fiziska un uz pieredzi balstīta mijiedarbība (Rekreācija)	Lauku rekreācijas uzņēmumi	3 km
	Novērošanas torņi	300 m
	Tūrisma takas	100 m
	Medību teritorijas	ietilpst (0 m)
	Telts vietas, ugunskura vietas	300 m
	Sanākšanas vietas	300 m
Intelektuāla mijiedarbība (Izglītība)	Mācību takas	100 m
	Mācību vietas (stendi)	100 m
Kultūrvēsturiskā vērtība	Kultūras pieminekļi	100 m
	Vecsaimniecības un muižas	100 m
	Tradicionālā zemes lietojuma veida lauki	300 m
Estētiskā vērtība	Ūdenstilpes un upes	300 m
	Daļēji dabiskie zālāji	100 m
	Zemes lietojuma veids "daļēji dabiskais zālājs"	ietilpst (0 m)
	Lineārie ainavu elementi (alejas, koku rindas)	300 m
	Reljefa saposmotība	standartnovirze >10 5 × 5 km režģī
	Ainavas atklātums	mežu segums <50% 5 × 5 km režģī

Ekosistēmu pakalpojumu kopas tika izdalītas, veicot galveno komponentu analīzi šo pakalpojumu novērtējuma kategoriju rādītājiem (novērojumi) un ekosistēmu pakalpojumiem (mainīgie) (Queiroz et al. 2015) SPSS datorprogrammā. Ekosistēmu pakalpojumu kompromiss un sinerģija[1] ārpus ekosistēmu pakalpojumu kopām tika analizēti, izmantojot katra ekosistēmu pakalpojumu pāra korelācijas analīzi. Ekosistēmu pakalpojumu nodrošinājuma “karsto” punktu izdalīšana tika veikta, saskaitot ekosistēmu pakalpojumus ar augstām vērtībām (4, 5), savukārt “auksto” punktu izdalīšana –, saskaitot ekosistēmu pakalpojumus ar zemām vērtībām (1, 2) (Egoh et al. 2009).

1.5. Daudzkritēriju lēmumu atbalsta rīka izstrāde

Daudzkritēriju lēmumu atbalsts (DKLA) ir izstrādāts, lai virzītu lēmumu pieņemšanas procesu, ņemot vērā vairākus kritērijus situācijās, kad jāsasniedz vairāki mērķi un ir vairākas ieinteresētās personas (Belton & Stewart, 2002). Plānošanas un teritoriju pārvaldes mērķiem ir raksturīga sarežģīta struktūra, kas nav izsakāma ar atsevišķu indikatoru vai vienu datu kopu (Koschke et al., 2012). Piedāvātais DKLA rīks sniedz strukturētu shēmu, kas apvieno ekosistēmu pakalpojumu novērtēšanas rezultātus ar biofizikālām un sociālekonomiskām datu kopām jēgpilnā veidā, paverot iespēju integrētai izmantošanai plānošanas procesā.

Atsevišķie rīka modeļi ir konstruēti atšķirīgām funkcionalitātēm un dažādām lietotāju grupām (5. tabula). DKLA procesa pilno funkcionālo atbalstu sniedz modulis “Viva Grass plānotājs”, kura pilnvērtīgai izmantošanai ir nepieciešama ĢIS datu apstrādes procesu izpratne. “Viva Grass pārlūkam” primāri ir ekosistēmu pakalpojumu novērtējuma un ekosistēmu pakalpojumu mijiedarbības pārskata funkcija, modulis “Viva Grass bioenerģija” ir izveidots, lai plānotu zāles biomasas izmantošanu kā kurināmā avotu.

5. tabula

DKLA rīka funkcionalitātes un mērķauditorija

	Funkcionalitātes									
Rīka moduļi	Zemes izmantošanas veids (LIZ)	Ekosistēmu pakalpojumu novērtējums	Ekosistēmu pakalpojumu kopas, aukstie/karstie punkti	Biomasas potenciāls	Bioenerģijas potenciāls	Apsaimniekošanas ieteikumi	Prioritāšu noteikšana, klasifikācija	Karšu eksportēšana	Rediģēšana. augšupielāde, lejupielāde	Mērķauditorija
Viva Grass pārlūks	X	X	X			X		X		Jebkurš interesents
Viva Grass bioenerģija	X			X	X	X		X		Plānotāji, pētnieki, politiku veidotāji
Viva Grass plānotājs	X	X	X			X	X	X	X	Plānotāji, pētnieki, politiku veidotāji

[1] Ekosistēmu pakalpojuma kompromiss ir situācija, kad, palielinoties viena pakalpojuma vērtībai, samazinās cita pakalpojuma vērtība; ekosistēmu pakalpojuma sinerģija ir situācija, kad, palielinoties viena pakalpojuma vērtībai, palielinās arī cita pakalpojuma vērtība.

Daudzkritēriju lēmumu atbalsta shēmu (3. attēls) izstrādājusi grupa pētnieku (Langemeyer et al. 2016), un uz tās pamata promocijas darbā tika izveidots DKLA rīks. Aprobējot DKLA rīku, katra procesa posma izstrādē sevišķa uzmanība tika veltīta ieinteresētajām personām – tās tika iesaistītas pēctecīgās darba grupu sanāksmēs un šo sanāksmju rezultātu apspriedēs. Promocijas darba autors DKLA rīka aprobāciju veica vienā administratīvajā teritorijā (Cēsu novadā), sasaistot to ar novada attīstības programmas un teritorijas plāna izstrādi. Ieinteresēto personu sanāksmēs tika pārstāvēti novada telpiskās plānošanas speciālisti, Cēsu novada administratīvās pārvaldes darbinieki, lauku konsultanti, tūrisma speciālisti, zemnieku, uzņēmēju un iedzīvotāju pārstāvji. Kritēriju formulēšanas posmā tika organizēti arī izglītojoši informatīvas sanāksmes, lai dalībniekus iepazīstinātu ar ekosistēmu pakalpojumu konceptu, tā izmantošanu telpiskajā plānošanā un ar to saistītu lēmumu pieņemšanā.

3. attēls. Daudzkritēriju lēmumu atbalsta procesa shēma (pēc Langemeyer et al. 2016)

DKLA kritēriju svēršanas un alternatīvu prioritizācijas pamatā tika izmantots svērtās summas modelis (Triantaphyllou, 2000), kur atsevišķi ekosistēmu pakalpojumi tika izvēlēti kā svēršanas kritēriji, kuriem lietotājs (ieinteresēto personu kopa) piešķir noteiktas vērtības ar summāro vērtību 100. Šīs vērtības rezultējas noteikto prioritāšu svarā, kas tiek aprēķināts pēc formulas:

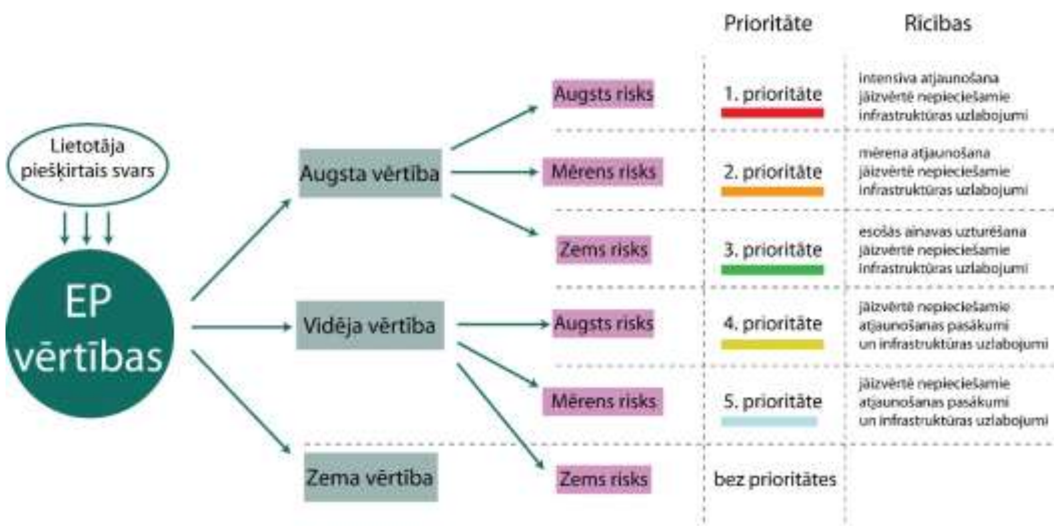
$$\sum_{i=0}^{n} \frac{Index_i}{\max(Index) * n} Weight/100$$

kurā *Index* ir noteiktā indeksa vērtība (ekosistēmu pakalpojumu vērtība), *max(Index)* – izvēlētā indeksa maksimālā vērtība un *Weight* – lietotāja noteiktais kritērija svars. Kopējais svara indekss ir atsevišķo komponentu summa. Tā kā svērtās summas modelī izmantojamās vērtības izteiktas atšķirīgās mērvienībās, ir nepieciešams, lai visi kritēriji tiktu normalizēti un lai DKLA rīkā ir iekļauta datu klasifikācijas iespēja, kas ļauj alternatīvu prioritizācijai pievienot atšķirīgi izteiktus datus, piemēram, "aukstā" punkta vērtību vai piederību pie kāda no ekosistēmu pakalpojumu kompromisiem, kā arī datus, kas tiek veidoti noteiktu problēmsituāciju risināšanai, piemēram, lauksaimniecības zemes pamešanas riska indeksu. Papildus nepieciešamie rādītāji DKLA rīkā ir izmantojami kā pamatdatu atvasinājumi vai kā jauni saliktie indeksi, kas veidoti kā svērtās summas modeļi pēc formulas:

$$A_i^{SSM-vērtība} = \sum_{j=1}^{n} w_j\, a_{ij}, \text{kur } i = 1, 2, 3, \dots\ m$$

kur w_i ir kritērija svars, a_{ij} ir kritērija vērtība un $A_i^{SSM\text{-}vērtība}$ ir saliktā indeksa vērtība.

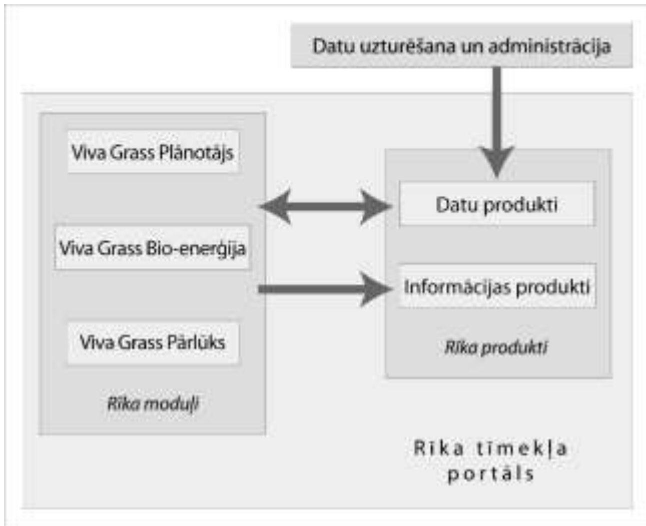
Cēsu novadā DKLA rīks tika aprobēts, nosakot tās lauksaimniecības zemes apsaimniekošanas prioritātes, kas palīdzētu saglabāt un palielināt tūrisma potenciālu. DKLA darbplūsma (4. attēls) tika īstenota piecās secīgās ieinteresēto personu sanāksmēs. Pirmajā sanāksmē klātesošie tika iepazīstināti ar ekosistēmu pakalpojumu pieeju un to izmantošanu. Nākamajās vispirms tika apspriesti iepriekšējās sapulces rezultāti un, ja nepieciešams, veikti lēmumu labojumi.



4. attēls. Lauksaimniecības zemes apsaimniekošanas prioritāšu izstrādes DKLA darbplūsma.

1.6. ĢIS un kartogrāfiskie risinājumi tīmekļa rīkam

DKLA tīmekļa rīka pamatā ir *ArcGIS Enterprise* platforma. Dati tiek glabāti kopējā telpiskajā datubāzē (*PostgreSQL*) un publicēti kā ĢIS pakalpojumi (kartes). Tīmeklī balstītie rīku moduļi tiek veidoti, izmantojot *ArcGIS* lietojumprogrammu veidotāju. Lai īstenotu pielāgotās prasības, tika izveidoti papildu lietojumprogrammu logrīki (5. attēls). DKLA tīmekļa rīks ietver trīs galvenos rīku moduļus. Tie ir: "Viva Grass pārlūks", "Viva Grass bioenerģija" un "Viva Grass plānotājs", kas paredzēti konkrētiem lietotājiem un lēmumu pieņemšanai noteiktās jomās. Šie trīs moduļi izmanto dažādus datus un veido informācijas produktus, kurus var saistīt ar citām informācijas platformām.



5. attēls. DKLA tīmekļa rīka struktūra

Ģeotelpiskās analīzes rezultāti, kas iegūti ekosistēmu pakalpojumu novērtēšanas un/vai rīka izstrādes laikā, ir pieejami kā "datu produkti" – apveidfailu (*.shp) arhīvi, savukārt ekosistēmu pakalpojumu novērtējuma matrica, DKLA risinājumu algoritmi un ieteicamās apsaimniekošanas prakses ir pieejami kā "informācijas produkti".

2. REZULTĀTI UN DISKUSIJA

Šajā promocijas darba nodaļā ir aprakstīti galvenie darba rezultāti – zemes izmantošanas izmaiņu virzītājspēku analīze, ekosistēmu pakalpojumu novērtēšana un to mijiedarbības analīze, daudzkritēriju lēmumu pieņemšanas atbalsta rīka aprobēšana, kā arī ir šie rezultāti saistīti ar citiem nozarē aktuāliem pētījumiem.

2.1. Zemes izmantošanas virzītājspēku analīzes rezultāti

Promocijas darbā īstenotā metode identificēja zemes izmantošanas izmaiņu virzītājspēkus un lauksaimniecības zemes pamešanas varbūtību (risku). Apzinātās zemes izmantošanas izmaiņas ir saistāmas ar zemes reformu pēc PSRS sabrukuma un lauksaimniecības nozares pārstrukturizāciju pēc iestāšanās ES.

6. tabula

Autoloģistiskās binārās regresijas modeļa rezultāti

Zemes apsaimniekošanas veids	*Mainīgais*	*Novērtējums*	*Iespējamību attiecība*	*Standartkļūda*	*t vērtība*	*p vērtība*
Daļēji pamesta LIZ	KVP	– 0,38	0,69	0,06	– 6,55	< 0,001
	KLI	– 0,32	0,72	0,05	7,09	< 0,001
	ALC	– 0,07	0,93	0,04	– 1,59	0,113
	ALF	0,23	1,27	0,04	5,97	< 0,001
	AMM	– 0,26	0,77	0,05	– 5,63	< 0,001
	ACS	0,17	1,19	0,04	4,18	< 0,001
	ZKV	– 0,32	0,73	0,05	– 6,36	< 0,001
	MSK	– 0,58	0,56	0,01	– 5,76	< 0,001
	NST	– 0,03	0,97	0,10	– 0,25	0,803
	Augsnes granulometriskais satāvs (kūdra kā reference)					
	M	– 0,55	0,58	0,21	– 2,68	0,007
	sM	– 0,40	0,67	0,14	– 2,85	0,004
	S	– 0,19	0,83	0,16	1,21	0,227
	mS	– 0,38	0,67	0,14	– 2,85	0,004
Pamesta LIZ	KVP	– 0,09	0,91	0,02	– 2,85	< 0,001
	KLI	– 0,22	0,80	0,02	– 2,85	< 0,001
	ALC	0,04	1,04	0,02	– 2,85	
	ALF	0,24	1,27	0,02	– 2,85	< 0,001
	AMM	– 0,59	0,55	0,03	– 2,85	< 0,001
	ACS	0,17	1,18	0,02	– 2,85	< 0,001
	ZKV	– 0,58	0,56	0,03	– 2,85	< 0,001
	MSK	– 0,40	0,67	0,05	– 2,85	< 0,001
	NST	– 0,33	0,72	0,05	– 2,85	< 0,001
	Augsnes granulometriskais sastāvs (kūdra kā reference)					
	M	– 0,95	0,39	0,10	– 2,85	< 0,001
	sM	– 0,61	0,54	0,07	– 2,85	< 0,001
	S	– 0,40	0,67	0,09	– 2,85	< 0,001
	mS	– 0,72	0,49	0,06	– 2,85	< 0,001

KVP – kadastra vienības platības, KLI – kādreizējā lauka izmērs, ALC – attālums līdz lauku centram, ALF – attālums līdz dzīvnieku novietnei, AMM – attālums līdz meža malai, ACS – attālums līdz ceļam ar segumu, ZKV – zemes kvalitatīvā vērtība, MSK – meliorācijas sistēmu klātbūtne, NST – nogāzes slīpums >15°, M – māls, sM – smilšmāls, S – smilts, mS – mālsmilts.

Regresijas modeļi ierasti tiek izmantoti, lai novērtētu zemes izmantošanas izmaiņu virzītājspēkus dažādos reģionos un mērogos (Millington et al. 2007). Autoloģistiskās binārās regresijas rezultāti (6. tabula) liecina, ka Vidzemes mozaīkveida ainavā augstāka zemes kvalitatīvā vērtība samazina iespēju, ka lauksaimniecībā izmantojamā zeme tiks transformēta par daļēji pamestu (neizmantotu) lauksaimniecības zemi (iespējamību attiecība 0,73, $p < 0,001$) vai pamestu lauksaimniecības zemi (iespējamību attiecība 0,56, $p < 0,001$). Augsnes granulometriskajam sastāvam nav statistiski nozīmīgas ietekmes uz varbūtību, ka lauksaimniecības zeme tiks transformēta par daļēji pamestu, savukārt varbūtība, ka lauksaimniecības zeme tiks pamesta, samazinājās visos augsnes granulometriskā sastāva variantos, kas tika aprēķināti attiecībā pret kūdru. Stāvu nogāžu neesamība (iespējamību attiecība 0,72, $p < 0,001$) samazina varbūtību, ka lauksaimniecībā izmantotā zeme tiks pamesta, savukārt meliorācijas sistēmu esamība samazināja iespēju, ka lauksaimniecības zeme tiks daļēji pamesta (iespējamību attiecība 0,56, $p < 0,001$) vai pamesta (iespējamību attiecība 0,67, $p < 0,001$). Attāluma palielināšanās līdz dzīvnieku novietnei (iespējamību attiecība 1,27, $p < 0,001$) un ceļš ar grants vai asfalta segumu (iespējamību attiecība 1,18, $p < 0,001$), kā arī attāluma samazināšanās līdz meža malai (iespējamību attiecība 0,55, $p < 0,001$) palielināja varbūtību, ka lauksaimniecības zeme tiks pamesta. Lielāks attālums līdz dzīvnieku novietnei (iespējamību attiecība 1,27, $p < 0,001$), mazāks attālums līdz meža malai (iespējamību attiecība 0,78, $p < 0,001$) palielināja varbūtību, ka lauksaimniecības zeme netiks izmantota lauksaimnieciskai ražošanai.

Kopējā izskaidrotā varbūtība Vidzemes mozaīkveida ainavā autoloģistiskās binārās regresijas modelim attiecībā uz lauksaimniecības zemes pamešanu ir 29,21%, savukārt varbūtība, ka lauksaimniecības zeme kļūs daļēji pamesta, ir 40,48%. Lai arī pētāmajā teritorijā izskaidrotā varbūtība variēja, visos pagastos zemes kvalitatīvā vērtība un attālums līdz mežmalai bija nozīmīgi lauksaimniecības zemes pamešanas riska palielināšanās faktori. Lielākajā daļā teritorijas arī attālums līdz dzīvnieku novietnei palielināja lauksaimniecības zemes pamešanas risku. Modeļa neizskaidrotā varbūtība ir saistāma ar modelī neiekļauto faktoru ietekmi. No tiem nozīmīgākie ir tādi saimnieciskā līmeņa sociālekonomiskie faktori kā saimniecības ieņēmumi un lielums, zemnieka vecums un izglītība, lauksaimniecisko prakšu pēctecība un pārmantojamība, mehanizācijas līmenis (Baldock et al. 1996; Van Doorn and Bakker, 2007; Kristensen et al. 2004; MacDonald et al. 2000, Terres et al. 2015). Svarīga nozīme ir arī reģionāla līmeņa sociālekonomiskiem un demogrāfiskiem rādītājiem (Kuemmerle et al., 2008; Prishchepov et al., 2013).

Iegūtie rezultāti ļauj veidot salikto indikatoru no vairākiem mainīgajiem, kuri modelī uzrādīja nozīmīgu ietekmi uz zemes izmantošanas izmaiņām, piemēram, zemes kvalitatīvās vērtības, attāluma līdz lopu novietnei un attāluma līdz mežmalai izmantošana svērtās summas modelī ļauj izveidot lauksaimniecības zemes pamešanas riska indeksu, kas tiek izmantots daudzkritēriju lēmumu pieņemšanas atbalsta rīkā (2.3 apakšnodaļa).

2.2. Ekosistēmu pakalpojumu novērtēšana

Novērtējot ekosistēmu pakalpojumus, katra pakalpojuma izteikšanai tika piemērots noteikts indikators, kas izteikts indikatora vienībās (apgādes pakalpojumiem metriskās vienībās, regulējošiem pakalpojumiem relatīvās vērtībās) un kategorizēts ekosistēmu pakalpojumu novērtēšanas matricas skalā (1–5). Piemēram, pakalpojumam "lopbarība" indikators ir t/ha/gadā un vērtībai "1" atbilst <1 t/ha/gadā, "2" – 2–3 t/ha/gadā utt.

Pakalpojumam “dzīvotņu uzturēšana” indikators ir sugu skaits 1 m^2 un vērtībai “1” atbilst “ļoti mazs sugu skaits”, savukārt “5” atbilst “ļoti liels sugu skaits” (7. tabula, 6. attēls). Novērtējuma matricas datu struktūra ļauj kategorizētos datus aizvietot ar reālajām vērtībām, kad tādas kļūst pieejamas.

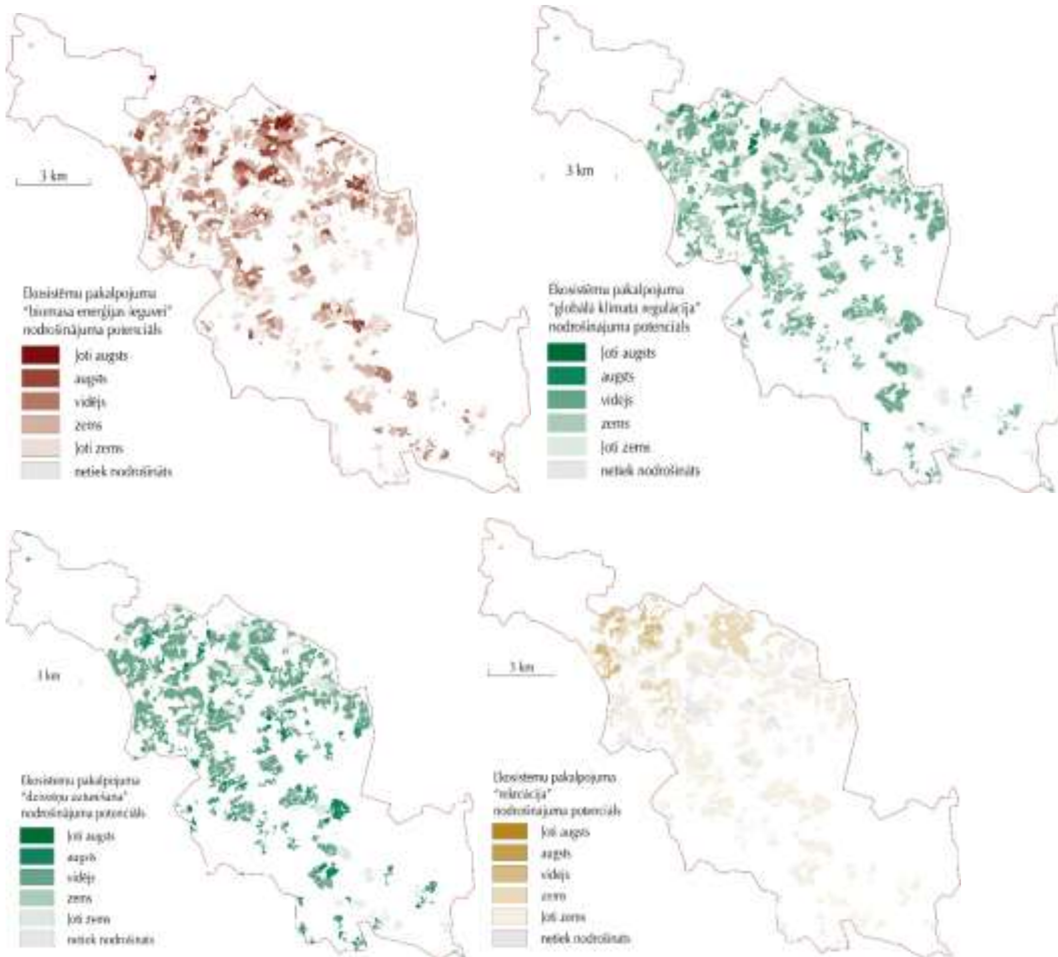
7. tabula

Apgādes un regulējošo ekosistēmu pakalpojumu novērtēšanas matrica (fragments)

	Apgādes ekosistēmu pakalpojumu					*Regulējošie ekosistēmu pakalpojumu*							
LIZ klase	Kultūraugi	Mājlopi	Lopbarība	Biomasa enerģijai	Ārstniecības augi	Bioremediācija	Filtrācija / akumulācija	Erozijas kontrole	Apputeksnēšana	Dzīvotņu uzturēšana	Dēdēšana	Ūdeņu ķīmiskais stāvoklis	Globālā klimata regulācija
11. Ilggadīgie zālāji, līdzens reljefs, zema zemes vērtība	0	2	1	1	3	3	2	0	4	4	2	3	3
12. Ilggadīgie zālāji, līdzens reljefs, vidēja zemes vērtība	0	3	2	2	2	4	3	0	4	3	3	4	3
13. Ilggadīgie zālāji, līdzens reljefs, augsta zemes vērtība	0	4	3	3	2	4	4	0	4	3	4	5	3
14. Ilggadīgie zālāji, līdzens reljefs, organiskās augsnes	0	3	2	2	2	5	4	0	4	3	0	3	4
15. Ilggadīgie zālāji, lēzena nogāze, zema zemes vērtība	0	2	1	1	3	3	2	4	4	4	2	3	3
16. Ilggadīgie zālāji, lēzena nogāze, vidēja zemes vērtība	0	3	2	2	2	4	3	3	4	3	3	4	3
17. Ilggadīgie zālāji, lēzena nogāze, augsta zemes vērtība	0	4	3	3	2	4	4	3	4	3	4	5	3
18. Ilggadīgie zālāji, lēzena nogāze, organiskās augsnes	0	3	2	2	2	5	4	0	4	3	0	3	4
19. Ilggadīgie zālāji, līdzens reljefs, zema zemes vērtība	0	2	1	1	3	3	2	5	4	4	2	3	3
20. Ilggadīgie zālāji, līdzens reljefs, vidēja zemes vērtība	0	3	2	2	2	4	3	5	4	3	2	4	3

Promocijas darba laikā izstrādātā ekosistēmu pakalpojumu novērtēšanas metode identificē pakalpojuma nodrošinājuma potenciālu konkrētajos agroekoloģiskajos apstākļos, ņemot vērā zemes apsaimniekošanas intensitāti. Piemēram, aramzemē sēts zālājs, t. i., vismaz reizi piecos gados uzarta, piesēta, mēslota agroekosistēma, jebkuros agroekoloģiskajos apstākļos nodrošinās augstāku apgādes pakalpojumu vērtību nekā ilggadīgie zālāji. Savukārt daļēji dabiskie zālāji, neintensīvi apsaimniekota un dabiskām sugām bagāta agroekosistēma, jebkuros agroekoloģiskajos apstākļos nodrošinās augstāku regulējošo pakalpojumu vērtību.

Galveno komponentu analīzes rezultātā (8. tabula) ekosistēmu pakalpojumu novērtējuma matricā var izdalīt 3 komponentes, kas izskaidro 90,53% varianci. Pirmā komponente izskaidro 48,18%, un tajā pozitīvi korelē tādi pakalpojumi kā “ārstniecības augi”, “apputeksnēšana”, “dzīvotņu uzturēšana” un “globālā klimata regulācija”, savukārt negatīvi korelē tādi pakalpojumi kā “mājlopi”, “lopbarība” un “biomasa enerģijai”. Šajā komponentē parādās izteikta ekosistēmu pakalpojumu savstarpēja konkurence. Otrā komponente izskaidro 28,1%, trešā komponente izskaidro 14, 25%, un tās ir saistāmas ar pakalpojumiem, ko sniedz augsnes procesi.



6. attēls. Ekosistēmu pakalpojumu novērtējuma piemērs pētījuma teritorijas fragmentam (Cēsu novads).

8. tabula

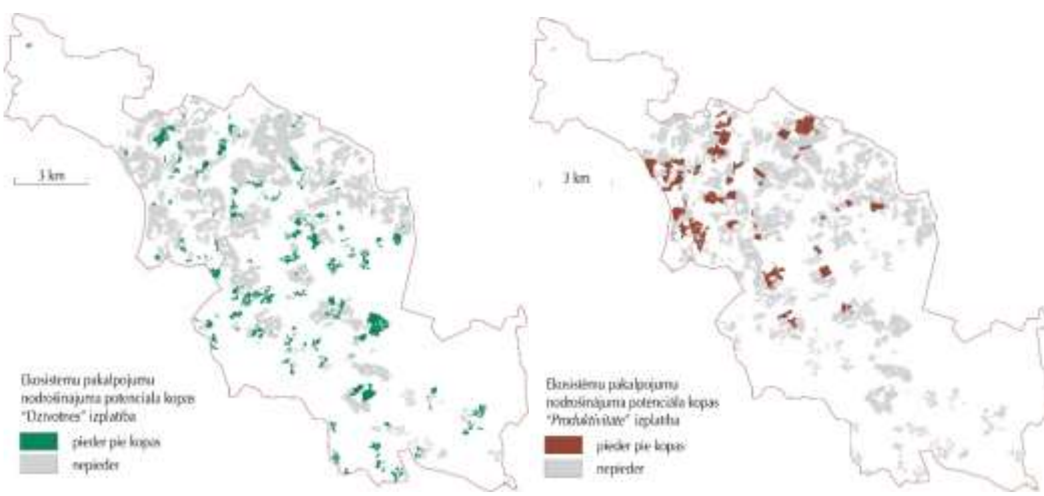
Galveno komponentu analīzes rezultāti

Ekosistēmu pakalpojumi	*1. komponente*	*2. komponente*	*3. komponente*
Mājlopi	–0,958		
Lopbarība	–0,807		
Biomasa enerģijai	–0,808		
Ārstniecības augi	0,921		
Apputeksnēšana	0,846		
Dzīvotņu uzturēšana	0,953		
Globālā klimata regulācija	0,726		
Bioremediācija		0,839	
Filtrācija/akumulācija		0,845	
Ūdeņu ķīmiskais stāvoklis		0,766	
Erozijas kontrole			0,608
Dēdēšana			0,902

Balstoties uz galveno komponentu analīzes rezultātiem, ir iespējams izdalīt ekosistēmu pakalpojumu kopas – sava veida pakalpojumu grupas, kurās pakalpojumi veido sinerģiju, kad, palielinoties viena pakalpojuma vērtībai, palielinās visu citu kopā esošo pakalpojumu vērtība, vai konkurenci, kad, palielinoties viena pakalpojuma vērtībai, samazinās visu citu kopā esošo pakalpojumu vērtība (Mochet et al. 2014; Spake et al. 2017). Tā kā pirmajā komponentē izšķiramas divas polaritātes, tika izdalītas divas kopas atbilstoši katrai polaritātei, tādējādi nodrošinot, ka kopā ekosistēmu pakalpojumu starpā ir tikai sinerģiskas attiecības. Pētījumā kopām tika piešķirti nosaukumi, kas ataino to funkcionalitāti un skaidrāk atklāj to būtību:

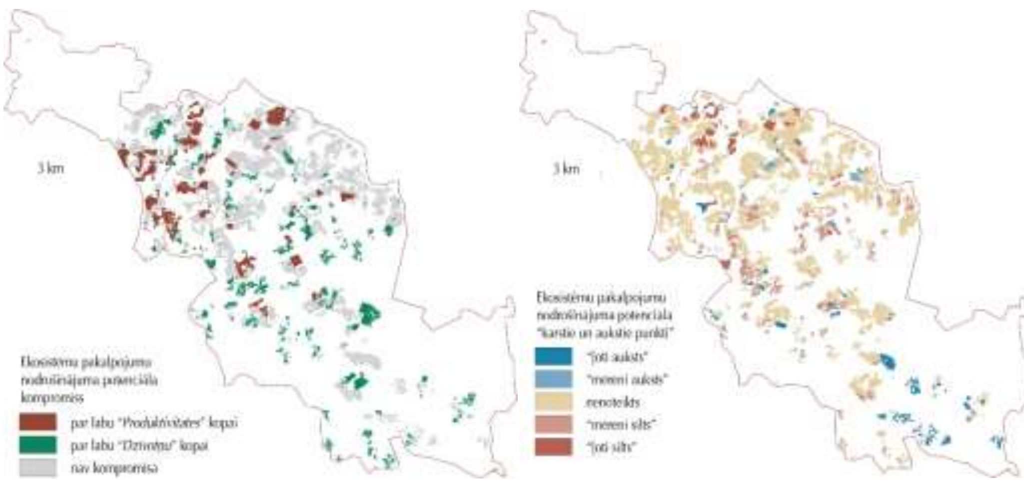
- “Dzīvotņu kopa”. Sinerģiski mijiedarbojas šādi pakalpojumi: “ārstniecības augi”, “apputeksnēšana”, “dzīvotņu uzturēšana” un “globālā klimata regulācija”;
- “Ražošanas kopa”. Sinerģiski mijiedarbojas šādi pakalpojumi: “mājlopi”, “lopbarība”, “biomasa enerģijai”. Funkcionāli šai kopai pieder arī pakalpojums “kultūraugi”, kas faktiski var tikt īstenots tikai aramzemēs, aizvietojot pakalpojumu “mājlopi”;
- “Augsnes kopa”. Sinerģiski mijiedarbojas šādi pakalpojumi: “bioremediācija”, “filtrācija/akumulācija”, “ūdeņu ķīmiskais stāvoklis”, “erozijas kontrole” un “dēdēšana”.

Konkrētā lauka piederība konkrētai ekosistēmu pakalpojumu kopai tika noteikta, ja kopā esošo ekosistēmu pakalpojumu vidējā vērtība pārsniedza sliekšņa vērtību 3 – proti, pakalpojumu potenciāls tika novērtēts virs vidējās iespējamās vērtības (7. attēls).



7. attēls. Ekosistēmu pakalpojumu “Dzīvotņu kopa” un “Ražošanas kopa” izplatība pētījuma teritorijas daļā (Cēsu novadā).

Ekosistēmu pakalpojumu kopu analīzes kartēšana nodrošina pamatinformāciju par pakalpojumu telpisko mijiedarbību, tādējādi sniedzot pamatinformāciju tālākai lēmumu pieņemšanai attiecībā uz lauksaimnieciskās zemes turpmāko izmantošanu. Situācija, ja konkrētajā laukā “dzīvotņu kopas” pakalpojumi tiek sniegti augstās vērtībās, bet “produktivitātes kopas” pakalpojumi tiek sniegti zemās vērtībās, tiek saukta par “kompromisu par labu dzīvotnes kopai”, savukārt situācija, ja konkrētajā laukā “produktivitātes kopas” pakalpojumi tiek sniegti augstās vērtībās, bet “dzīvotņu kopas” pakalpojumi tiek sniegti zemās vērtībās, tiek saukta “kompromiss par labu produktivitātes kopai” (8. attēls). Pētījuma teritorijā faktiski tika identificētas situācijas, kurās vidējā vērtība abās kopās bija vai nu augsta, vai tieši otrādi – zema, pirmajā gadījumā konkrētie lauki tiek saukti par ekosistēmu pakalpojumu nodrošinājuma “karstajiem” punktiem, otrajā – par “aukstajiem” punktiem.



8. attēls. Ekosistēmu pakalpojumu kompromisi un karstie/aukstie punkti pētījuma teritorijas daļā (Cēsu novads).

Ekosistēmu pakalpojumu kompromisu izpēte ainavu ekoloģiskos pētījumos ir aktualizējusi nopietnus jautājumus, proti, agroekosistēmas ir lielā mērā atkarīgas no vidi regulējošo pakalpojumu nodrošinājuma (piemēram, apputeksnēšanas, kaitēkļu un slimību ierobežošanas, augsnes auglības uzturēšanas), bet tajā pašā laikā agroekosistēmas ir arī svarīgu ekosistēmu pakalpojumu nodrošinātājas (pirmkārt jau, apgādes pakalpojumu, bet arī atsevišķu regulējošo un kultūras pakalpojumu) (Garbach et al. 2014; Willemen et al. 2017). Tomēr lauksaimniecības intensifikācijas rezultātā noris koncentrēšanās tikai uz apgādes pakalpojumiem, kas ir saistāmi ar nopietniem kompromisiem (Kirchner et at. 2015). Zinātniskajā literatūrā ir detāli aprakstīti kompromisi starp lauksaimniecisko produkciju un vidi regulējošiem pakalpojumiem (Haines–Young et al. 2012; Maes et al. 2012), piemēram, oglekļa piesaistīšanu (Schulze et al. 2005; Glendell & Brazier, 2014), apputeksnēšanu (Power, 2010; Cole et al. 2017), dzīvotņu uzturēšanu ((McLaughlin & Mineau 1995; Tscharntke et al., 2005). Pētījums pamato, ka vienādos agroekoloģiskos apstākļos, intensificējot lauksaimnieciskās darbības veidu, palielināsies “produktivitātes kopas” pakalpojumu vērtības un samazināsies “dzīvotnes kopas” pakalpojumu vērtības.

2.3. Daudzkritēriju lēmumu pieņemšanas atbalsts

Daudzkritēriju lēmumu pieņemšana ietilpst lēmumu pieņemšanas sistēmā (*decision making systems*), kas ļauj īstenot lēmumu pieņemšanas procesu atšķirīgām problēmsituācijām. Promocijas darba kopsavilkumā ir prezentēta teritoriju apsaimniekošanas prioritāšu noteikšana ainavas uzturēšanas kontekstā Cēsu novada Vaives pagastā.

Ekspertu un ieinteresēto personu diskusijā tika identificēti kritēriji ainaviski vērtīgo un tūrismam nozīmīgo teritoriju atlasei: kultūras ekosistēmu pakalpojumi (estētiskā vērtība, rekreācijas vērtība, izglītojošā vērtība, kultūrvēsturiskā vērtība) un ekoloģiskā vērtība (“dzīvotņu kopas” ekosistēmu pakalpojumu vidējā vērtība). Riska teritoriju atlasei tika identificētas un izmantotas divas kompozītvērtības: “latvāņu izvāzijas risks”, ko veido teritoriju atrašanās attiecībā pret ar Sosnovska latvāni invadētām teritorijām, un “lauksaimniecības zemes pamešanas risks”, ko veido svērtā vērtība no zemes kvalitatīvas vērtības (50%) attāluma no liellopu novietnes (30%) un attālums līdz ceļam (20%).

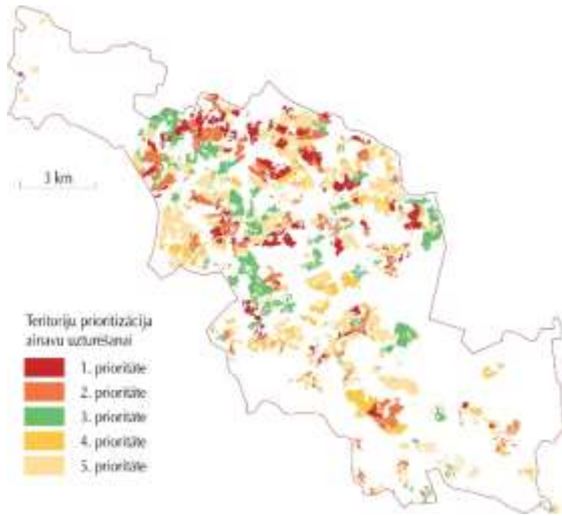
Kritēriju svēršanas rezultātā tika izveidota uz ekosistēmu pakalpojumiem balstīto kritēriju svaru matrica, kas saistīta ar Cēsu novada ilgtspējīgas attīstības stratēģijā līdz 2030. gadam noteiktām iedzīvotāju dzīves kvalitātes dimensijām: kvalitatīva dzīves telpa un vide, nodarbinātības iespējas, veselība, drošība, kultūras pieejamība, izglītības un mūžizglītības pieejamība, attīstīta infrastruktūra, sociālā drošība un aprūpe. Katra kritērija prioritāšu vidējais rādītājs, pārrēķinot procentos, tika izteikts kā “svars”, kas tika izmantots DKLA rīka prioritāšu noteikšanas aprēķinos (9. tabula).

9. tabula

Ekspertu un ieinteresēto personu nolemtais kritēriju būtiskums

Kritērijs	*Svars (%)*
Ainavas estētiskā vērtība	25
Rekreācijas vērtība	18
Izglītojošā vērtība	12
Kultūrvēsturiskā vērtība	22
Ekoloģiskā vērtība	23

DKLA rīkā prioritātes tiek noteiktas piešķirot katrai teritoriālai vienībai kārtas skaitli, un šo kopu pēc noklusējuma ataino, dalot piecās kategorijās pēc dabiskās sliekšņa vērtības (*natural brakes*). Tāpat var izmantot dalījumu kvantilēs un aritmētisko dalījumu vienāda skaita grupās. Šis dalījums tiek kategorizēts trīs kategorijās jeb ainaviskās vērtības kategorijās – augsta, vidēja un zema. Vērtības kategorijām piemērojot riska kategorijas, tiek izveidotas noslēdzošās teritoriju apsaimniekošanas prioritātes (9. attēls)

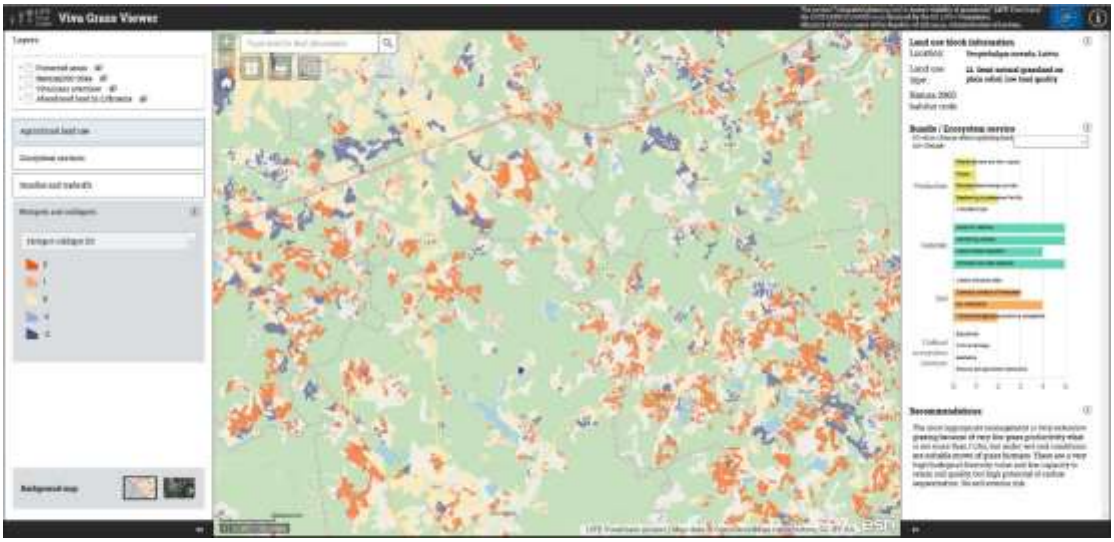


9. attēls. Ainavas uzturēšanai noteiktās teritoriju prioritātes Cēsu novadā

Aprakstītajā daudzkritēriju lēmumu atbalsta īstenošanas plānošanas procesā, lai izvairītos no riskiem, ka neliela ieinteresēto personu kopa var būtiski ietekmēt noteiktas vērtības jeb svarus (Stirling, 2006), tika izmantots konsultatīvs daudzkritēriju novērtējums (*deliberative multi–criteria evaluation*) (Mavrommati et al. 2017), kas ļauj sasniegt plašāku izpratni un sabiedrības iesaisti plānošanas procesā.

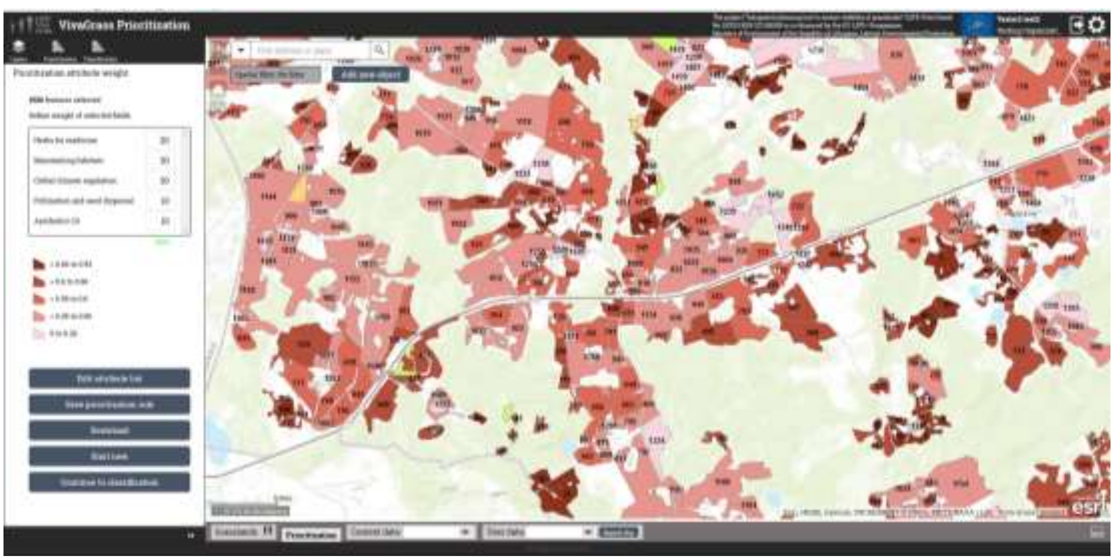
2.4. ĢIS un kartogrāfiskie risinājumi tīmekļa rīkam

"Viva Grass pārlūks" ir DKLA pamatmodulis, kas pieejams ikvienam lietotājam. Tas veidots kā tematisko karšu (kontekstuālo slāņu) pārlūks (10. attēls) ar ierobežotām rediģēšana iespējām – lietotājs var potenciāli mainīt lauksaimnieciskās zemes izmantošanas veidu izvēlētam laukam un noskaidrot, kādas izmaiņas tas radīs ekosistēmu pakalpojumu nodrošinājuma potenciālā, piederībā pie ekosistēmu pakalpojumu kopām, kompromisiem un ekosistēmu pakalpojumu nodrošinājuma "karstajiem"/"aukstajiem" punktiem, kā arī var iegūt rekomendācijas par ieteicamo lauksaimniecības zemes apsaimniekošanu konkrētajos agroekoloģiskajos apstākļos.



10. attēls. “Viva Grass pārlūks”, ekrānuzņēmums.

“Viva Grass plānotājs” ir DKLA galvenais modulis, kas pieejams tikai reģistrētiem lietotājiem, un tā lietošanai ir nepieciešamas ĢIS zināšanas. Šajā modulī ir pieejami visi ekosistēmu pakalpojumu novērtēšanas un mijiedarbības kontekstuālie slāņi (11. attēls), kā arī ir iespēja augšupielādēt citus lēmumu pieņemšanai nepieciešamos telpiskos datus. Šis modulis strādā kā tiešsaistes ĢIS programmatūra, kurā iespējams veikt telpiski analītiskas pamatdarbības, attēlot un eksportēt to rezultātus.



11. attēls. “Viva Grass plānotājs”, ekrānuzņēmums.

SECINĀJUMI

Promocijas darbā tika īstenoti trīs secīgi pētījumi, kuru mērķis bija izstrādāt un aprobēt jaunu, ekosistēmu pakalpojumu pieejā balstītu agroekosistēmu pārvaldības risinājumu mozaīkveida ainavā.

1. pētījums. Zemes izmantošanas izmaiņu virzītājspēku apzināšana un novērtēšana mozaīkveida ainavā.

Promocijas darbā ir parādīta autoloģistiskās bināras regresijas modeļu efektivitāte ainavu izmaiņu virzītājspēku novērtēšanā. Pētījumu rezultātā ir noskaidrots, ka nozīmīgākie biofizikālie un novietojuma faktori jeb virzītājspēki, kas nosaka lauksaimniecībā izmantojamās zemes pamešanu mozaīkveida ainavā Vidzemē, ir zemes kvalitatīvā vērtība, attālums līdz lopu novietnei, attālums līdz ceļam un meža malai. Pētījums parādīja, ka precīzāku zemes izmantošanas scenāriju izstrādei ABR modelis ir papildināms ar saimniecības līmeņa sociālekonomiskiem datiem.

2. pētījums. Biofizikālās ekosistēmu pakalpojumu novērtēšanas un kartēšanas metodes izstrāde Vidzemes augstienē un aprobācija Baltijas valstīs, to skaitā Latvijā.

Promocijas darba laikā ir izstrādāta un aprobēta ekosistēmu pakalpojumu novērtēšanas un kartēšanas metode lauksaimniecībā izmantojamām zemēm un tajās veikta ekosistēmu pakalpojumu mijiedarbības analīze. Pētījumā noskaidrots, ka līdzīgos agroekoloģiskos apstākļos zemes apsaimniekošanas intensifikācija palielina apgādes pakalpojumu vērtības un samazina regulējošo pakalpojumu vērtības, tādējādi veidojot kompromisa situācijas. Savukārt nelabvēlīgos agroekoloģiskos apstākļos, piemēram, nabadzīgās augsnēs vai stāvās nogāzēs, intensifikācijas rezultātā samazinās arī apgādes pakalpojumi un izveidojas ekosistēmu pakalpojumu nodrošinājuma "aukstie" punkti. Promocijas darbā prezentētā metode ir izmantota ekosistēmu pakalpojumu nodrošinājuma kartēšanai lauksaimniecības zemēs Baltijas valstīs.

3. pētījums. Ekosistēmu pakalpojumu un zemes izmantošanas virzītājspēku integrēšana daudzkritēriju lēmumu atbalstā agroekosistēmu plānošanā un pārvaldībā.

Zemes izmantošanas maiņas virzītājspēki un ekosistēmu pakalpojumu novērtējums ir izmantojami daudzkritēriju lēmuma atbalstā kā svērtie kritēriji zemes pārvaldības uzlabošanai, ja zeme atrodas perifērijā. Promocijas darba laikā ir izstrādāta un aprobēta integrētās plānošanas shēma lauksaimniecības zemes apsaimniekošanas prioritāšu noteikšanai ainavas estētisko un tūrisma vērtību uzturēšanas un uzlabošanas kontekstā. Izstrādātā pieeja ir iekļauta integrētās plānošanas rīkā *Viva Grass Tool*.

Promocijas darba rezultāti ir izmantojami lauksaimniecības zemes izmantošanas un ekosistēmu pakalpojumu izmaiņu prognožu izstrādei un īstenoto lauksaimniecības politikas ietekmju analīzei. Ekosistēmu pakalpojumu novērtējums ir izmantojams kā MAES (*Mapping and Assessment of Ecosystem Services*) integrāla sastāvdaļa.

Tālākai promocijas darba rezultātu attīstībai ir nepieciešams papildināt izstrādātos modeļus ar meža zemju un ūdens objektu datiem, tādējādi iegūstot efektīvu instrumentu lēmumu atbalstam lauku teritoriju plānošanai un pārvaldībai.

PATEICĪBAS

Promocijas darba autors izsaka pateicību darba vadītājam prof. Oļģertam Nikodemum, Latvijas Universitātes kolēģiem un zinātnisko rakstu līdzautoriem Raimondam Kasparinskim, Didzim Elfertam, Guntim Brūmelim un Anitai Zariņai, Baltijas Vides Foruma kolēģēm un zinātnisko rakstu līdzautorēm Andai Ruskulei, Kristīnai Veidemanei un Danai Prižavoitei, Igaunijas Dzīvības zinātņu universitātes kolēģiem un zinātnisko rakstu līdzautoriem Miguel Villoslada, prof. Kalev Sepp, Henri Järv un Jaak Klimask, Baltijas Vides Foruma (Lietuva) kolēģiem un zinātnisko rakstu līdzautoriem Justas Gulbinas, Kestutis Navickas, Arvydas Dotas un Žymantas Morkvenas, Hnit Baltic kolēģim un zinātnisko rakstu līdzautoram Audrius Kryžanauskas.

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Paper I

Title:

Assessment of site-specific drivers of farmland abandonment in mosaic-type landscapes: a case study in Vidzeme, Latvia

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Abstract

Farmland abandonment, which causes changes in rural life and farming practices, can be observed throughout Europe. Over the last decades natural afforestation has decreased the area of farmland used for agricultural production, thereby leading to landscape homogenization and polarization. This process is explicitly evident in mosaic type landscapes consisting of highly complex land cover patterns, soil composition and topography. The aim of the study was to determine the site-specific driving forces of farmland abandonment at landscape scale in relation to agro-ecological and geographic factors, in a post-Soviet country in Eastern Europe. An extensive field survey approach with statistical analysis was developed to model landscape change in a case study area in the western part of Vidzeme Uplands, Latvia. The results showed that land quality, proximity to forest edge and distance from farm were strong determinants of farmland abandonment in the mosaic type landscapes and that these parameters can be used to determine probability of occurrence of farmland abandonment. Land quality, a composite indicator, was a robust factor associated with farmland abandonment, in contrast to specific factors like soil texture. The developed model can be employed to assess risk of farmland abandonment in mosaic type landscapes, thus providing valuable information and application as a tool for agricultural policy makers and rural planners.

Keywords: farmland abandonment, site scale, land use change, autologistic binary regression, agro-ecological factors, geographic location factors

Highlights

A spatial model estimated probability of farmland abandonment in post-Soviet landscape.

Land quality and geographic locations are key drivers of farmland abandonment.

On a fine scale similar biophysical conditions can have different drivers of abandonment.

1. Introduction

Farmland abandonment is a complex process with interlinked economic, environmental and social aspects and is often associated with social and economic problems in rural areas (Terres et al., 2015). It can be defined as the cessation of agricultural activities on a given surface of land (Pointereau et al., 2008), including a change towards less intensive type of land use (Baudry, 1991) and thus elimination or polarization of landscape mosaics and promotion of vegetation homogeneity (Benayas et al., 2007). Farmland abandonment has multiple consequences on ecosystem services, biodiversity and economies (Prishchepov et al., 2013). To understand, manage or prevent farmland abandonment, it is necessary to assess the driving forces (Bürgi et al., 2005).

The concept of driving forces or drivers of landscape change has been evolving over the past two decades and has attained an indispensable position in landscape studies. European scale studies have shown that farmland abandonment occurs in unfavorable agro-ecological conditions, such as steep slopes, high elevations, non-fertile soils and geographically remote locations (MacDonald et al., 2000) and is driven by agricultural marginalization and rural depopulation (Jepsen et al., 2015; Strijker, 2005). However, land abandonment is not always limited to marginal areas (Hatna and Bakker, 2011). National scale studies have shown that distance to settlements as well a lack of finances and farmer motivation (Kristensen et al., 2004; Lieskovský et al., 2015; Müller et al., 2013), rural depopulation (Bell et al., 2009), unfavorable agricultural conditions (Vu et al., 2014) and former land use type (Gellrich et al., 2007) are determinants of farmland abandonment. Regional studies have reported that subsidies and land quality (Alix-Garcia et al., 2012; Vanwambeke et al., 2012), accessibility (Eiter and Potthoff, 2016; Müller et al., 2009), poor soils (Sluiter and de Jong, 2007)as well as isolation and distance to rural centers (Prishchepov et al., 2013) and opening the EU market for former socialist countries (Stoate et al., 2009) are key drivers of farmland abandonment. The few studies conducted at the landscape level have reported that bio-physical variables and farmers' socio-economic position play important roles in rural land use change, including farmland abandonment (Doorn and Bakker, 2007). A comprehensive review of farmland abandonment in Europe identified recurrent drivers (Terres et al., 2015, 2013), but was not able to present results for assessing agro-ecological factors that can act as restrainers or catalysts of farmland abandonment, likely due to the large spatial scale employed. Studies at the landscape level in post-Soviet landscapes have been few (Lieskovský et al., 2015; Nikodemus et al., 2005; Vinogradovs et al., 2016; Zarina, 2010) and often have been methodologically complicated due to the complex ownership pattern, land use patterns inherited from the Soviet period and scarcity of precise land use data. In many post-Soviet European countries, after the collapse of the Soviet system, restitution or privatization of farmland resulted in a high number of small farms as well as great fragmentation of estates (Platonova et al., 2007). Thus, cadastral parcel size and previous land use patch size might be variables associated with farmland abandonment.

Terres et al. (2015) indicated that the main constraint to studying farmland abandonment at the landscape level was lack of data on farmland abandonment. The aim of the present study was to develop a model to assess site-specific drivers of farmland abandonment in mosaic-type landscape (matrix of forest land interspersed with patch elements of arable lands, grasslands, lakes, wetlands, etc.) in a post-Soviet country. We used extensive field survey and collection of data on spatially explicit site-specific factors related to agro-ecological conditions, and geographic location and cadastral parcel size and previous land use patch size. We use two autologistic binary regression (ABR) models to assess effect of each spatial determinant separately and in relation with others to determine main drivers of farmland abandonment. In the analysis of farmland abandonment, we also studied determinants of the so-called semi-abandonment, where management of farmland was performed in a non-productive manner (Zariņa et al., 2017) to receive single area payments (SAP). The study was conducted both for a large area (713.7 km^2) and its subdivision into six smaller territorial units, to determine robustness of the model and explanatory factors.

2. Materials and methods

2.1 Study area

The study area (Fig. 1) is located in the western part of Vidzeme Uplands. The study area has a comparatively temperate and rainy climate with an average temperature of 16.5°C during the warmest month and -6°C during the coldest month. Annual precipitation is 750–850 mm, of which about 500 mm falls in the summer (Krauklis, 2000). The area is located in the Hemiboreal forest zone, where woodlands are dominated by coniferous tree species (*Pinus sylvestris* and *Picea abies*) mixed with deciduous tree species like *Betula pendula, Populus tremula, Alnus glutinosa* and *Alnus incana*, and to a lesser extent with *Quercus robur* and *Fraxinus excelsior* (Hytteborn et al., 2005). There is a large variety of soil groups (Arenosols, Podzols, Cambisols, Retisols, Luvisols, Stagnosols and Gleysols) that have developed on glacial till, glaciofluvial and glaciolacustrine deposits (loamy sand, sandy clay, loam, clay, gravel, sand) and Histosols on peat deposits

(Kasparinskis and Nikodemus, 2012). The landscape of the study area consists of diverse mosaic-type elements; the dominant features are mixed forests, agricultural lands, shrub-lands (including abandoned farmland), water bodies, wetlands and farmsteads. Administratively the case study area consists of, Drusti (A) pagast of Rauna municipality, Dzērbene (B), Taurene (C), and Vecpiebalga (E) pagasts of Vecpiebalga municipality, Vaive pagast of Cesis municipality and Zosēni (F) pagast of Jaunpiebalga municipality. A pagast is the smallest territorial unit in Latvia and until 2009 pagasts were also administrative units. The study area included 429 farms and the total number of mature bovine animals was 6990. The number of farms and amount of animals varied between the pagasts', where 54 farms were situated in Pagast A and only 26 in Pagast C, which however had the highest number of LSU – 1672. The study unit was a homogeneous land use patch in case of maintained farmland and homogeneous land cover patch in case of abandoned farmland.

[FIGURE 1 ABOUT HERE]

2.2 Identification of drivers of farmland abandonment

As farmland abandonment can be a complex and gradual process, in this study we recognized two types of abandonment, which were used as dependent variables: total abandonment and semi-abandonment or partial abandonment. Total abandonment of agricultural land was defined as complete cessation of any land management, expressed in landscape as natural afforestation with different degree of tree/shrub coverage or complete afforestation with birch or spruce. Semi-abandoned farmland was defined as farmland that was not used for agricultural production, but showed some signs of management, for example, cut hay that was left on the field. While there might be succession from semi-abandonment to abandonment, we rather perceived them as separate states of intensity of maintenance of agricultural land, where each type of abandonment was driven by a different set of determinants.

We classified drivers of farmland abandonment using a classification system modified from Pointereau et al. (2008) where geographic factors included slope (Slope <15°/slope >15°), distance from farm, field size and distance to road, and agro-ecological factors included soil quality, soil texture, and presence of a drainage system (Table 1). The factors were chosen to represent potential site-specific spatially explicit drivers of farmland abandonment, which could show variety at landscape level. Other employed drivers were previous land cover patch size, cadaster parcel size, as well as distances to rural center, road, farm and forest edge. The employed site-specific drivers (considered to be specific for the unit of study) are described in Table 1.

[TABLE 1 ABOUT HERE]

A land use/land cover map of farmland maintenance type and level of abandonment was obtained through extensive field survey and combined with analysis of color orthophoto maps (scale 1:10,000; resolution 0.5 m) acquired from the Latvian Geospatial Information Agency, produced from airborne remote sensing images taken in 2011 and 2013. A high precision land use/land cover map was created for the study area. Only agricultural and post-agricultural land uses/land cover types were mapped. The fieldwork was carried out in the late vegetation period (September) in 2014 and 2015. The Land use/cover map was supplemented with features like rural centers, paved roads obtained during survey, forest stands obtained from State Forest Service and farms obtained from Agricultural Data Centre, which were needed for further calculations.

The concept of land quality is an integrated evaluation of fertility of soils used in Latvia's land evaluation systems and was composed of factors like soil texture, soil type, topography and stoniness. Land quality is expressed in points per hectare with 100 points being maximum (Boruks et al., 2001). Data was obtained from a digitized version of soil maps obtained from the State Land Service of the Republic of Latvia. Data on soil texture were derived from digitized soil maps of the State Land Service of the Republic of Latvia. Slope was estimated as a dummy variable from a DEM (digital elevation model) estimated from topographic maps (scale 1:10000), where '1' represented slope with high erosion potential (<15°) and '0' represented slope with low or no erosion risk (>15°). Information on presence of a drainage system was obtained from the Ministry of Agriculture, Department of Land Amelioration in digitized format. Information on area of cadastral parcel was acquired from the State Land Service. Previous land use patches were identified from the soil survey map and represented separate fields in the previous period of Soviet collective farming. The borders of land use patches were verified in field survey as well from orthophoto maps during digitization of survey results.

2.3 GIS analysis

Data were entered in a grid based analysis model in ArcMap (Fig. 2). The ArcMap function "create fishnet" was used to generate an 100x100 m data collection grid. Grid cell size was chosen according to the diversity of patch sizes in the landscape. For further data sampling, a feature file of 22000 points was created, wherein points were placed as centroids in the grid. Land quality, soil texture, cadaster parcel area, drainage systems, topography, land use were laid as separate layers and their values were extracted to the feature points. Distances to closest rural center, paved road, farm and forest edge were assigned to the feature points using ArcMap function "near". To perform spatial autocorrelation, XY coordinates were added for each data feature point. All extracted and calculated values were represented as columns in a point feature class' attribute table and exported as tab delimited text for further analysis in R.

[FIGURE 2 ABOUT HERE]

2.4 Statistical analysis

To estimate the probability of farmland abandonment we constructed two autologistic binary regression (ABR) models as implemented in software R 3.4.0. (R Core Team, 2017). One model was made to compare probabilities for semi-abandoned farmland versus farmland in active agricultural use and the second model to compare abandoned farmland versus farmland in active agricultural use. To account for spatial autocorrelation, in both models a distance-weighted autocovariate was included (calculated in R package spdep (Bivand et al., 2013)). Land quality, distance to road, cadaster area, previous land use patch area, soil texture (peat as reference level), erosion risk and drainage were used as independent variables in both models. There was no multicollinearity between independent variables, as generalized variance-inflation factors values were below 2 for all variables. All distance and area variables were scaled to unit variance before analysis as they had high difference in amplitude. Log-odds were also expressed as odds ratio values for easier interpretation of results. Explained variance was calculated using the McFadden method of pseudo r-squared for generalized linear models as implemented in R library pscl (Jackmans, 2017).

3. Results

A large part of the farmland area in 1990 was abandoned (Table 2). Only minor change in area of suburban settlement was observed, and only in Pagast D, and therefore this factor was considered as an exception and excluded from further analysis. The rate of abandonment during the studied 25-year period ranged from 18.9% to 31.9%. The proportion of farmland in 1990 in Pagast F reached almost 40%, while in Pagast B it was 29.5% of the total pagast area. Rate of farmland abandonment ranged from 18.9% in Pagast to 31.9% in Pagast B. The proportional area of semi-abandonment ranged from 5.0 – 7.8% of the area of farmland in 1990. Cattle density varied from 0.3 to 0.6 LSU/ha, and the overall situation indicated non-intensive farmland use by livestock farming.

[TABLE 2 ABOUT HERE]

[TABLE 3 ABOUT HERE]

Land quality, presence of a drainage system and distance to forest edge largely differed between abandoned and not abandoned farmland: average land quality by ten points, presence of a drainage system by 27.8 points and almost twice in average distance to forest edge (Table 3). For semi-abandoned farmland, these factors had values between those for abandoned and not abandoned farmland. Farmland in active use in 1990 had larger mean area and closer mean distance to farm than for abandoned farmland, with mid values for semi-abandoned farmland. Land quality ranged from 5 pt/ha to 65 pt/ha, with mean values higher in farmland under agricultural use, lower in semi-abandoned farmland and abandoned farmland. Soil texture types were similar among different types of maintenance of farmland, except that sandy loam was more common under active management and peat soils on abandoned land. Farmland in active use was mostly on drained land (60%), whereas semi-abandoned farmland and abandoned farmland were mostly on land without a drainage system (36.9% and 28.1% respectively). Frequency distributions of variables in land use types are show in Fig. 3.

[FIGURE 3 ABOUT HERE]

In all pagasts the dominating soil texture among farmland maintenance types was sandy loam (Table 4). In Pagasts A, E and F the second most common soil texture was peat. Sandy soils were relatively rare. Size of farmland varied from 0.1 to 357 ha and size of parcel varied from 0.1 to 627.7 ha, where the largest parcels were State-owned land managed by the State Stock Company "Latvijas Valsts Meži".

[TABLE 4 ABOUT HERE]

ABR results (Table 5) showed that higher land quality reduced risk of farmland change to semi-abandoned farmland (odds ratio 0.73, p-value < 0.001) and to abandoned farmland (odds ratio 0.56, p-value<0.001). Soil texture had no significant effect on probability for land use as semi-abandoned farmland, while clay, sand, loamy sand and sandy loam all decreased probability of abandoned farmland land use. Absence of potential erosion (slope < 15°) was significantly related to lower probability of occurrence of abandoned farmland (odds ratio 0.72, p-value < 0.001), while absence of a drainage system significantly decreased probability for land use as semi-abandoned farmland (odds ratio 0.56, p-value < 0.001) and abandoned farmland (odds ratio 0.67 p-value < 0.001). Longer distance to farm (odds ratio 1.27, p-value < 0.001) and road (odds ratio 1.18, p-value < 0.001) as well shorter distance to forest edge (odds ratio 0.55, p-value < 0.001) had significant positive effect on the risk of farmland abandonment. Longer distance to farm (odds ratio 1.27, p-value < 0.001) and shorter distance to forest edge (odds ratio 0.78, p-value < 0.001) also significantly increased risk of being in the category semi-abandoned farmland.

[TABLE 5 ABOUT HERE]

The overall explained variance of the ABR model for abandoned farmland was 29.21 %, which varied between pagasts – Pagast A 27.47 %, Pagast B 29.19 %, Pagast C 33.35%, Pagast D 29.30%, Pagast E 36.09% and Pagast F 41.73 %. The overall explained variance of ABR model for semi-abandoned farmland was 40,48%, which varied between pagasts – Pagast A 43.20 %, Pagast B 59.56 %, Pagast C 41.39%, Pagast D 36.67%, Pagast E 51.68% and Pagast F 53.14 %. Odds ratios for each pagast are shown in Table 6, where only factors with p<0.001 are displayed. Among the pagasts, occurrence of semi-abandoned farmland was less related to the examined risk factors than for abandoned farmland.

In all pagasts, land quality and distance to forest edge (Table 6) were significantly related to occurrence of abandoned farmland, i.e. farmland not used for more than 20 years. Distance to farm was also an important factor in almost all pagasts. Land quality and distances to rural center and farm were significant risk factors in about half of the pagasts.

[TABLE 6 ABOUT HERE]

4. Discussion

4. Discussion

During the last 25 years, restructuring of the political and economic system in post-Soviet Europe caused significant changes in farmland management and rural landscapes (Baumann et al., 2011; Griffiths et al., 2013; Prishchepov et al., 2012), as in the greater part of Central and Eastern Europe (Kuemmerle et al., 2009; Łowicki, 2008; Mander and Jongman, 1998). These changes occurred by natural (Ruskule et al., 2012) or deliberate afforestation of farmland. Our results showed that in the case study, 25.4% of farmland was abandoned since 1990. Previous studies in Latvia through analysis of satellite imagery and at the municipality level showed that farmland abandonment was determined by factors such as distance to the nearest town, the percentage of farm area that received less favored areas payment, average cadaster value of the land (Vanwambeke et al., 2012), population density and range of elevation (Fonji and Taff, 2014). In addition to the identified common drivers of farmland abandonment (et al., 2016), we used previous land use patch and cadastral parcel as independent variables in order to take into account the inheritance of massive agricultural units form the Soviet period and the large variability of size of restituted cadastral parcels. Farmland abandonment in the form of natural afforestation in Latvia became common during the collapse of collective farming system in the early 1990's and subsequent land reform. We observed that occurrence of abandonment and semi-abandonment was linked with low land quality, proximity to forest edge, remoteness from farms, size of previous land use patch and parcel size.

Land quality is a composite indicator that is covers factors like soil texture, soil type, topography and stoniness. In our study, land quality was a reliable risk indicator of land abandonment at both the whole study area level and pagast level. However, other agroecological variables often lacked significance as risks, and particularly at the pagast level and for semi-abandoned farmland. Some factors showed unexpected results. For example, steep slopes were not associated with risk of abandonment, in contrast to previous studies (Lieskovský et al., 2015; Pazúr et al., 2014; Prishchepov et al., 2013; Van Doorn and Bakker, 2007). While steepness of slope might restrain occurrence of arable farmland, it might increase occurrence of hay meadows and pastures due to improved drainage conditions under conditions when slope has relatively short length, as in the study area. Proximity to forest likely promoted secondary succession on abandoned farmland by shorter dispersal distance for tree seeds (Ruskule et al., 2012), which could have explained significance of this risk factor in our study. However, proximity to forest, while significant at the case study area level, was not significant in any pagast for semi-abandoned farmland.

Undoubtedly, factors other than those studied also have an important impact on land abandonment. Low population density in pagasts is also associated with afforestation on abandoned farmland (Fonji and Taff, 2014). In addition to the risk factors discussed, there may be other types of motivation for farmers to choose land management methods (Antrop, 2005; Doorn and Bakker, 2007; Lange et al., 2013).

The category of semi-abandoned farmland can be perceived as farmland used for non-productive management. In this case, semi-abandonment, whereby hay is cut, but not removed, does not depend on land quality or agricultural production. As this form of land use is associated with EU CAP support, it seems likely that risk of semi-abandonment at the pagast level (Table 6) therefore became less associated with agro-ecological and geographical factors after Latvia joined the EU (Dobele et al., 2012; Nikodemus et al., 2010; Vinogradovs et al., 2016). However, locations closer to farms tended to have less risk of semi-abandonment. In our study, a small part of farmland under agricultural use was on soils with very low land quality (5-20 points), where agricultural activities were likely conducted solely to receive subsidies without interest in production, observed as hay left to decompose on fields. This probably also applies to risk of land abandonment, i.e., EU CAP support can maintain agricultural land use on marginal land.

The residual deviance in the ABR model might be associated with variables not included in the model, such as socio-economic characteristics at the farm level. Similar studies have shown that farmland abandonment is determined by factors like farmer's age, type of agricultural activities and education level, and farm income and size and mechanization level (Baldock et al., 1996; Doorn and Bakker, 2007; Kristensen et al., 2004; MacDonald et al., 2000), which can be combined in a composite indicator of farmland abandonment (Terres et al., 2015). However, in Latvia information on these variables is not accessible at landscape and municipality scales, but only at the national scale. The unexplained variance in our study confirms that there is great need for quality empirical data at local, regional and country scales to thoroughly study farmland abandonment drivers (Rounsevell et al., 2012).

Studies carried out at scales coarser than landscape are more dependent on indicators at municipality or regional levels. However, these studies were not able to include site-specific agro-ecological and geographical factors, which were relative and landscape specific and only partially accessible for generalization (Hatna and Bakker, 2011).

Differences in rates of post-socialist farmland abandonment in the Carpathians (13.9% in Poland, 20.7% in Slovakia and 13.3% in Ukraine) in cross-border regions were explained by political and economic changes, socialist land ownership patterns, post-socialist land reform strategies and rural population density (Kuemmerle et al., 2008). In the Western Ukraine, 30% of farmland used during the socialist period was abandoned after 1991 and topography, soil type and population variables were most important predictors to explain spatial variation in abandonment rates (Baumann et al., 2011). In these studies, the results obtained differed depending on the scale of studied phenomenon and also scale of factors used as variables. Thus, the drivers of farmland abandonment in studies can differ both due to geographical location and the employed scale.

Regression models have been commonly used to assess driving forces that lie behind landscape change in different regions and at various scales (Millington et al., 2007; Pueyo and Beguería, 2007; Serneels and Lambin, 2001; Serra et al., 2008; Verburg and Chen, 2000; Xu et al., 2013).

The method employed in our study was successfully used to identify the drivers of change and risk of abandonment for two types of abandonment in a landscape with great variety of agro-ecological factors. The described landscape changes were associated with land reform after breakdown of Soviet Union and agricultural restructuring after joining EU.

The ABR model identified landscape and parcel level risks of farmland abandonment in the study area, but the model could have been fortified by socio-economic and other factors. We tested the model for the whole study area and for smaller spatial units - pagast. Greater homogeneity of agroecological and geographical variables and specific socio-economic conditions within pagasts might have caused the lesser number of significant risk factors in the smaller units. However, analysis by pagast showed the robustness of composite indicators like land quality. The proposed method could be better tested by extending the study area, thereby involving a wider range of values for variables. The main restraint for this was lack of a national land use data base and the need to delimit the study area by the area that could be surveyed in the field. The presented method can be used to add multi-level data, such as farmers' motivation and socioeconomic variables on farm and municipality levels if available.

Conclusion

In this study of agro-ecological and geographical site-specific factors of farmland abandonment and semi-abandonment in six pagasts in Vidzeme Uplands, East-Central Latvia, autologistic binary regression (ABR) models were shown to be efficient in assessing drivers underlying farmland abandonment and semi-abandonment in mosaic type landscape. The ABR model showed that land quality, size of previous land use patch, size of cadaster plot, and distances to farm, paved road and forest edge were important site-specific drivers of semi-abandonment and farmland abandonment. Abandonment and semi-abandonment depended on agro-ecological conditions and location in the landscape. However, site-specific and regional socio-economic factors and national and transnational political factors can play major roles in farmland abandonment, and thus need to be considered in subsequent studies. The findings of our research could be employed to assess the risk of farmland abandonment in mosaic type landscapes in post-Soviet conditions, and could be used to assess the main risks in different types of landscapes.

Our model explained 29.21 % of the variability in occurrence of abandonment and 40.48 % of that of semi-abandonment. The quantitative assessment of relative risk of abandonment provides valuable information for agricultural policy makers and rural planners. When appraising results of our research it should be taken into account that in Latvia, as in other post-Soviet countries, transition from collective farms back to relatively small farmsteads happened only recently. Further, after joining the EU in 2004, the opposite process began, where some farmsteads started to manage estates of surrounding small farms that had withdrawn from agricultural production.

In such dynamic politico-economic conditions, agro-ecological and geographical factors temporally have weakened impact.

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FIGURES

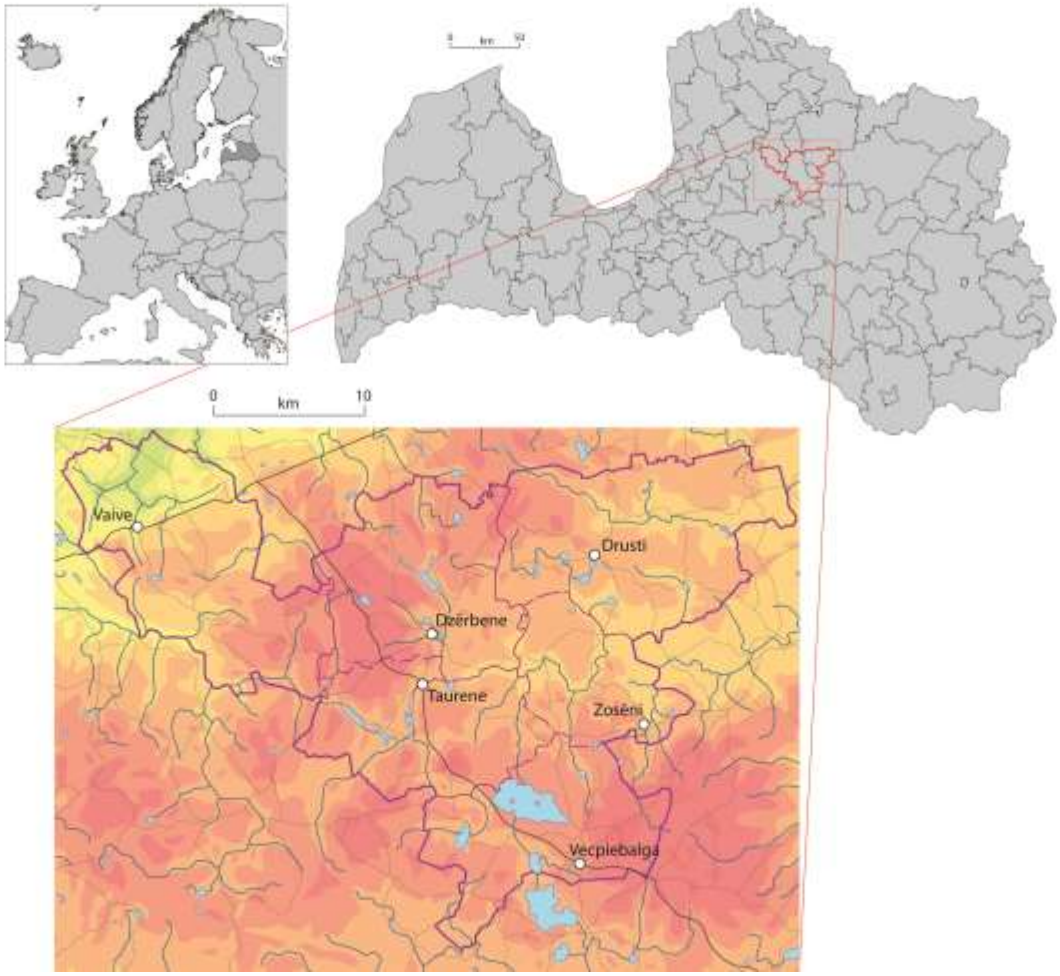

Fig. 1. Study area.

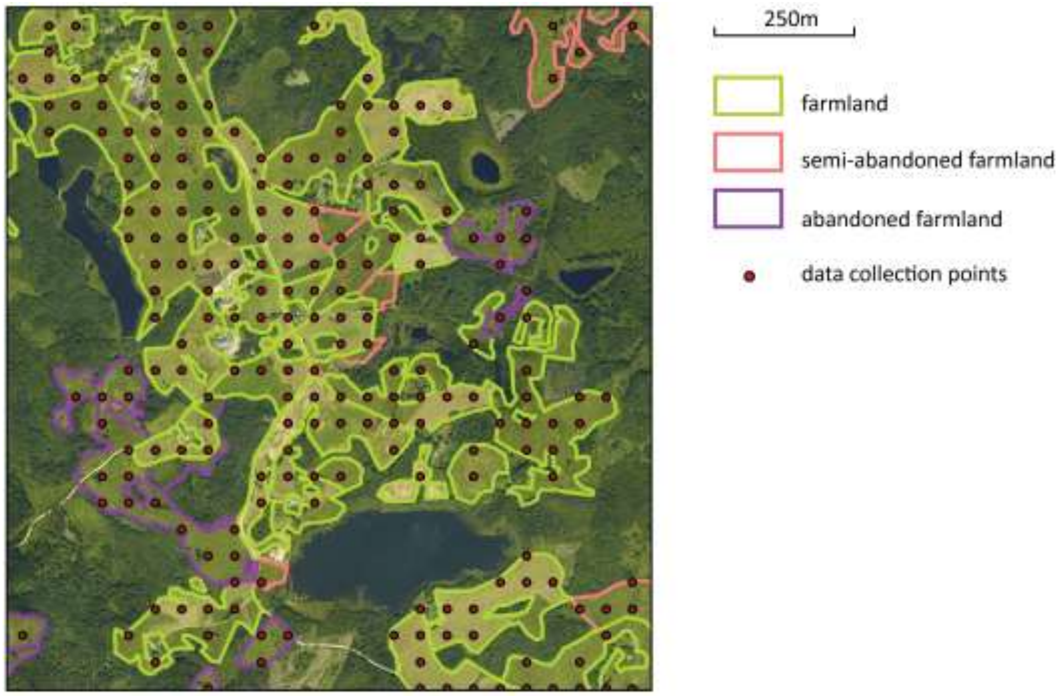

Fig. 2. Map fragment of data collection model. (Greyscale in print/Colour online)

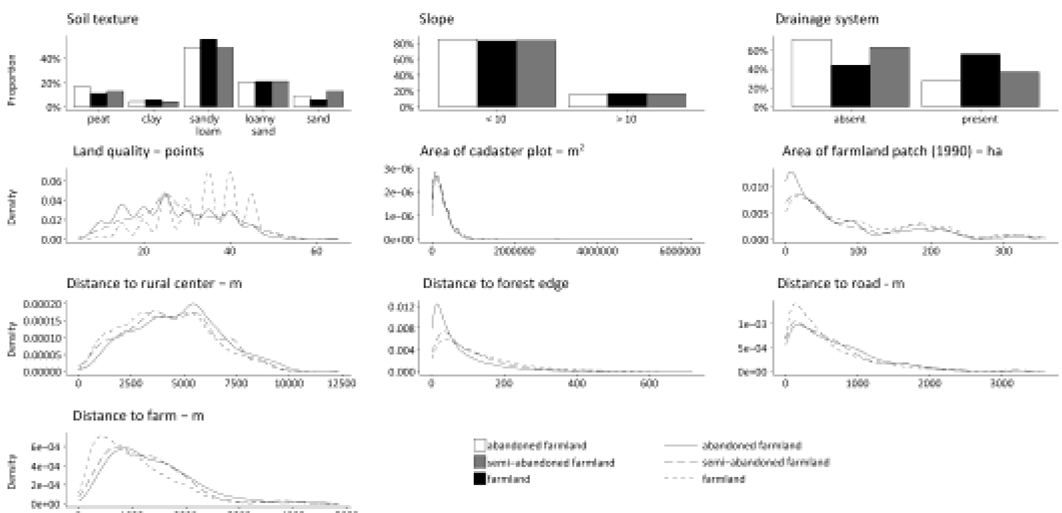

Fig. 3. Frequency distributions of variables under different land use. (Greyscale in print/Greyscale online)

Table 1. Factors used in analysis

Variable	Unit	Description	Data source and specifics
Agro-ecological factors			
Land quality	Pt/ha (0-100)	Quality of agricultural land described as 100-point max grades. 5point steps.	Digitized land quality maps 1:10000, Latvian soil classification
Soil texture	group	Groups of soil texture: sand, loamy sand, sandy loam, clay, peat.	Soil survey maps 1:10000, digitalized Latvian classification
Cadaster area	ha	Size (ha) of cadaster parcel in 2016	State Land Survey cadaster data
Drainage systems	0/1, dummy	Presence of functioning drainage system	Ministry of Agriculture Estates, Department of Land Amelioration
Geographical factors			
Topography	0/1, dummy	Slope <10°/slope >10°	DEM derived from topographic maps 1:10000
Previous farmland patch area	ha	Size (ha) of homogeneous land use type in 1990	Soil survey maps, field surveys, orthophoto of State Land Survey
Distance to rural center	m	meters	GIS calculations. Only pagast centers were considered
Distance to paved road	m	meters	GIS calculations. Only paved roads were considered
Distance to farm	m	meters	GIS calculations.
Distance to forest edge	m	meters	GIS calculations

Table 2. Distribution of farmland maintenance types, cattle density in surveyed land.

	Area	Population density	Farmland in 1990		Farmland in 2015		Semi-abandoned farmland in 2015			Abandoned farmland in 2015				Cattle density
Pagast	ha	people / km^2	ha	% area	ha	% area	ha	% area	% farm-land 1990	ha	% area	% farmland 1990	Affores-ted land (ha)	LSU/ha farmland
A	15672	6,18	5379.3	34.3	3774.8	24.1	284.6	1.8	5.3	1319.9	8.4	24.5	4.2	0.3
B	12463	6,93	3299.3	26.5	1987.9	15.9	257.6	2.1	7.8	1053.8	8.5	31.9	92.8	0.4
C	10241	8,61	3770.4	36.8	2559.6	25.0	189.9	1.8	5.0	1017.1	9.9	26.9	34.5	0.6
D	15244	10,83	5262.8	34.5	3385.4	22.2	336.5	2.2	6.4	1510.1	9.9	28.6	19.8	0.4
E	11020	13,23	4034.3	36.6	3010.5	27.3	262.9	2.4	6.5	760.9	6.9	18.8	10.1	0.4
F	6741	7,14	2650.5	39.3	1978.6	29.3	136.3	2.0	5.1	526.2	7.8	19.8	3.2	0.4
Total study area	71381	8,83	24396.6	34.2	16696.8	23.3	1467.8	2.1	6.0	6188.0	8.7	25.4	164.8	0.4

Table 3. Descriptive statistics for explanatory variables.

Variable	Data ranges			
	Expression	Farmland in agricultural use	Extensively used farmland	Abandoned farmland
Land quality (points/ha)	Max	65	65	65
	Mean	33.64	28.92	26.84
	Median	35	25	25
	Min	5	5	5
	Mode	35	25	25
	St.dev	9.34	10.58	10.51
Soil texture (%)	clay	6.0	4.2	4.4
	loamy sand	21.1	21.2	20.8
	peat (organic)	11.2	12.8	16.7
	sand	5.9	12.9	9.3
	sandy loam	55.8	48.9	48.8
Slope (%)	<15°	83.13	83.66	85.13
	>15°	16.87	16.34	14.87
Drainage system (%)	Drained	55.9	36.9	28.1
	Not drained	44.1	63.1	71.9
Cadaster parcel (ha)	Max	627.7	126.3	627.7
	Mean	24.6	22.0	25.5
	Median	19.4	18.0	20.4
	Min	0.1	0.3	0.3
	Mode	76.8	34.8	63.4
	St.dev	24.7	18.2	29.6
Land use patch area (ha)	Max	357.3	357.3	357.3
	Mean	100.3	88.1	71.0
	Median	73.8	42.9	38.7
	Min	0.1	0.2	0.1
	Mode	357.3	176.8	137.6
	St.dev	90.6	92.8	80.9
Distance to rural center (m)	Max	11055	10304	12326
	Mean	4188.8	4418.6	4745.1
	Median	4111	4416	4794
	Min	13	226	78
	Mode	2673	4744	6211
	St.dev	2051.5	2057.3	2070.4
Distance to road (m)	Max	3599	3318	3575
	Mean	543.3	623.8	682.4
	Median	388	471	552
	Min	1	3	1
	Mode	42	45	17
	St.dev	501.51	573.21	565.87
Distance to farm (m)	Max	4618	4161	4838
	Mean	1019.3	1223.7	1363.9
	Median	875	1145	1233
	Min	9	79	46
	Mode	531	641	1132
	St.dev	693.2	719.0	770.1
Distance to forest edge (m)	Max	717	539	634
	Mean	124.6	99.2	67.3
	Median	96	73	42
	Min	1	1	1
	St.dev	105.3	88.1	73.8

Table 4. Descriptive statistics for selected explanatory variables in different pagasts.

	A			B			C			D			E			F		
	Farmland	Semi-abandoned farmland	Abandoned farmland	Farmland	Semi-abandoned farmland	Abandoned farmland	Farmland	Semi-abandoned farmland	Abandoned farmland	Farmland	Semi-abandoned farmland	Abandoned farmland	Farmland	Semi-abandoned farmland	Abandoned farmland	Farmland	Semi-abandoned farmland	Abandoned farmland
Soil texture (%):																		
clay	10.4	6.2	6.7	1.4	NA	0.9	11.7	9.0	5.9	2.0	3.1	2.5	2.8	4.1	2.2	5.6	3.2	11.0
loamy sand	8.4	8.6	8.3	36.1	23.6	37.3	15.8	15.7	11.8	32.0	30.0	28.2	27.7	25.4	26.0	10.2	20.0	9.6
peat	14.5	16.0	28.6	8.2	9.1	6.6	7.4	5.1	11.4	3.5	4.1	5.5	16.8	24.6	32.3	16.7	21.6	25.5
sand	3.0	8.2	5.4	4.7	15.4	8.6	11.5	15.2	14.7	7.8	17.4	11.4	3.0	5.7	3.2	6.6	18.4	13.2
sandy loam	63.7	60.9	51.0	49.6	51.9	46.6	53.6	55.1	56.2	54.7	45.4	52.4	49.8	40.2	36.3	60.9	36.8	40.7
Size of farmland (ha):																		
Max	357.3	223.8	357.3	325.3	325.3	325.3	220.8	220.8	220.8	312.8	312.8	312.8	287.2	287.2	287.2	357.3	357.3	357.3
Mean	112.2	99.2	98.6	100.5	53.1	60.9	79.1	49.0	57.6	120.8	150.0	80.4	72.2	73.3	49.9	113.1	64.2	49.4
Min	0.1	0.3	0.2	0.1	0.3	0.2	0.2	0.2	0.3	0.3	0.4	0.2	0.1	0.2	0.2	0.3	0.2	0.1
Size of parcel (ha):																		
Max	546.2	126.3	126.3	86.3	79.2	299.7	627.7	61.0	627.7	158.0	53.2	158.0	74.1	70.0	74.1	96.5	65.1	96.5
Mean	30.7	24.7	27.7	26.3	21.3	27.7	26.0	21.6	28.6	20.6	21.8	22.1	19.1	20.9	21.6	24.3	21.1	24.7
Min	0.2	0.8	0.5	0.1	0.5	0.3	0.3	0.3	0.4	0.4	0.8	0.5	0.2	0.5	0.6	0.2	0.3	0.5

Table 5. Results of ABR model (variables with significance level p<0.001 displayed in bold). Overall explained variance of the ABR model was 29.21 % for abandoned farmland and 40.48 % for semi abandoned farmland

Land use maintenance type	Variable	Estimate	Odds ratio	Std. Error	t-value	p-value
Semi-abandoned farmland	**size of cadaster parcel**	**-0.38**	**0.69**	**0.06**	**-6.55**	**<0.001**
	size of previous land use patch	**-0.32**	**0.72**	**0.05**	**7.09**	**<0.001**
	distance to rural center	-0.07	0.93	0.04	-1.59	0.113
	distance to farm	**0.23**	**1.27**	**0.04**	**5.97**	**<0.001**
	distance to forest edge	**-0.26**	**0.77**	**0.05**	**-5.63**	**<0.001**
	distance to road	**0.17**	**1.19**	**0.04**	**4.18**	**>0.001**
	land quality	**-0.32**	**0.73**	**0.05**	**-6.36**	**<0.001**
	presence of drainage	**-0.58**	**0.56**	**0.10**	**-5.76**	**<0.001**
	slope >15°	-0.03	0.97	0.10	-0.25	0.803
	Soil texture (peat reference)					
	clay	-0.55	0.58	0.21	-2.68	0.007
	loamy sand	-0.40	0.67	0.14	-2.85	0.004
	sand	-0.19	0.83	0.16	1.21	0.227
	sandy loam	-0.38	0.67	0.14	-2.85	0.004
Abandoned farmland	**size of cadaster parcel**	**-0.09**	**0.91**	**0.02**	**-3.81**	**<0.001**
	size of previous land use	**-0.22**	**0.80**	**0.02**	**-9.10**	**<0.001**
	distance to rural center	0.04	1.04	0.02	1.63	0.103
	distance to farm	**0.24**	**1.27**	**0.02**	**11.82**	**<0.001**
	distance to forest edge	**-0.59**	**0.55**	**0.03**	**-20.22**	**<0.001**
	distance to road	**0.17**	**1.18**	**0.02**	**8.63**	**<0.001**
	land quality	**-0.58**	**0.56**	**0.03**	**-22.18**	**<0.001**
	presence of drainage	**-0.40**	**0.67**	**0.05**	**-7.57**	**<0.001**
	slope >15°	**-0.33**	**0.72**	**0.05**	**-6.01**	**<0.001**
	Soil texture (peat reference)					
	clay	**-0.95**	**0.39**	**0.10**	**-9.57**	**<0.001**
	loamy sand	**-0.61**	**0.54**	**0.07**	**-8.94**	**<0.001**
	sand	**-0.40**	**0.67**	**0.09**	**-4.53**	**<0.001**
	sandy loam	**-0.72**	**0.49**	**0.06**	**-12.06**	**<0.001**

Table 6. Odds ratio ratios, explained variation for each pagast (only risk ratios for variables with p<0.001 displayed). Explained variance of the ABR model for semi-abandonment: Pagast A 43.20 %, Pagast B 59.56 %, Pagast C 41.39%, Pagast D 51.68%, Eagast E 36.67% and Pagast F 53.14%. Explained variance of the ABRM model for abandonment: Pagast A 27.47 %, Pagast B 29.19 %, Pagast C 33.35%, Pagast D 29.30%, Pagast E 33.09% and Pagast F 41.73%.

	Variables	A	B	C	D	E	F
Semi-abandoned farmland	size of cadaster parcel	0.58					
	Size of land use patch	0,51			0.61	0.59	
	Distance to rural center		2.23				2.74
	Distance to farm		1.70		2.01		3.21
	Distance to forest edge						
	Distance to road						
	Land quality			0.59			0.54
	Presence of drainage				0.37		
	Slope >15°						
	Soil texture (peat as reference)						
	Clay						
	Loamy sand						
	Sand						
	Sandy loam						
Abandoned farmland	Size of cadaster parcel	0.82			0.80		
	Size of land use patch	0.82		0,69			
	Distance to rural center	1.60	1,27		1.22		
	Distance to farm	1.69	1.30	1.39		1.23	1.83
	Distance to forest edge	0.56		0.51	0.54	0.43	0.33
	Distance to road	1.18	1.31		1.39	1.53	
	Land quality	0.52		0.43	0.85	0.39	0.42
	Presence of drainage		0.36		0.49		
	Slope >15°					0.38	
	Soil texture (peat as reference)						
	Clay	0.35		0.28		0.20	
	Loamy sand	0,37				0.26	
	Sand						
	Sandy loam	0.39				0.24	0.49

Paper II

Title:

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

1. 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.

2. Methods

2.1 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:

plain surface (0o – 4^{o}),

gentle steepness (5o – 10^{o}) and

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 ABOUT HERE]

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.

[FIGURE 2 ABOUT HERE]

2.2 *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 ABOUT HERE]

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.

2.3 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 ABOUT HERE]

2.4 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 ABOUT HERE]

[FIGURE 4 ABOUT HERE]

2.5 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.

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.

3. 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.

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 ABOUT HERE]

[FIGURE 5ABOUT HERE]

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 ABOUT HERE]

4. 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).

Conclusion

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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FIGURES

Fig. 1. Viva Grass base map workflow.

Grassland classes	Provisioning					Regulation & Maintenance							
	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 climatic 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 fertility	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 fertility	0	2	2	2	4	5	3	4	5	4	3	4	4
27. Semi-natural grassland on gentle slope, high soil fertility	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

Fig. 2. Extract of the expert-based scores matrix including grassland classes 21 to 30, corresponding to semi-natural grasslands.

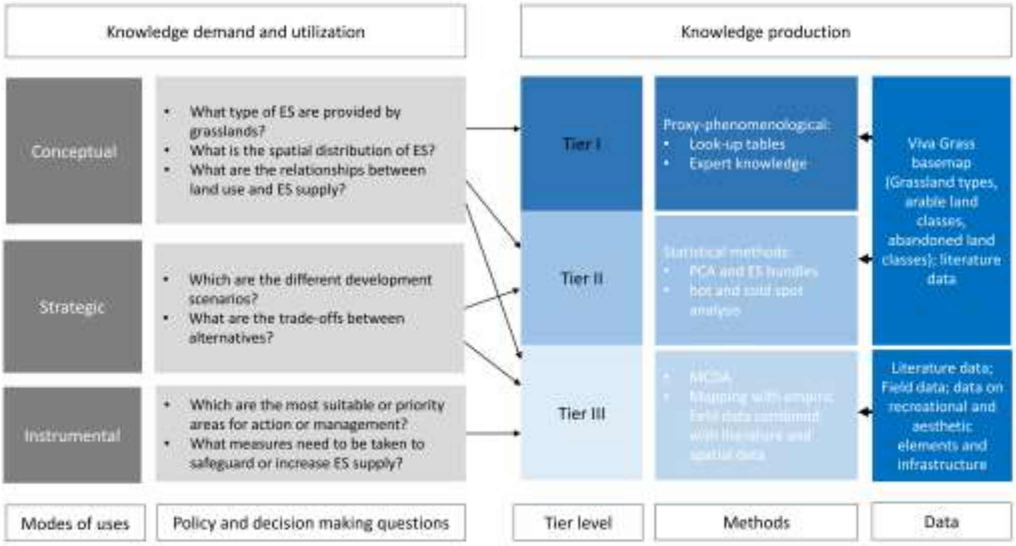

Fig. 3. The tiered approach for grassland ES mapping and assessment in the Baltic States

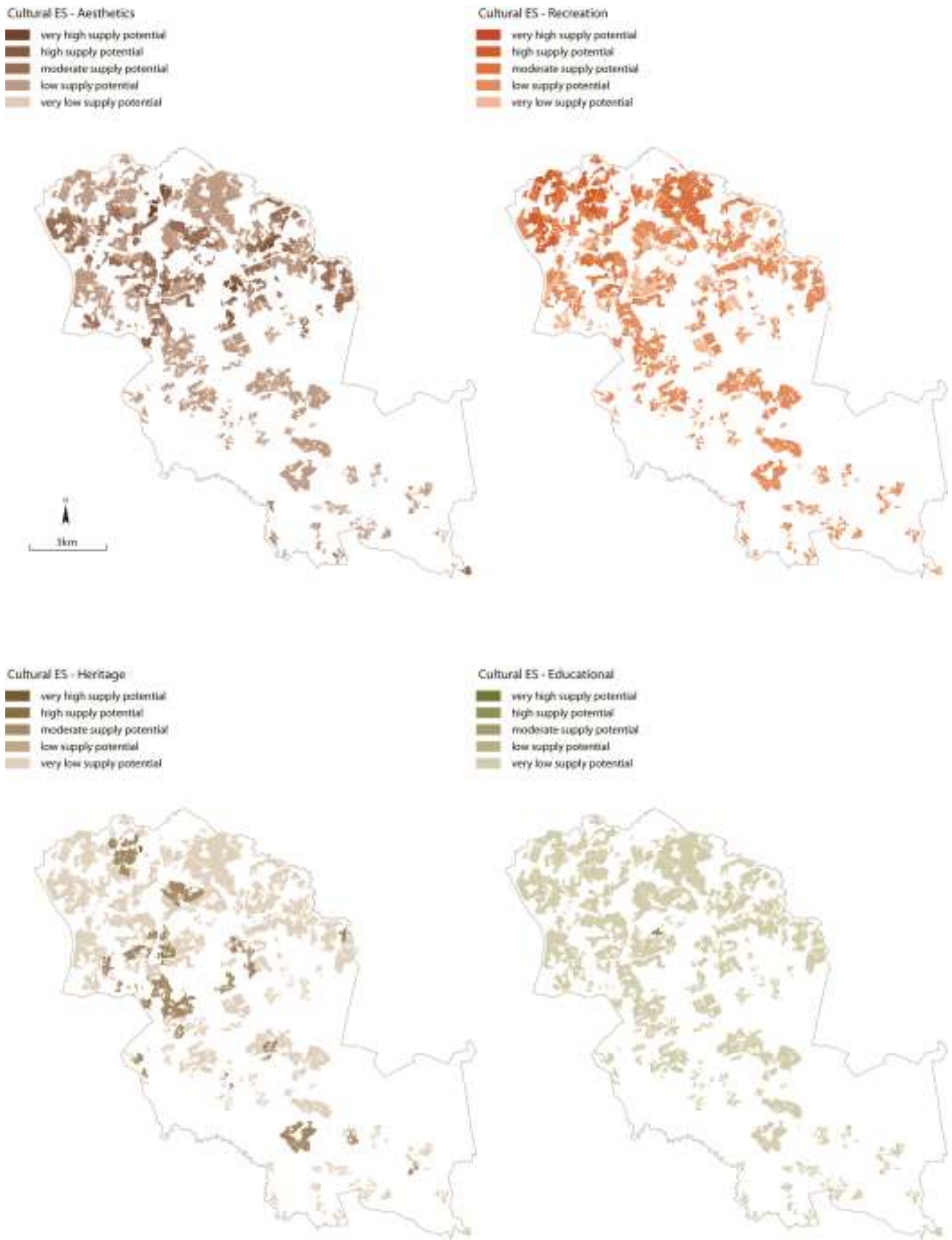

Fig. 4. Supply potential of four cultural ES in Vaive parish, Cēsis municipality (Latvia).

Fig.5 Interface of the Viva Grass tool viewer. The viewer displays the ES maps corresponding to Tiers 1 and 2.

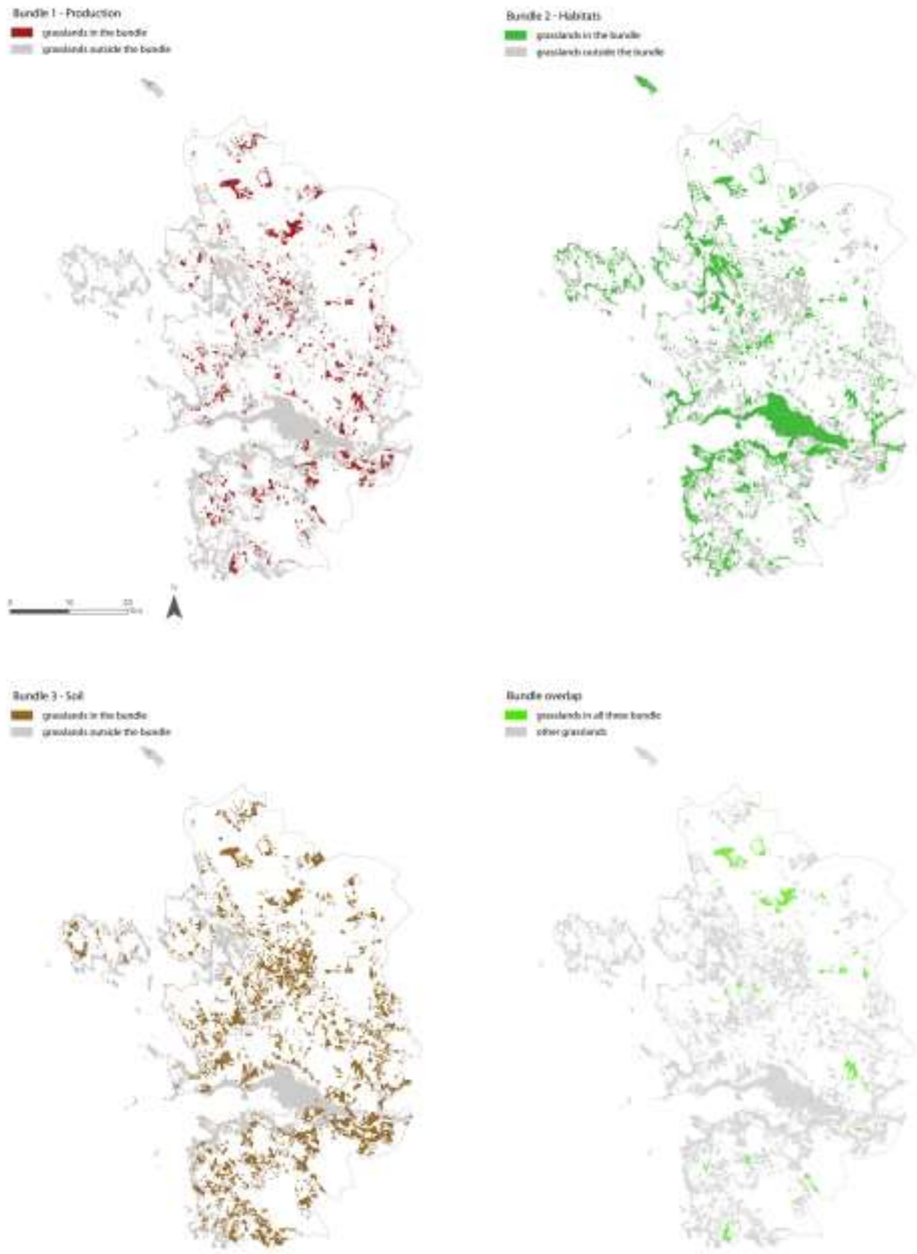

Fig.6 Grassland ES bundles in a Viva Grass pilot area: Lääne County (West Estonia)

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

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
Chemical condition of freshwaters	Absorption of nutrients	Land use + soil fertility
Global climate regulation	Carbon sequestration in vegetation and soils	Land use + soil fertility

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	

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

Paper III

Title:

Integrating ecosystem services into decision support for management of agroecosystems: Viva Grass tool

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Abstract

The area covered by low-input agroecosystems (e.g. semi-natural and permanent grasslands) in Europe has considerably decreased throughout the last century. To support more sustainable management practices, and to promote biodiversity and ecosystem service value of such agroecosystems a decision support tool was developed to enhance the operationalization of ecosystem services and address the challenge of their integration into spatial planning. We present the Viva Grass tool aimed to enhance the maintenance of low-input agroecosystem ecosystem services by providing spatially explicit decision support for land use planning and sustainable management of agroecosystems. We describe the structure of the Viva Grass Tool – multi-criteria decision analysis tool for integrating planning designed for farmers, spatial planners and policy makers to support decisions of management of agro-ecosystems. We also present results of testing of the tool by application in spatial planning contexts in eight case study areas across the Baltic States.

Keywords: ecosystem services, decision-support tool, agroecosystems, spatial planning, the Baltic States

1. Introduction

Ecosystem services (ES) are acknowledged as an important concept to support land-use decision making, because of the holistic view on interactions between nature and humans and potential to address conflicts and synergies between environmental and socio-economic goals. The ecosystem service concept offers a comprehensive framework for trade-off analysis, addressing compromises between competing land uses, and can facilitate planning and development decisions across sectors, scales and administrative boundaries (Fürst et al. 2017). Ecosystem service mapping and assessment can provide various inputs and contextual information for spatial planning (Albert et al. 2017), including identification of areas of particular environmental sensitivity with high potential for ecosystem service supply (e.g. 'hot-spot' or 'cold-spot' areas). This type of mapping can provide a basis for green infrastructure planning; visualization of the trade-offs of different land use alternatives; assessment of the impacts of the planning solutions; and enhance stakeholder engagement in communicating the overall benefits and shortcomings of planning proposals. Furthermore, the ecosystem service concept is strengthening its role also in policy making in different land use sectors, including agriculture (Bouwma et al. 2018). Results from recent studies have revealed that understanding of ecosystem functions and services can support better design of agri-environmental measures (Prager et al. 2012) and targeting of the intervention locations (Willemen et al. 2010, Frueh-Mueller et al. 2018) in order to increase the ES supply. Support for improving biodiversity and ecosystem services has been also highlighted in the new proposal for Regulation on support for strategic plans to be drawn up by Member States under the Common Agricultural Policy (European Comission 2018). The ES concept have been around for decades, but its involvement in spatial planning and land-use policies remains challenging (Grêt-Regamey et al. 2017a). Decision support tools are a great way to operationalize ES, that is, to promote their use by decision makers (Potschin and Haines-Young 2013). However, the best means to operationalize the ES concept to provide applicable data to support decision making processes still require improvement (Jacobs et al. 2015). A great variety of tools to support decision making through operationalizing ES are available in the review paper of (Grêt-Regamey et al. 2017b). Indicative description of selected tools is summarized in Table 1.

[TABLE 1 ABOUT HERE]

The existing tools vary by the level of complexity, scalability, time and data requirements, related cost-efficiency to support decision-making process, level of development, documentation and accessibility for independent applications. Bagstad et al. (2013) conclude that although the level of complexity should be dictated by the purpose of the tool, the most complex models not always perform better than less complex models.In the presented study, we aimed to create an uncomplicated decision support system – the Viva Grass tool, which would allow assessment of ES and its change under various scenarios in agroecosystems. It is aimed to be employed by different stakeholders (i.e. farmers, municipalities, state institutions etc.). Unlike other tools it uses a land quality assessment index and historical soil maps common in Eastern Europe, as well as a digital elevation model (LIDAR data), Integrated Administration and Control System (IACS) data and habitat mapping data where available. The novelty of the presented tool is that it is explicitly aimed to assess and analyze ES at the field level, where the service providing area is delineated by declared fields of farmers extracted from the IACS database land parcel identification system (LPIS).The Viva Grass tool was tested in eight case study areas across Lithuania, Latvia and Estonia (including two farms, four municipalities, two protected areas and one county), each of them having spatial and thematic scale, as well as with different data availability. The Viva Grass tool captures the applicability of ES related information at different planning scales and contexts, which requires a consistent but flexible approach.The present study tested the applicability of the ES approach in land-use planning in agro-ecosystems, based on the example of the Viva Grass tool. In this paper we first describe the structure and main functionalities of the Viva Grass tool. Secondly, we test its application in various spatial planning contexts across eight case study areas for the analysis of ES bundles, hot-spot and cold-spot areas as well as prioritization of areas for particular management practice based on ES supply potential.

European-scale

2. Project description

2.1 Study area description

Case study areas (Fig. 1) are chosen to represent various planning levels and contexts (agriculture land management, landscape management, nature conservation, tourism, and energy) in the three countries. Indicative qualities of case study areas are shown in Table 2

[FIGURE 1 ABOUT HERE]

[TABLE 2 ABOUT HERE]

2.2 Design description

The Viva Grass tool operates at two scales – site scale for mapping and assessing ES supply potential and landscape scale to elaborate decision support. At the site scale assessment is carried out for a basic agro-ecological unit – field or plot, which is the unit where actual management decision is applied and is defined as a continuous area with identical land use

(Villoslada et al. 2018). Prioritization is performed at landscape scale, which can be any user defined area considered as applicable for a certain planning process. The following chapter outlines the functioning of the Viva Grass tool.

Development of the web-based integrated planning tool. The Viva Grass Tool is based on an ArcGIS Enterprise platform. Data is stored in a common spatial database (PostgreSQL) and published as GIS services (maps). Web based tool modules/applications are constructed using the ArcGIS Web application builder. To fulfil custom requirements additional application widgets were developed (Fig. 2). The Viva Grass tool includes three main Tool modules: Viva Grass Viewer, Viva Grass Bio-energy and Viva Grass Planner targeted to particular users and decision making contexts (Table 3). The three modules produce and use various data and information products, which can be linked with other information platforms.

[TABLE 3 ABOUT HERE]

[FIGURE 2 ABOUT HERE]

Data products. Common base map information (agricultural land use, ES service values, etc.) is available as data services or downloadable datasets and can be re-used and integrated into other solutions and information products. Exportable thematic maps produced by the Tool modules, tutorials and teaching materials on the ES concept and its application are products and project deliverables.

Data management and administration. The common farmland base map data is updated by experts in each country. A new version of the data is prepared outside the tool using desktop GIS software, using predefined data structure. The data management workflow developed during the project allows to provide only the field boundaries and management category. After uploading farmland fields, relief category and land quality SPA unit category can be determined automatically, and then farmland type and default ecosystem service values can be calculated. Organizations and experts having need to work with more detailed analysis capabilities and custom data should use planning tools and custom data that are available to authenticated users. Initially, organization users can download part of the public base map data, add custom land use attributes, collect the required data and configure prioritization and classification rules.

Contextual layers and criteria developed for the Viva Grass tool

Creation of the base-map. The base-map used in Viva Grass tool is an overlay of underlying natural conditions and management regimes of farmlands and displays as both a contextual layer and separate underlying natural conditions. The choice of parameters for ES assessment were based on availability of the same structure and detailed data over three countries. We included a composite land quality for evaluation of soil fertility that was used in the ex-USSR and other Eastern European countries, which includes factors like soil texture, soil type, topography and stoniness (Vinogradovs et al. 2018). Data on soil composition were derived from digitized soil maps 1:10000. Farmland management regimes were derived from the IACS data base LPIS and categorized according to intensity of interference of a given management practice on topsoil (ploughing, fertilizing) and species composition (seeding). Based on these variables, five categories of farmland management regimes were created – cultivated grassland, permanent grassland, semi-natural grassland, arable land and abandoned farmland. Land use data is updated yearly when the annual IACS data base LPIS becomes available and uploaded by the tool administrator. Each of the three layers were combined in a GIS environment and the outcome consisted of 50 possible combinations or "classes" of underlying natural conditions and management regimes i.e. "permanent grassland on steep slope, low land quality" or "semi-natural grassland on organic soil, plain surface" etc. (Villoslada et al. 2018).

Assessment of ES supply potential was conducted using a matrix approach (Burkhard et al. 2009) based on multiple datasets derived from underlying natural conditions and management practices described above. Five provisioning services and eight regulating services (European Environment Agency 2015) relevant to agroecosystems were chosen by an international expert panel and one indicator per service was defined. In another panel, experts individually assigned values of each ES for each class based on a qualitative scale ranging from 0 (no relevant supply of the selected ES) to 5 (very high supply of the selected ES). A third expert panel consisted of several rounds as focus group discussions where final scores for each ES for every base-map class were reached through consensus of experts. As assigned ES supply potential values are based on common understanding of indicator values by experts, they are substitutable with actual values when available.

Cultural ES were not included in matrix valuation as they are explicitly, i.e. distinctively, connected to their service providing areas (SPA) and were assessed through evaluation of criteria created by an expert panel.

Bundles and trade-offs. A PCA was carried out using the qualitative scores for farmland plots (observations) and ecosystem services (variables) based on the matrix as input data. To assess potential tradeoffs and synergies between ES services, pairwise correlation was carried out. The interactions found were discussed in expert panels to designate the underlying driver for each interaction. The Viva Grass Tool allows the users to choose the most suitable management regime for the underlying biophysical conditions and thus increasing the ES supply and minimising trade-offs.

Cold/hot spot analysis. We defined a cold spot as a spatial unit providing a great number of ecosystem services at low or very low values and a hotspot as a spatial unit providing ES at high or very high values. The number of services with particular values of interest (low/high) was derived from analysis of the ES assessment matrix.

Risk of abandonment was created as composite indicator consisting of a sum of factors like land quality, field size, accessibility and distance to farms. Factors were chosen based on results revealed in previous studies (Vinogradovs et al. 2018).

3. Implementation

3.1 Viva grass Viewer

The Viva grass Viewer is a basic module of the Viva Grass tool that is accessible to the general public. It aims to present results of mapping and assessment of supply potential of ES, as well the grouping of ES in bundles and interaction among ES in agro-ecosystems. The Viva Grass viewer was implemented for informative and educational purposes, where the user is able to become acquainted with the ES approach, spatial representation of basic logic behind assessment of ES, and the spatial interaction between ES. Contextual data layers available in the Viva Grass Viewer are farmland land use, supply potential of selected ES, bundles and tradeoffs of ES supply potential, and cold/hot spots of ES supply potential. The default view (Fig. 3) of the Viewer is a background map with land use data obtained from the IACS database land parcel identification system, representing the main classes of land use in agro-ecosystems: grasslands – semi-natural, permanent, cultivated and arable land. Additionally, where there is available data, abandoned farmland is shown.By clicking on the land block of interest, the user can view supply potential of ES in a selected field. For informative and educational purposes, the user can change land use type to view changes in supply potential in case of land use change. Short descriptions and recommended maintenance practices are provided when available.The supply potential of ES is the contextual data layer, which is derived from the expert based ES assessment matrix. Distribution of particular ES supply potential is visualized by selecting the particular service from a drop-down menu. For example, cultivated grassland, which is a monoculture agro-ecosystem, is ploughed at least once in 5 years, fertilized and seeded, and under certain natural conditions can provide a greater amount of provisioning services associated with biomass production, but has less ability to provide regulating services. Semi-natural grassland, a low-input agro-ecosystem dominated by natural species, potentially delivers an abundance of regulating services, especially those associated with habitat maintenance Bundles and tradeoffs of ES supply

potential are presented in a contextual data layer showing spatial grouping and interactions of ES. The user is able to explore groupings and interactions by choosing one in a drop-down menu. Cold/hot spots of ES supply potential are available in a contextual layer that gives the number of ES with either low or high values. The user is able to choose different representations of cold/hot spots of ES supply potential from a drop-down menu. The default choice for "cold/hot spots" is the combined value of "number of ES with high values" and "number of ES with low values". Willemen et al. (2010) defined cold spots as areas with conflicts between two or more landscape functions, which in our case can be described as inappropriate management practice in given natural conditions. Moderate cold spots mostly display one of the trade-offs, and planning decisions should be based on these. For defining the meaning of "hotspot" we follow Bagstad et al. (2016) who defined it as areas which should draw attention of decision makers, because of high conservation value and high vulnerability. This selection gives a general overview of a selected territory in the context of its current potential to deliver ES. To obtain a specific view on the character of the territory in the context of shortages or abundance of ES supply potential, the user can choose between additional selections ("Number of ES with high values" or "Number of ES with low values") to view the actual number of ES with high/low values or by choosing a specific ranked 1-5 value.
[FIGURE 3 ABOUT HERE]

3.2 Viva Grass BioEnergy

The Viva Grass Bioenergy decision support system was developed as a tool for assessing grass-based energy resources (Fig. 4) to inform relevant planners/stakeholders about areas with the highest potential for grass for energy (prioritizing). It is accessible for registered users only. The analysis of the energy potential includes parameters like grassland area, biomass production and calorific potential for district heating. The Viva Grass bioenergy module uses additional sources of information to enrich both the basemap and the ES assessment. The 10 semi-natural grassland classes are updated with information about the Annex I habitat type they belong to. Subsequently, quantitative data collected from scientific literature sources is linked to the Annex I habitat types. The module is therefore able to provide detailed information to the user about the average biomass production and average grass calorific power per semi-natural grassland type, and allows to select and summarize bioenergy potential from several grasslands. Additionally, the module provides information on the current management status of the selected grasslands, as well as information about presence of reed encroachment and recommended grazing pressures per habitat type.The bioenergy sub-module was designed with the aim of assessing the availability of grass-based energy sources. It was aprobated in Lääne County, Estonia. Grasslands have a potential for energy production as solid biomass heating fuels. Whether grasslands are specifically cultivated for this purpose, or the grass mown from permanent and semi-natural meadows is used, grass can be burnt in co-fired plants for heat generation. In many cases, the use of grass bales for heating is a feasible alternative to regular biomass-based resources such as woodchips. The bioenergy sub-module specifically aims at assessing the area, distribution, average production and average calorific potential of different semi-natural grasslands and it is designed to inform relevant planners/stakeholders about areas with the highest potential for grass for energy (prioritizing). This is achieved by enriching the Viva Grass base map with additional information on biomass production and calorific potential in Estonian semi-natural meadows collected from several literature sources (Heinsoo et al. 2010, Melts et al. 2013, Melts et al. 2014b, Melts et al. 2014a). Additionally, the bioenergy sub-module includes information on the estimated demand of heating from grass biomass sources, understood as the amount of inhabitants living in district-heated blockhouses.

[FIGURE 4 ABOUT HERE]

3.3 Viva Grass Planner

The Viva Grass Planner is a decision support system designed to operationalize the ES concept for spatial planning. The Viva Grass Planer is accessible for registered users; registration is carried out by the system administrator. The Viva Grass Planner consists of two basic sub-modules designed to carry out prioritization and classification functions, subsequent representation of the results in a map, and to provide the possibility to export processed data.Prioritization is performed by applying Multi Criteria Decision Support (MCDS) – an accepted scheme for supporting complex decision-making situations with multiple and often conflicting objectives that stakeholders groups and/or researchers value differently (Saarikoski et al. 2016). We developed a MCDS approach for viable grassland management through ecosystem service and site-specific factor assessment. We followed the scheme proposed by Langemeyer et al. (2016) (Fig. 5).MCDS was carried out in consecutive steps involving definition of a problem, collaborative definition of preferred criteria by stakeholders and experts, weighting of criteria and prioritization of alternatives. Problems addressed in MCDS were elaborated and defined in round table meetings of experts and local stakeholders at selected case study areas. Round table meetings began with presentation of ES assessment, ES trade-offs and cold/hotspots, followed by problem-oriented discussion to define MCDS objectives.To evaluate adequacy of different alternatives, clear criteria must be defined. As the whole process of definition of the problem was contextualized in ES assessment it was possible to use the outcomes of it to define a core set of criteria, thus making them directly connected to ecosystem structure and functions. Additional criteria were developed to meet objectives of a particular MCDS. Thus, the criteria relevant for a particular decision making context can be selected from the available attributes consisting of the results of ES assessment or from additional data on case specific attributes that are added by the user. To indicate relative importance of chosen criteria, a weighted sum model was applied. The weighted sum is commonly used to form a comprehensive judgement in case of problematic ranking (Rowley et al. 2012). The Tool user can assign weights ranging from 0-100%, such that the sum of all percentages is equal to 100% (Fig. 6). The resulting weighted index is calculated as follows:

$$\sum_{i=0}^{n} \frac{Index_i}{\max(Index)*n} Weight/100$$

where Index – value of a particular index, max(Index) – maximum value of a selected index, and Weight – user-defined weight for the component. The total weight index is the sum of the selected components. Weighting scales can be saved and edited.The resulting weighted index can be further divided into priority classes. To create final prioritization of alternatives, additional classification can be performed by employing supplementary data specified by the objective of the MCDS. Classification can be done both based on performed prioritization and stand alone. To perform classification, some GIS skills are needed – writing an expression in SQL syntax. The user also requires knowledge of data structure.To improve quality of performed analysis, data editing and additional data upload is provided. The user is able to edit and store underlying natural conditions of a selected field in cases when more precise information is available. The calculations of ES supply potential and interactions among ES are recalculated and updated by the Viva Grass Tool and subsequently stored in the user account.To indicate relative importance of a chosen criteria, the Tool user can assign weights ranging from 0-100%, such that the sum of all percentages is equal to 100%.

[FIGURE 5 ABOUT HERE]

[FIGURE 6 ABOUT HERE]

3.4 Audience

All Viva Grass tool modules were tested and improved in case studies through stakeholder engagement, and based on that the beta version was developed. Later the tool was tested in regional workshops in all three countries, all together 150 practitioners in various fields (spatial planning, agricultural consultancy, farmers, researchers) participated in 7 all-day workshops. The entire populations of spatial planners and agriculture planners in the respective regions were approached, and all who could arrive to the training sessions participated. Some interested students and farmers participated as well. During the workshops participants were introduced to concept of ES and its application in different fields, in the second part of workshop participants were introduced to main functionalities of the Viva Grass tool and how the main results were generated for case study areas. After participants were introduced to all modules of the tool and were familiarized with working and weighting different criteria, they in small groups developed preliminary case studies for their own localities, discussed weights and assessed suitability of the tool to support decisions in their cases. Participants were assisted by researchers, who supported operationalization of tool functionalities to local cases. After the workshop participants filled in reports were they expressed their opinion on tool's applicability in their field of activity, its advantages and disadvantages, as well stated their suggestions for further improvement of the Viva Grass tool, which were partially incorporated in the final version of the tool.

Viva Grass Viewer was evaluated as most usable of the modules and Viva Grass BioEnergy as least usable in daily work of participants of the workshops. Spatial planning alongside land management and land use transformation were valued as most suitable applications of the Viva Grass tool, reported by participants of workshops. As main disadvantages named by the participants of the workshops were base map data accuracy and reliability (especially soil data), language barrier as the tool's working language is English, and slow performance. As main advantages named by participants of the workshops were that the tool is simple and reviewable, it is possible to conduct data processing without having a GIS software and that this tool is novel.

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4. Examples of application of Viva Grass Planner

4.1 Prioritization of areas for landscape maintenance in the Cēsis case study area

The Viva Grass planner was tested in the Cēsis municipality case study area. The aim was to support landscape management planning at the municipality level. Since 56% of the rural area in the Cēsis municipality is covered by forest, maintenance of grasslands as well as removal of shrub in abandoned agriculture land are essential to preserve the characteristics of the mosaic landscape. The prioritization model based on MCDS was applied to select sites for landscape maintenance or restoration measures. The criteria for prioritization included the value of 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) (Table 4). The prioritization model for landscape maintenance is presented in Fig. 7. The results of application of landscape management prioritization model is shown in Fig. 8. The testing of the prioritization model of the Viva Grass planner in the Cēsis case study area was performed through an iterative process of stakeholder engagement, including two rounds of meeting with groups of ca. 15 municipality representatives (spatial planners and tourism experts from the municipality, farmers and local entrepreneurs). During the first round the stakeholders assigned the weights to the selected ES supply criteria, while during the second the round the prioritization results, derived from the tool, were examined, weighting of the criteria adjusted to the priorities of the planning area, and concreate management proposals for the specific areas elaborated. The obtained results are used to formulate proposals to the Cēsis municipality Development Plan and related Action Plan, defining areas where specific management is required to maintain or improve the landscape value.

[TABLE 4 ABOUT HERE]

[FIGURE 7 ABOUT HERE]

[FIGURE 8 ABOUT HERE]

4.2 Green network planning support

The aim of green network (GN) planning MCDS is to guide planners in adaptation of a County-level GN into a rural municipality General Plan, stressing the role of grasslands in GN and to identify possible land use conflicts in GN implementation.The criteria for the inclusion of semi-natural grasslands in the GN of a rural municipality General Plan is based on their capacity to potentially deliver a certain set of ES (Table 5). In terms of the role of semi-natural grasslands inside the GN, ES belonging to “habitats” bundle and the “soils” bundle offer a wide array of environmental benefits. These benefits (soil protection, pollination, etc.) are not only constrained to the grassland plot itself, but have a wider spatial effect (e.g. increased pollination benefits also in surrounding agricultural land). The GN MCDS scheme is presented in Fig. 9 and output maps in Fig. 10.

[TABLE 5 ABOUT HERE]

[FIGURE 9 ABOUT HERE]

[FIGURE 10 ABOUT HERE]

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FIGURES

Fig. 1. Case study areas.

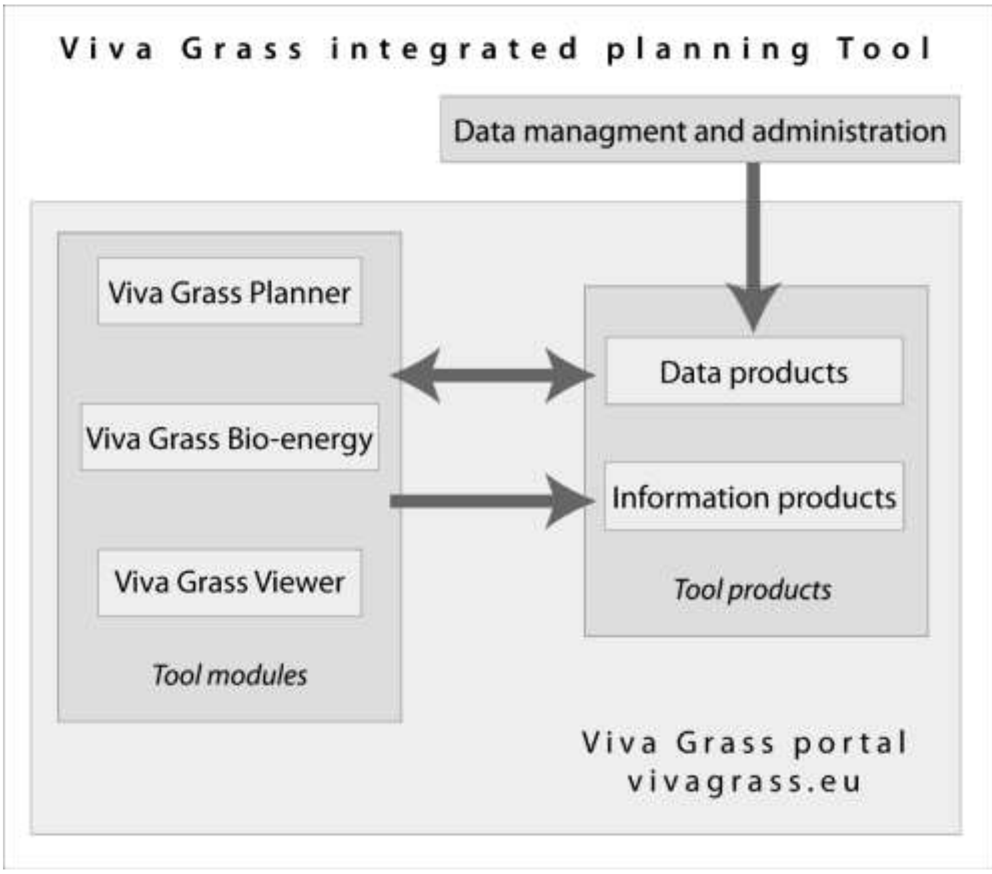

Fig. 2. Conceptual scheme of Viva Grass Tool.

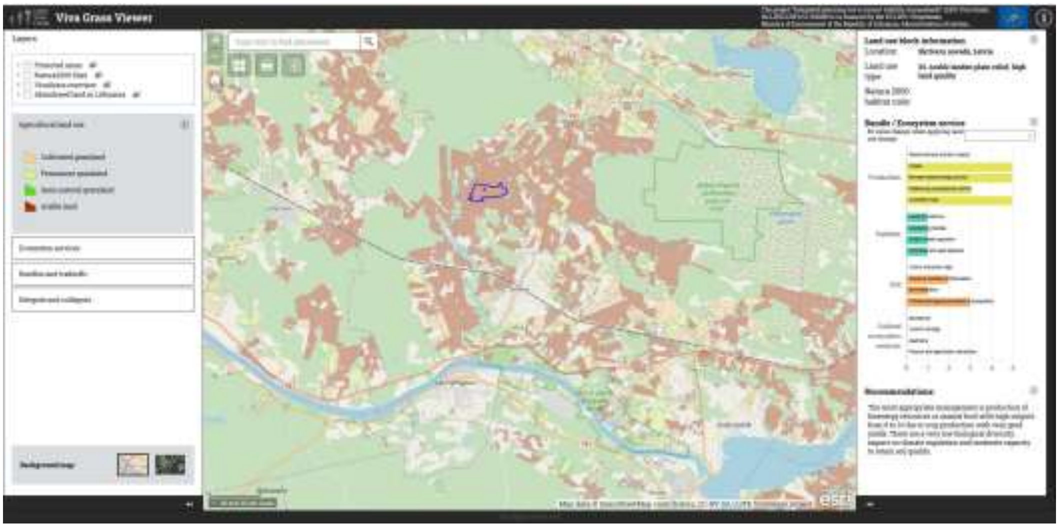

Fig. 3. Default view of the Viva Grass Viewer.

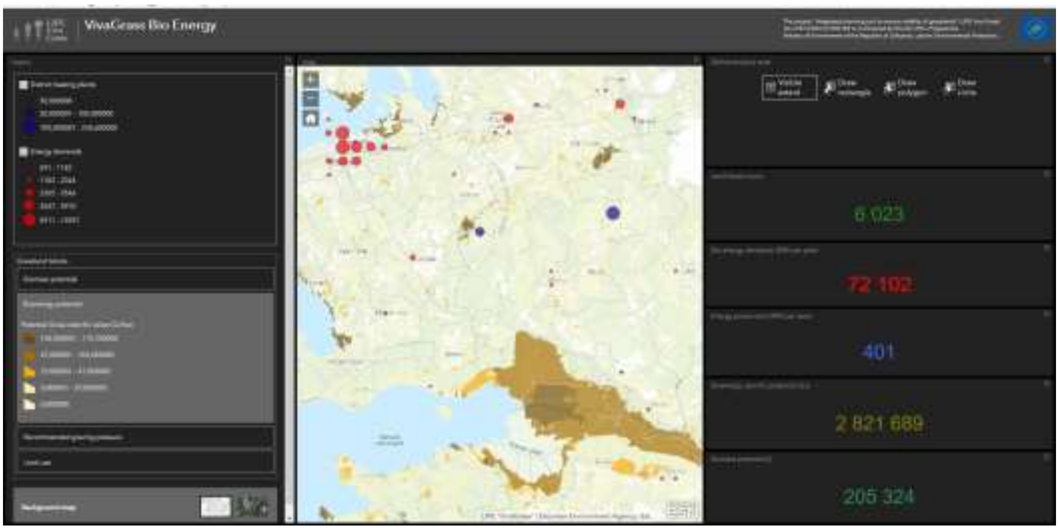

Fig. 4. Viva grass Bio-energy module displaying potential Gross calorific value and heating plants and demands.

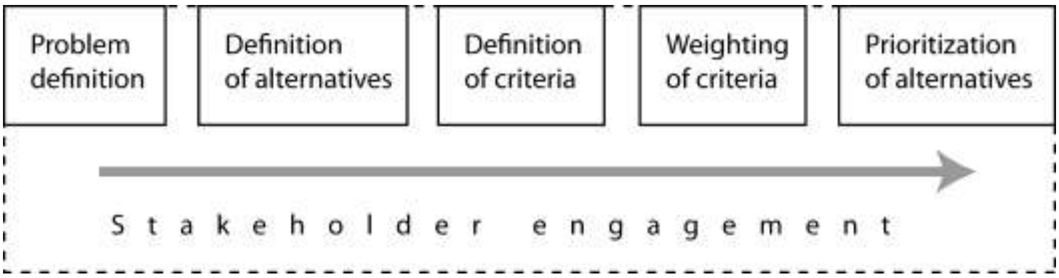

Fig.5 MCDS workflow (adapted from Langemayer et al. 2016)

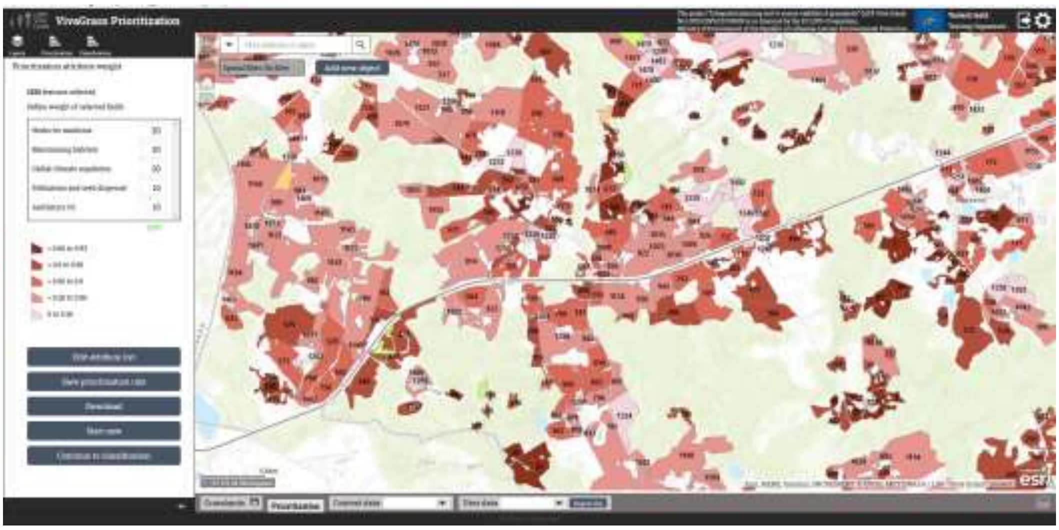

Fig. 6. Weighting the criteria in Viva Grass Planner.

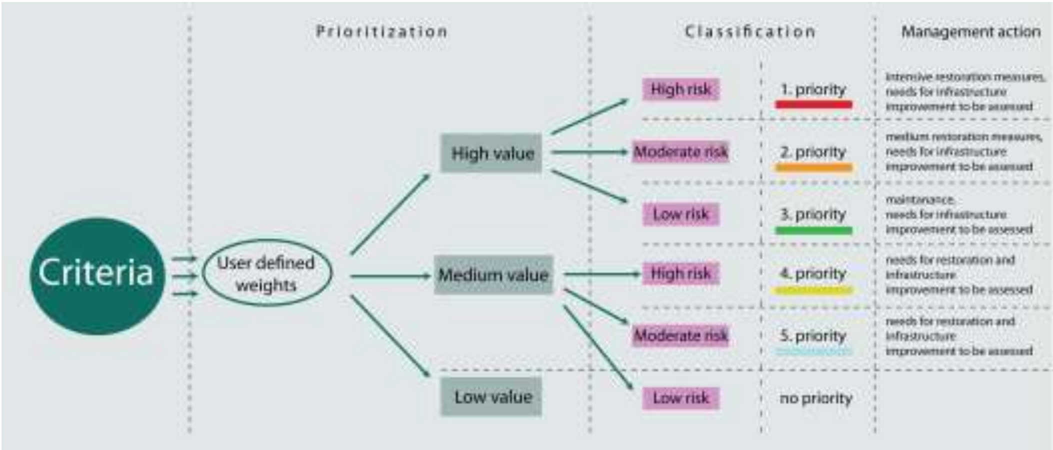

Fig.7 Prioritisation scheme for landscape planning.

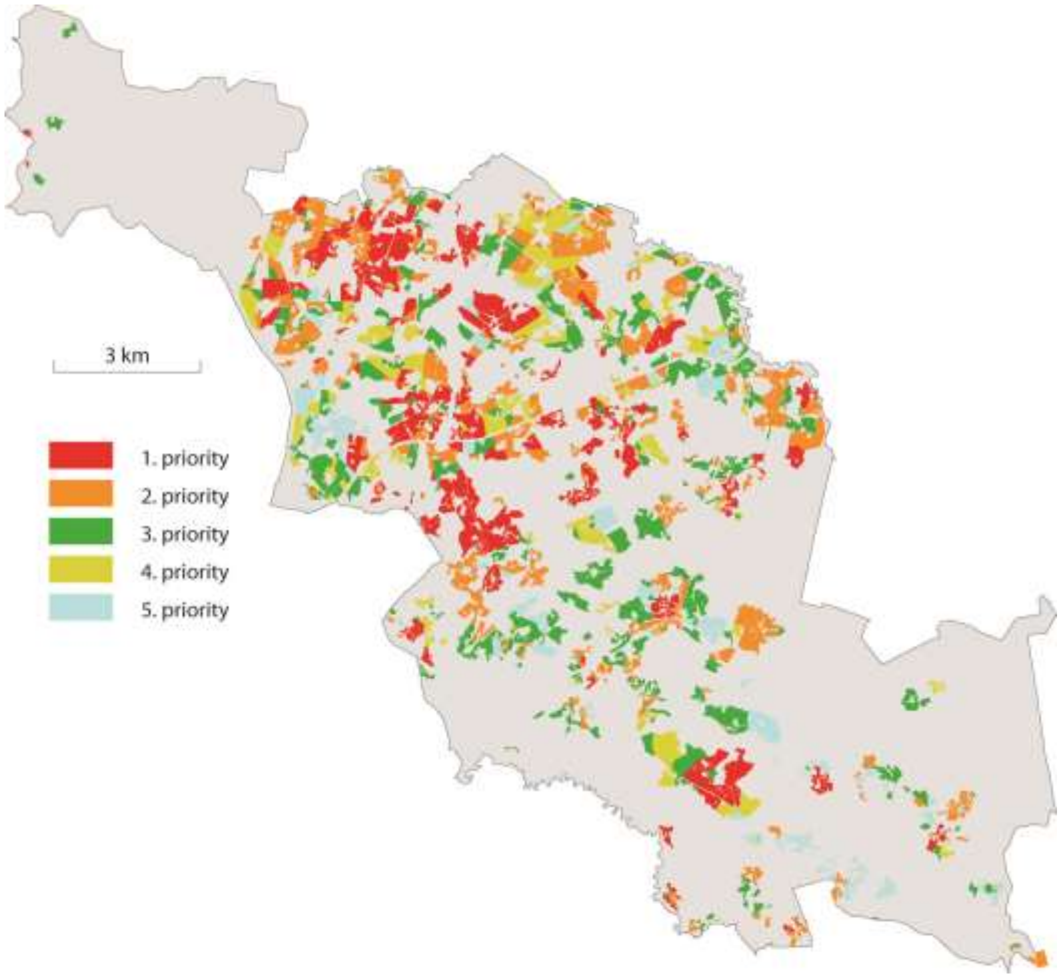

Fig.8 The results of landscape management prioritization in the Cēsis municipality.

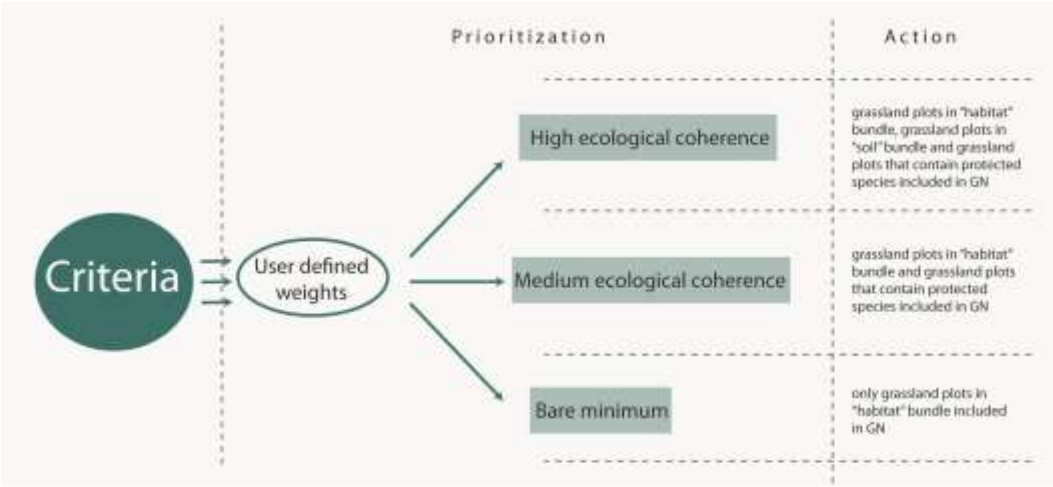

Fig.9 GN planning scheme.

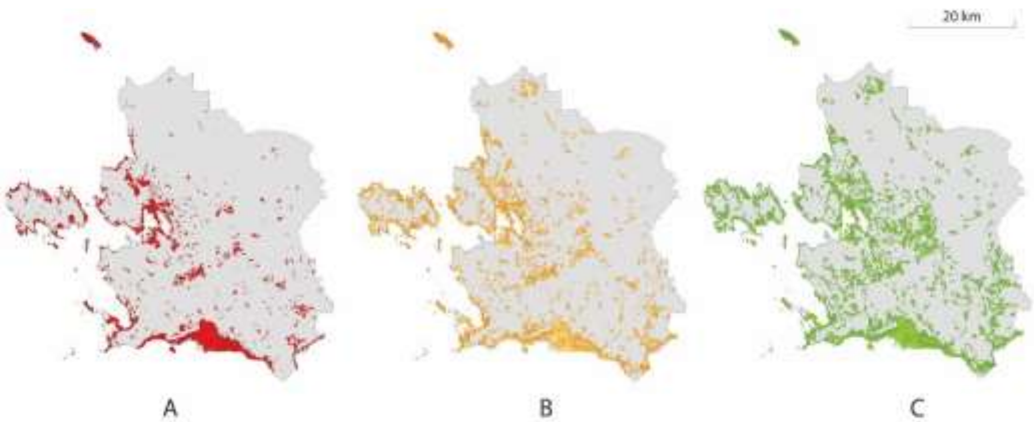

Fig.10 Three consecutive scenarios of grassland inclusion in Lääne County, Estonia GN: (A) Scenario 1: bare minimum, (B) Scenario 2: medium ecological coherence, (C) Scenario 3: High ecological coherence.

Table 1. Description of selected decision support tools based on ES assessment.

Tool	Indicative description	Publication
InVEST	Open source ES mapping and valuation models accessible through GIS at watershed or landscape scale.	Daily et al. 2009
ARIES	Web browser or stand-alone open source modelling framework for mapping ES flows	Bagstad et al. 2011
LUCI	Open source GIS toolbox to map areas providing services and potential gain or loss of services under different management scenarios	Jackson et al. 2013
MIMES	Open source multiscale dynamic modelling system for mapping and valuation of ES	Boumans and Costanza 2007
EcoServ	Web based tool to model ES providing maps of service provision under scenarios for climate and land use change in wetlands	Feng et al. 2011
Envision	Modular open source tool integrated in an urban growth-ES modeling framework	Guzy et al. 2008
PYL	Tool for qualitative evaluation of the effects of regional planning measures on ES	Fürst et al. 2010
SAORES	Modular farmland retiring planning tool	Hu et al. 2015
TESSA	Suite of tools for measuring and monitoring ecosystem services	Peh et al. 2013
EnviroAtlas	Web-based open access tool that brings together environmental, economic and demographic data into an ES framework at multiple scales	Pickard et al. 2015
PALM	Web-based tool that employs ES and various location factors to allocate urban development zones, explore trade-offs and support discussions in participatory planning	Grêt-Regamey et al. 2017b

Table 2. Description of case study areas

Case study area	Nr. in Fig. 6	Planning level	Area (km^2)	Indicative qualities
Lääne County	1	Regional	2413	Most of the farmland is permanent grasslands. Large share of semi-natural grasslands with high proportion of coastal meadows and reedbeds.
Saaremaa municipality	2	Regional	2683	Municipality is an island that has a mosaic landscape with a high share of semi-natural grasslands, mainly alvars, coastal meadows and wooded meadows and pastures.
Kurese farm	3	Site	1,3	Alvars on thin limestone soils, contains a wide variety of cultural heritage and traditional landscape elements, such as stone walls, burial sites, old roads, limestone quarries and old farmhouses.
Cesis municipality	4	Local	171,7	Diverse mosaic landscape, undulated relief, dominated agricultural land use is grasslands, but very low share of semi-natural grasslands.
Kalnāji farm	5	Site	0,99	Farm in transition from high to low input farming, with high share of restored previously abandoned farmland
Silute municipality	6	Regional	1706	Nemunas river delta, polder landscape with high share of semi-natural grasslands important for bird migration.
Dubysa regional park	7	Local	106	Protected area of river valley surrounded by intensive agriculture lands with high share of semi-natural grasslands.
Pavilniai regional park	8	Local	21,76	Area is situated within the city on intense erosion relief alongside river valley. Most of the territory is covered by forest, low share but high ecological value grasslands

Table 3. Functionalities of the Viva Grass tool modules.

	Functionalities

Tool modules	Land use (agricultural)	ES Assessment	ES bundles	ES Cold/hot spots	Biomass potential	Bioenergy potential	Management recommendations	Prioritization, classification	Export map as PDF	Edit, upload, download data
Viva Grass Viewer	X	X	X	X			X		X	
Viva Grass Bioenergy	X				X	X	X		X	
Viva Grass Planner	X	X	X				X	X	X	X

Table 4. Criteria identified and mapped for Landscape planning.

Criteria	Type	Description
Physical and experiential interactions	Cultural ES	Vicinity to recreational objects and territories
Educational value	Cultural ES	Vicinity to educational objects and territories
Cultural heritage value	Cultural ES	Vicinity to cultural heritage objects and territories
Landscape aesthetics value	Cultural ES	Selected landscape features (openness of landscape, relief undulation, vicinity to water bodies and streams, character of land use and character of surrounding land use
Ecological value	Aggregated ES values	Average value of ES in "Habitats" bundle
Risk of farmland abandonment	Composite indicator	Agro-ecological qualities of farmland, vicinity to farms, roads and settlements
Risk of Hogweed Sosnowsky invasion	Composite indicator	Vicinity to invaded sites, position in seeding corridor (streams, roads)

Table 5. Criteria identified and mapped for Green Network planning module.

Criteria	Type	Description
Pollination and seed dispersal	Regulating ES	Diversity and occurrence of insect pollinators
Maintaining habitats for plant and animal nursery	Regulating ES	Number of species
Global climate regulation	Regulating ES	Carbon sequestration in vegetation and soils
Control of erosion rates	Regulating ES	Amount of soil retained
Chemical conditions of freshwaters	Regulating ES	Absorption of nutrients
Bio-remediation	Regulating ES	Soil capacity to enhance bio-remediation
Filtration-storage accumulation	Regulating ES	Soil capacity to store/accumulate nutrients
Protected species distribution	Location factor	Presence of protected species in grassland