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Research Article

National ecosystem services assessment in Slovakia - meeting old liabilities and introducing new methods

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Abstract

This article provides an overview and results of the pilot national ecosystem services assessment in Slovakia. It follows the MAES process and past ecosystem services (ES) research in Slovakia and is based on original research methodology using spatial and statistical data. The initial step of national ES assessment resulted in the selection of significant ES for the evaluation process, where 18 ES in three groups were selected (five provisioning, 10 regulatory/maintenance and three cultural ES). An original assessment model provided the theoretical and methodological framework for national ES evaluation. The principal result is an assessment of the national landscape's capacity for ES provision, based on evaluation of the landscape units and selected properties and indicators at the ecosystem level. These inputs included habitat types and watersheds, administrative units, natural topology, geology, soils, climate, water and biota. The ES capacity models were created and evaluated for each ES, for the main groups and, finally, for overall ES provision. The highest capacity to provide ES in Slovakia comes from natural and semi-natural ecosystems, mainly deciduous, mixed and coniferous forests which cover over 38% of Slovak territory. The water ecosystems and wetlands are also significant, followed by grasslands and permanent crops. The research highlights the crucial importance of the mountainous and sub-mountainous areas in Slovakia and confirms the significant contribution of the natural and semi-natural ecosystems for ensuring ES provision.

Keywords

ecosystem services, MAES process, national assessment, valuation methods, Slovakia

Introduction

Although the ecosystem services (ES) concept was introduced in the early 1980, it has received most attention within the last twenty years. The ES issue progressively interweaves various fields of the natural sciences and touches on practical and political areas as well and, although it is gradually incorporating considerations of global economics, its level of practical application remains insufficient (Costanza et al. 2017).

The basic definition states that "ecosystem services include all direct and indirect contributions of ecosystems to human well-being" (TEEB 2010). Authors such as de Groot et al. (2010) argue that the concept of ES and their assessment enables a better understanding of the ecological, social and economic benefits of the sustainable use and protection of ecosystems. The methods of bringing this about include ES mapping, assessment, quantification and further interpretation (Burkhard and Maes 2017). There is a wide range of ranking schemes, indicators and quantification methods, including spatial localisation (Burkhard et al. 2014), but the most frequently used and recommended ES assessment methods combine the biophysical, socio-cultural and economic fields. In addition, a broad consensus in the scientific community for the need to link different ES assessment methods has led to the development of integrated assessment methods (Dunford et al. 2018, Jacobs et al. 2016).

The mapping and assessment of ecosystems and ecosystem services (MAES) process in the EU countries (BISE 2019) aims at the ES valuation and implementation, mainly at the national level. National ES assessment studies have gradually developed since 2010 - Schröter et al. (2016), Nedkov et al. (2018) have recently analysed the state of ES mapping in European countries. In 2019, the overall level of implementation of MAES commitments reached 70%. Full implementation means mapping and assessment of the state of ecosystems and ES, economic valuation of ES and integration of the ES within national policies. The United Kingdom, the Netherlands, Ireland, Finland and Bulgaria have already achieved full implementation and Italy, Romania and France are making significant progress towards this objective. Besides these countries, Greece, Estonia and Slovenia have made the most significant progress since 2015 (BISE 2019).

Slovakia created a MAES expert working group of representatives from various governing and administration institutions and academia in 2014, to map and assess ecosystems and their services. The Ministry of the Environment also prepared two strategic policy frameworks at the national level. In 2014, "Biodiversity Protection Strategy for 2012-2020" set targets for 2020, highlighting the preservation and enhancement of ecosystems and their services through the establishment of green infrastructure and the restoration of at least 15% of degraded ecosystems. This target has, however, not been fulfilled so far. In 2018, the "Environmental Policy Strategy" defined goals for 2030 stating that “ES are evaluated and quantified and they will be considered for investments and policy-making, as well as for environmental impact assessment”. Nevertheless, Slovakia currently has one of the lowest ES implementation rates in Europe. The MAES assessment records only 20% implementation for the Slovak Republic, which puts it at the lowest ranking together with Cyprus (BISE 2019).

Bezák et al. (2017) provided an assessment of the current state of ES implementation in Slovakia for planning and decision-making processes; Izakovičová et al. (2017) also explicitly address ES integration in both of these spheres. Although these studies provided the basis for better implementation of the ES concept in our country, recent ES research is still scattered over various institutions, resulting in partial case studies that lack unity. Mederly and Černecký (2019) provided an overview of the “state of the art” of the ES research in Slovakia and find that the main ES implementation challenge has not yet been met.

To address the issues mentioned above, the main aim of this research is to prepare and present a pilot national ES assessment for the Slovak Republic. This goal partly addresses the policy targets of both of the above-mentioned national framework documents. Our research also supports the Ministry of Environment‘s MAES expert working group mission, which focuses on Target 2 of the EU Biodiversity Strategy. Furthermore, the scientific goal of our research is to establish a comprehensive biophysical approach for national ES assessment based on a development of unique computational procedures of ES assessment, drawing on a complex database of natural and partly socio-economic features.

Material and methods

Our research covers the entire 49,034 km² territory of the Slovak Republic, which is a land-locked country in Central Europe. The December 2019 national census identified 5,457,873 inhabitants in a dense settlement network administered by 2,890 municipalities. These include 140 cities with 53.5% of the population; there are only two cities with over 100,000 inhabitants and 10 more with over 50,000 (STATdat 2020). Most Slovak territory and, especially, the northern and central mountain areas, are in the Carpathians biogeographical region. The remaining areas, mostly in the south, lie in the Pannonian lowland plain. Agricultural land covers 40.1% of the territory, forest covers 40.2% and 19.7% belongs to other land-use classes, including settlements.

For the ES assessment, we followed a straightforward path: specifying which ES were to be addressed of ES addressed, gathering data and setting the assessment process and finally proceeding to the computation, standardisation and interpretation of the results. Fig. 1 provides the scheme of the research procedure.

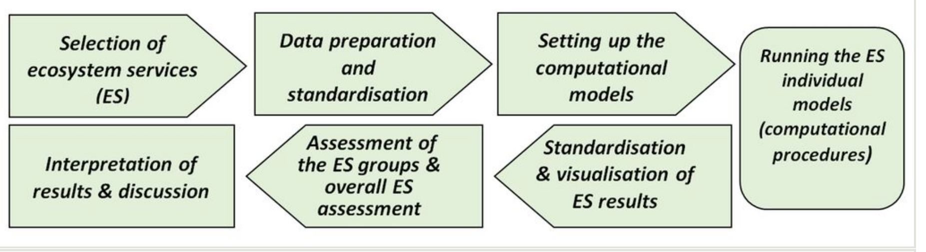

Figure 1.

The scheme of the research procedure.

Ecosystem services selection

The assessment process employs the standard ES classification with three main groups, from which 18 ES were selected - five provisioning, 10 regulatory/maintenance and three cultural ES. This selection resulted from expert determination of significant Slovak ES in the MAES process – in total, more than 20 experts from 14 governmental and scientific institutions (Ministries and their research institutions, universities and other academic institutes) were involved in this process. In addition, existing national assessment studies and review research (Schröter et al. 2016, Nedkov et al. 2018) influenced our selection. Table 1 presents a list of the investigated ES with brief definitions and the assessment context.

Table 1.

List of relevant ecosystem services, their definition and primary data for assessment.

Ecosystem service (ES)		**Definition (Burkhard et al. 2014)**	**CICES v 4.3 classification (CICES 2013)**	**Essential input landscape properties**
Provisioning ES				
P1	Crops & Fodder	Plants usable for human nutrition. Nutritional substances for domestic animals.	Nutrition - biomass: Cultivated crops/ Wild plants	Land use types Soil fertility Slope inclination Climate suitability Water availability

Ecosystem service (ES)		Definition (Burkhard et al. 2014)	CICES v 4.3 classification (CICES 2013)	Essential input landscape properties
P2	Timber & Fibre	Wood usable for human purposes (e.g. construction). Natural fibre (e.g. cotton, silk, cellulose) usable for clothes, fabric, paper etc.	Materials - biomass: Fibres and other materials from plants, algae and animals for direct use or processing	Land use types Forest productivity Soil fertility Slope inclination Climate suitability Water availability
P3	Drinking water	Fresh and process water available for drinking & domestic use.	Nutrition - water: Surface and groundwater for drinking	Drinking water sources & protected zones Water reservoirs & watersheds
P4	Freshwater	Fresh and process water available for industrial use, irrigation etc.	Materials - water: Surface and groundwater for non-drinking purposes	Hydrogeological regions Important watercourses Water reservoirs
P5	Fish & Game & Wildfood	Berries, mushrooms, edible plants, wild animals, fish for recreational fishing, hunting or collection; semi-domestic animal husbandry.	Nutrition - biomass: Reared animals/ Wild animals and their outputs	Land use Forest structure & categories Game reserves Fishing grounds
Regulatory & Maintenance ES				
R1	Air quality regulation	Capturing/filtering of dust, chemicals and gases from air.	Mediation of air flows: Storm protection, ventilation and transpiration Mediation by ecosystems: smell/noise/visual impacts	Land use Forest structure and quality Biomass volume - Leaf area index
R2	Water quality regulation	Ecosystem ability to purify water, for example, from sediments, pollutants, nutrients, pesticides, disease-causing microbes and pathogens.	Maintenance: Water conditions (chemical condition of freshwater)	Land use Forest structure and quality Soil permeability Slope inclination
R3	Erosion & natural hazard regulation	Soil retention and the ability to prevent and mitigate soil erosion and landslides.	Mediation of mass flows: Mass stabilisation and control of erosion rates, buffering and attenuation of mass flows	Land use Forest and biotopes structure and quality Slope inclination & Aspect Soil properties Rainfall intensity
R4	Water flow regulation	Water cycle feature maintenance (e.g. water storage and buffer, natural drainage, irrigation and drought prevention).	Mediation of liquid flows: Hydrological cycle and water flow maintenance, flood protection	Land use, structure and quality of biotopes Slope inclination Soil permeability Water flow distribution - watersheds

Ecosystem service (ES)		Definition (Burkhard et al. 2014)	CICES v 4.3 classification (CICES 2013)	Essential input landscape properties
R5	Local climate regulation	Changes in local climate components like wind, precipitation, temperature, radiation due to ecosystem properties.	Maintenance: Atmospheric composition and climate regulation: Micro and regional climate regulation	Land use Forest structure and quality Biomass volume - Leaf area index Solar radiation & Temperature
R6	Global climate regulation	Long-term storage of potential greenhouse gases in ecosystems	Maintenance: Atmospheric composition and climate regulation: Global climate regulation by reduction of greenhouse gas concentrations	Land use Forest structure and quality Biomass volume - Leaf area index Photosynthesis capacity Soil properties - depth, C-content
R7	Biodiversity promotion	Species and ecosystem diversity promotion, habitat protection	Maintenance: Lifecycle maintenance, habitat and gene pool protection: Maintaining nursery populations and habitats	Biotopes naturalness & state Species & ecosystem diversity and uniqueness Spatial diversity of landscape
R8	Pollination	Bees, birds, bats, moths, flies, wind, non-flying animals contributing to pollen transfer and reproduction of plants	Maintenance: Lifecycle maintenance, habitat and gene pool protection: Pollination and seed dispersal	Land-use suitability for pollinators Species & ecosystem diversity Spatial diversity of landscape
R9	Pest and disease control	Ecosystem ability to control pests and diseases due to genetic variations of plants and animals making them less prone to diseases and actions of predators and parasites	Maintenance: Pest and disease control	Biotopes naturalness & state Spatial diversity of landscape
R10	Soil formation	Ecosystem ability to recycle nutrients, for example, N, P.	Maintenance: Soil formation and composition: Weathering, decomposition and fixing processes	Soil productivity Soil storing and filtering capacity Moisture balance
Cultural ES				
C1	Recreation & tourism	Outdoor activities and tourism relating to the local environment or landscape, including forms of sports, leisure and outdoor pursuit.	Physical and experiential interactions: Physical and experiential use of plants, animals and landscapes	Land use capacity for recreation Recreational infrastructure Forest types Nature protection Attraction of relief forms

Ecosystem service (ES)		Definition (Burkhard et al. 2014)	CICES v 4.3 classification (CICES 2013)	Essential input landscape properties
C2	Landscape aesthetics	The visual quality of the landscape/ ecosystems or parts of them influencing human well-being and the need to create something as well as the sense of beauty people obtain from looking at landscapes/ecosystems.	Representative interactions: Heritage, cultural, entertainment, aesthetic	Land use types aesthetical quality Forest and biotopes aesthetics Attraction of relief forms
C3	Natural & cultural heritage	The existence value of nature and species themselves, beyond economic or direct human benefits. Values that humans place on the maintenance of historically significant (cultural) landscapes and forms of land use (cultural heritage)	Intellectual interactions: Scientific, educational	Importance of land use types Natural heritage sites & Nature protection importance Cultural heritage sites & Cultural values

Data preparation and standardisation

For the assessment of individual ES, we mainly used data from available spatial and information datasets. We initially prepared all spatial layers and database information in a unified form, relying primarily on the internal datasets of organisations involved in this research. We also added available data from environmental agencies and specialised institutions and open data from Slovak and European cartographic and remote sensing resources. Table 2 provides the list of map layers (41 in total) used for the initial assessment process. Some of them we prepared as tailored layers by reclassification or computational algorithms from raw data and then they were used as intermediate assessment layers.

Table 2.

List of map layers used for assessment of ecosystem services in Slovakia.

Content (theme) of the map layer	Source of data	Data scale	Prod.	Reg.	Cult.
Digital elevation model - slope and other parameters	Database of CP Univ. Nitra	1:25,000	2	2	2
Morphological-positional type of relief	Database of ILE SAS	1:25,000	*	1	2
Hydrogeological regionalisation	Database of ILE SAS	1:50,000	1	*	*
Average annual temperature	SR Climate Atlas	1:50,000	*	1	*
Rainfall intensity (max 1-day totals)	SR Climate Atlas	1:50,000	*	1	*
Moisture balance indicator	SR Climate Atlas	1:50,000	*	1	*
Avg. annual amount of solar radiation	SR Climate Atlas	1:50,000	*	1	*
Territorial climate classification	SR Climate Atlas	1:50,000	2	*	*
Hydrological basins (watersheds)	Slovak Water Mng. Map	1:50,000	*	1	*
Watercourses and water bodies	Slovak Water Mng. Map	1:50,000	1	*	*

Content (theme) of the map layer	Source of data	Data scale	Prod.	Reg.	Cult.
Significant watercourses	Slovak Water Mng. Map	1:50,000	1	*	2
Water resources used	Slovak Water Mng. Map	1:50,000	1	*	*
Water resources protection zones	Slovak Water Mng. Map	1:50,000	1	*	*
Water reservoirs	Slovak Water Mng. Map	1:50,000	1	*	*
Basins of watercourses used for drinking purposes	Slovak Water Mng. Map	1:50,000	1	*	*
Natural medicinal resources protection zones	Slovak Water Mng. Map	1:50,000	1	*	1
Protected water management areas	Slovak Water Mng. Map	1:50,000	1	*	*
Avg. groundwater depth	Database of ILE SAS	1:25,000	2	*	*
Soil subtype	Soil Portal, Database of ILE SAS	1:25,000	2	2	*
Soil texture	Database of ILE SAS	1:25,000	2	2	*
Soil depth	Database of ILE SAS	1:25,000	2	1	*
Current landscape structure/land use	State ZB GIS, Corine Land Cover	1:25,000	3	3	3
Spatial diversity of landscape structure	Database of CP Univ. Nitra	1:25,000	*	2	*
Classification and use of forest spatial units	State Nature Conserv., Forest Portal	1:10,000	2	*	2
Forest types	State Nature Conserv., Forest Portal	1:10,000	*	3	*
Forest age classes	State Nature Conserv., Forest Portal	1:10,000	1	3	1
Significant ecosystems (habitats)	State Nature Conservancy of SR	1:25,000	*	2	*
Naturalness of ecosystems	Database of CP Univ. Nitra	1:25,000	*	2	*
State of ecosystems	State Nature Conservancy of SR	1:25,000	*	1	*
Categorisation of protected areas	State Nature Conservancy of SR	1:25,000	*	1	2
Natural conservation significance of a territory	Database of CP Univ. Nitra	1:25,000	*	1	2
Leaf area index (LAI)	Copernicus Global Land Survey	1:50,000	*	2	*
Photosynthetically active radiation (FAPAR)	Copernicus Global Land Survey	1:50,000	*	1	*
Normalised difference vegetation index (NDVI)	Copernicus Global Land Survey	1:50,000	*	1	*
Potential for geothermal energy	SR Landscape Atlas	1:100,000>	*	*	1
Fishing and hunting areas	SR Landscape Atlas	1:100,000>	1	*	*
Areas of traditional (historical) land use	SR Landscape Atlas	1:100,000>	*	*	3
Significant natural sites	SR Landscape Atlas	1:100,000>	*	*	2
Historical parks and gardens	SR Landscape Atlas	1:100,000>	*	*	2
Cultural and historical attractions and monuments	SR Landscape Atlas	1:100,000>	*	*	2

Content (theme) of the map layer	Source of data	Data scale	Prod.	Reg.	Cult.
Recreation and tourism objects	SR Landscape Atlas	1:100,000>	*	*	1

3 most important layers for ES assessment **2** important layers for ES assessment **1** complementary layers for ES assessment
* not included in the ES assessment

The essential layers, used in the assessment of most ES, include the following: a map of current land use/landscape structure and its interpretation; a map of ecosystems and selected derived features (Černecký et al. 2019); specific forest datasets; data on protected areas, a digital elevation model and soil properties. The detail and accuracy of the data are set in 1:25,000 scale, which is well above the national assessment standard. Supplementary input information includes selected climate and hydrological data at the 1:50,000 national accuracy level. For the cultural ES, we also used less accurate data from the Slovak Landscape Atlas (MoE SR 2002).

Our next step was to standardise the data. We converted all used layers from different sources to the same shape - a raster format with a pixel size of 25 m, in the S-JTSK coordinate system. During the assessment process, we kept all calculations in this format.

Table 2 supplies the list of employed data, information sources, accuracy and importance for ES assessment. A full description of data is provided in Suppl. material 1.

Setting up the computation models

To express the landscape's relative capacity to provide all valued ES, we employed a coordinated procedure, based mainly on spatially-expressed biophysical and environmental data (see previous point).

For this purpose, we used a qualitative expression of the landscape capacity for ES provision on a dimensionless relative scale (0 to *n* points). A computational algorithm was developed for each ES in consultation with team members with expertise in that ES, based on the different input layers. Computational procedures consisted of the reclassification and overlay of different data layers. The approach used could be considered one of the main innovations of our research. The essential landscape properties entering the computation of given ES are provided in Table 1; Table 2 gives a full overview of the data. For the data used and the computational algorithms for all ES, see Suppl. material 2.

By using this procedure, we produced 18 detailed ES landscape capacity maps on a 25 x 25 m grid, with different numeric values (generally from 0 to *n* points). The rough ES maps then went through a process of results standardisation (see next subsection).

ES results standardisation & visualisation

For standardisation of the ES results, better display value and in preparation for further statistical analysis, we recalculated the basic ES capacity values on a 1 km grid. Each value for a 1 x 1 km pixel was calculated as the arithmetic average (mean values) of 1600 original 25 x 25 m pixels. Finally, we converted the obtained values to a 0-100 range, using a simple transformation algorithm

Xitransf = *(Xi-Xmin/Xmax – Xmin)*100* , where

Xitransf = new transformed value of ES capacity within the range 0-100

Xi = value of ES capacity within the original range

Xmin = minimal value of ES capacity within the original range

Xmax = maximal value of ES capacity within the original range.

The final ES values use a relative 0-100 scale, where 0 indicates the minimum current capacity of any area in Slovakia for the provision of the given ES and a value of 100 represents maximum current capacity. Since the distribution of the majority of the ES capacity values was highly asymmetric and did not meet the preconditions for a statistically normal distribution, before the final transformation of the maps into the 0-100 scale, we proceeded to remove data outliers (those within 2% of the minimum and maximum values).

The final values, in a dimensionless scale, can be interpreted as a suitability scale from minimum (0%) to maximum (100%) landscape capacity for providing ES. Additionally, classification into several degrees of suitability is possible, for example, below average, average, above average and high to very high capacity, based on the percentile distribution of values.

The resulting ES maps for the territory of Slovakia contain about 49 000 pixels with individual values for each ES. They represent a basic statistical set suitable for further assessment of the interactions and factors affecting the provision of the ES.

For the graphical presentation of the ES maps, we chose a unified form: maps show the relative capacity of a landscape to provide a given ES in a 5-degree legend (every 20% of the scale is represented by one shade of a colour scale). Suppl. material 3 shows the histograms, box plots and maps of all 18 ES. Detailed results of the assessment of 18 individual ES for Slovakia, including the theoretical and methodological background, were published by Mederly and Černecký (2019).

Assessment of the ES groups & overall ES assessment

The main goal of our research is to introduce and assess those ES significant for the territory of Slovakia. Of course, staying only at the individual ES level without the assessment of ES groups and the overall ES would be insufficient. For this reason, we also decided to carry out assessments of the three main ES groups and a map of the landscape's overall capacity for ES provision.

For the computation of the landscape capacity for provisioning, regulatory/maintenance and cultural ES, we used a simple arithmetic average of the value of all ES in a given group (five ES, 10 ES and three ES). Evaluating the landscape's overall capacity to provide the ES required us to determine the weight (importance) of three main ES groups. Due to varying opinions about the importance of the ES groups in the research community, we decided to handle this problem in a relatively simple, but (in our opinion) sufficiently representative and "fair" way. In our approach, provisioning ES as a whole is weighted at 25% of the total weight, the same weight being applied for cultural ES. Regulatory/ maintenance ES constitute 50% of the total value. Finally, we calculated the resulting value as the sum of the capacity values for each ES group multiplied by the given weight. The theoretical value of the capacity ranges (as in the case of individual ES) from 0 to 100, where 0 means no capacity and 100 the maximum possible landscape capacity for ES provision.

An overview of the results for all ES groups is provided in the result section.

Results interpretation & discussion

Our ES assessment aims to cover the territory of Slovakia and, thus, is fundamentally orientated towards giving a national overview. In addition to this objective, we also tried to explain two ES spatial distribution factors: (1) the relationships between the main landscapes types and ES provision and (2) the importance of land use classes for ES provision. We used basic methods of spatial statistics for this interpretation; the last results subsection briefly summarises the findings.

In the discussion section, we seek to compare our approach to other national assessment studies and try to highlight some advantages and disadvantages of our methodology and discuss challenges for future research.

Results

In this section, we provide an overview of the results obtained for the three main analysed ES groups and overall ES assessment, together with interpretation of the results. Tables, charts and maps are used to illustrate the results.

Provisioning ES

Provisioning ES are perceived and directly appreciated by most people. These include physical products and goods from ecosystems which provide the following: nutrition, materials and energy, biomass for food, drinking water and water for other purposes, useful biomass, abiotic materials and substances and energy resources (MEA 2005 and others). Herein, we selected five ES for our pilot assessment based on the opinion of the MAES process experts from various Slovak institutions.

For the five assessed provisioning ES, the mean capacity values range from 13.2 (P3) to 34.5 (P5) - see Fig. 2. Basic statistic parameters are presented in Table 3, while Suppl. material 3 provides individual ES maps.

Table 3.

Basic statistical parameters of the provisioning ES*1.

Basic statistics	PROVISIONING ES	P1	P2	P3	P4	P5
Minimum	2.93	0.00	0.00	0.00	0.00	0.00
Maximum	78.44	100.00	100.00	100.00	100.00	100.00
Range	75.51	100.00	100.00	100.00	100.00	100.00
Mean value	34.17	24.77	26.16	13.17	14.72	34.50
Median value	33.68	16.00	18.00	5.00	12.00	33.00
1st Quartile	26.33	5.00	12.00	1.00	6.00	25.00
3rd Quartile	41.25	43.00	40.00	21.00	20.00	47.00
St. deviation	10.79					

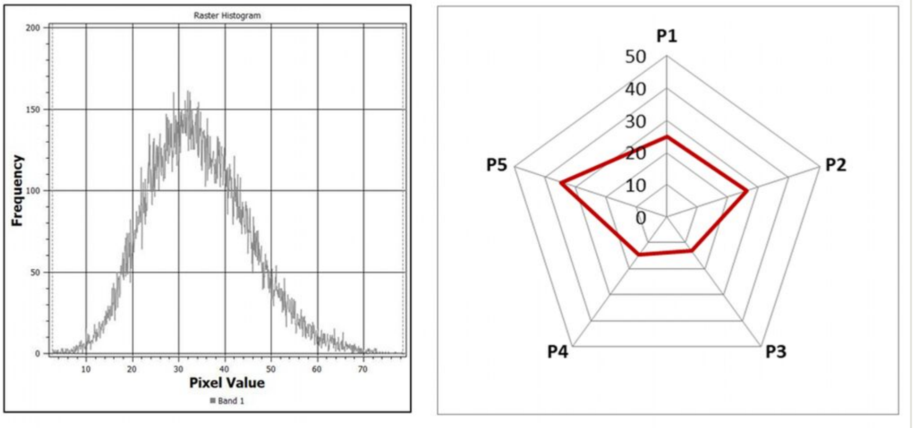

Figure 2.

Histogram and plot of the provisioning ES values*1.

1. ES **Biomass - Agricultural crops and fodder** is one of the “most visible” ES in the agricultural production process. The problem with biomass-agricultural crops is that the use of most other ES is largely suppressed or even eliminated by the intensive use of this ES. The spatial distribution of landscape capacity to provide this ES is significantly different from most other provisioning ES because, while the highest landscape capacity values are typically found for lowland areas with fertile soils and mild climate, the lowest values are found in high mountain areas.
2. ES **Biomass – Timber and fibre.** Although this is mainly provided by forestry, agri-ecosystems and other landscape types are also involved in this ES provision. Wood biomass and the benefits it provides, tends to grow on a decades-long timescale and a one-time benefit from this ES can cause decades of “loss of benefit” in the areas of other ES. This factor is largely neglected by sectoral landscape management. From spatial projections of this ES in Slovakia, we find

that the highest landscape capacity values are found for lower mountain areas and transitional sub-mountainous landscapes.

3. ES **Drinking water** and
4. ES **Freshwater** are closely related and sometimes considered and assessed as one ES. The landscape capacity for these ES mainly depends on abiotic conditions and processes, such as rainfall-runoff balance and hydrogeology. However, ecosystem status and environmental quality are also important, especially for drinking water which is concentrated in larger accumulations of water. The freshwater potential in mountain ranges is high with natural accumulation capacity and the wider river valleys and floodplains with quaternary gravel accumulation are of particular importance.
5. ES **Fish and Game/Wild-food** depends to a great extent on the predominant land use types, environmental quality and the regulations on fish and animal capture. Although wild-food dominates in lower and medium-altitude mountain ranges, the lowlands and basin areas also have great potential, especially in sub-mountainous areas and close to large bodies of water. This ES little with other ES because it does not fundamentally affect other ES benefits.

Fig. 3 shows the spatial projection of the overall capacity of the Slovak landscape to provide provisioning ES expressed as the average of the five evaluated ES. Small discontinuous areas in the Slovak higher and middle-elevation mountain ranges and forest areas achieve the highest ES levels and some lowlands and basin areas also have high levels. The landscape's lowest capacity to provide provisioning ES is found in urbanised and densely-populated areas and the less productive and non-forested parts of the lowlands and higher river basins. In addition, the highest parts of the mountain ranges also have limited capacity for provisioning ES.

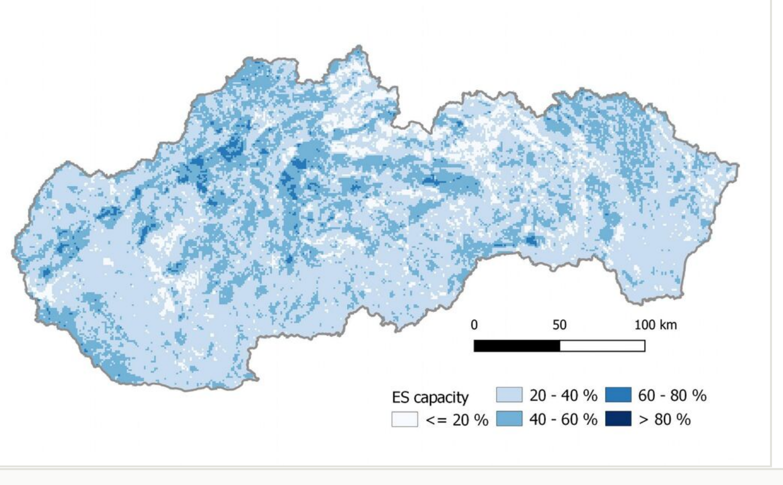

Figure 3.

The overall capacity of the landscape to provide provisioning ES.

Regulatory & Maintenance ES

Regulation ecosystem functions and services should be considered critical, because many natural processes have a positive influence on the environment and all living species' health and well-being. For the assessed regulatory/maintenance ES (Fig. 4), the mean capacity values range from 5.6 (R3) to 49.7 (R4). Basic statistic parameters are presented in Table 4, while Suppl. material 3 provides individual ES maps.

Table 4.

Basic statistical parameters of the regulatory/maintenance ES*2.

Basic statistics	REGULATORY / MAINTENANCE ES	R01	R02	R03	R04	R05	R06	R07	R08	R09	R10
Minimum	3.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	82.57	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Range	78.62	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mean value	38.93	38.47	31.03	5.64	49.74	30.41	38.06	23.00	42.76	43.95	33.14
Median value	36.67	24.00	21.00	1.00	50.00	19.00	31.00	20.00	42.00	47.00	27.00
1st Quartile	20.69	12.00	12.00	0.00	44.00	10.00	21.00	7.00	28.00	26.00	20.00
3rd Quartile	55.68	64.00	50.00	6.00	55.00	49.00	55.00	35.00	54.00	59.00	47.00
St. deviation	19.23										

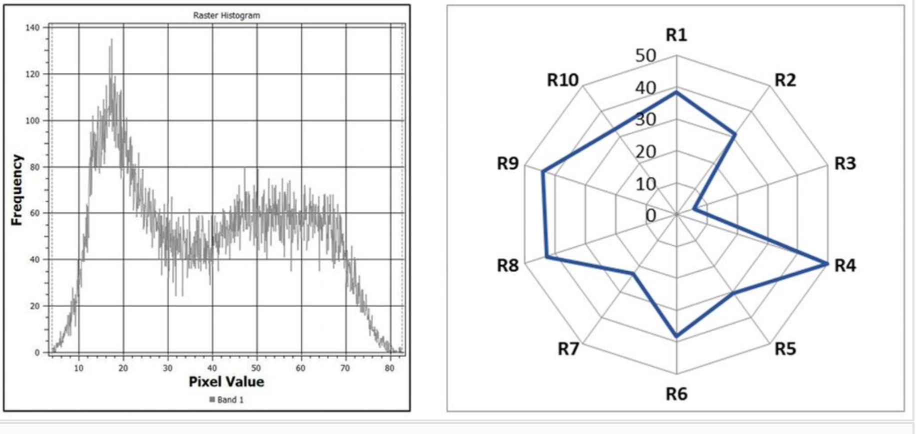

Figure 4.

Histogram and plot of the regulatory/maintenance ES values*2.

1. ES **Air quality regulation** mitigates the effects of air pollution on ecosystems and. therefore. also on humans. Forest ecosystems cover over a third of the Slovak land-mass and, from a national viewpoint, these are clearly the most important in the provision of the regulation of air quality ES. Other ecosystems, such as built-up

areas, can have local significance, because these areas impose the highest demand on and consumption of air quality ES.

2. ES **Water quality regulation**: this ES depends on different biophysical parameters. It is primarily provided by Slovak Medio-European beech forests and other wooded ecosystems, because of their quantity and favourable conservation status. Besides these ecosystems, mires, bogs and fens have a significant influence on provision ES Water quality regulation, but these habitats cover only 0.43% of Slovak territory.
3. ES **Erosion and natural hazard regulation** depends on the ability of the ecosystem and landscape to regulate adverse relief processes and to prevent and mitigate erosion, landslides and other gravitational processes. We chose water erosion regulation for the pilot assessment. While permanent grasslands provide very high anti-erosion effects, the main landscape type that provides this ES is the forested areas of hills, highlands and mountainous areas with appropriate spatial structure and quality.
4. ES **Water flow regulation** expresses the river catchments ability to regulate water runoff during extreme rainfall events so that flooding is avoided and risks are minimised. Natural and well-functioning watercourses, wetlands and valley ecosystems are best able to transform flood waves and high-water levels into lower basin areas - this is the principal mechanism of ES Water flow regulation. The open broad river valleys, water reservoirs and lowland landscapes with sufficient forests or water elements have the highest capacity for providing this ES out of all the Slovak landscape.
5. ES **Local climate regulation** affects the ability of ecosystems to regulate temperature, the amount of incident solar radiation and the spatial distribution of micro-climate factors (precipitation, wind, evapotranspiration). Mitigating the effects of pollutants, dust and noise-related processes also belongs to the crucial functions. Forests and woodlands are the main Slovak ecosystem types which provide this ES. This ES is also provided in lower quantity but high quality by water bodies, watercourses and riparian vegetation.
6. ES **Global climate regulation** is in our assessment represented by **carbon sequestration**. It consists of biogeochemical and biophysical processes which help avoid the adverse effects of global warming on humankind and biodiversity. Forest ecosystems participation in this ES is most prominent. The most widespread habitats which provide this ES in Slovakia are the beech forests and lowland hay meadows. The most qualitatively significant carbon pools are peat bogs.
7. ES **Biodiversity promotion.** Mountain and submountainous areas, together with grasslands, have the highest capacity to provide this ES because a significant proportion of their natural and semi-natural habitats are a part of the network of protected areas. The higher biodiversity there promotes ecosystem functioning, contributes to the maintenance of ecological stability and increases the terrestrial and freshwater ecosystems' potential to provide societal benefits.
8. ES **Pollination** is an essential ES because insect pollination has a significant and irreplaceable impact on ecosystem dynamics and thus supports multiple provisioning services. Forests and wooded habitats provide the high quality of this ES, especially beech, fir-beech, lime-oak and oak-hornbeam forest systems.

Pollination is also an essential ES in the orchards and submountainous hay-meadow and flowering-meadow habitats.

9. ES **Pest and disease control.** Healthy ecosystems with favourable conservation status can mitigate or resist the spread of disease and invasive non-native species through genetic variation. Our research highlights that natural and semi-natural diversified habitats around agro-ecosystems and urban areas provide the highest capacity for this ES. Moreover, the demand for ES in these areas is obviously quite high.
10. ES **Soil formation.** Soil properties are essential for both functioning of the agricultural landscape and other types of ecosystems which provide different nature functions. We find that, in addition to high quality agricultural soils, this ES is provided at a high level by natural and semi-natural forest and grassland ecosystems. Furthermore, watercourses, water bodies and wetlands play a significant role as transformation media for nutrient transfer to soils.

Fig. 5 illustrates the overall capacity of the Slovak landscape for regulatory/maintenance ES provision and shows that the highest value is present in forested mountain and foothill areas. Other mountain ranges and sub-mountainous areas provide medium to relatively high landscape capacity, while lowlands and basin areas with predominantly arable land have a low ES capacity.

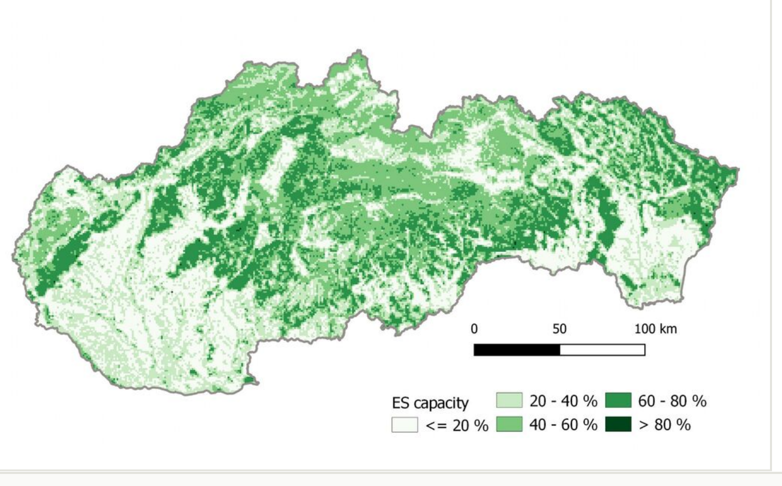

Figure 5.

The overall capacity of the landscape to provide regulatory/maintenance ES.

Cultural ES

Most cultural ES are challenging to measure, monitor and model and other authors assert that the value assigned to natural and cultural heritage often depends on individual and cultural assessment of their contribution to human well-being (Charles and Dukes 2008). Beauty, aesthetics and visual quality are perceived individually, with each person preferring a different type of landscape. Moreover, although cultural ES are tied to given landscape types, it is evident that all landscapes have something to offer in the way of natural assets and cultural and historical monuments.

We have, therefore, used the most recent available biophysical methods in assessing the landscape capacity for cultural ES provision based on available datasets. For the assessed cultural ES (Fig. 6), the mean capacity values range from 17.1 (C3) to 27.5 (C2). Basic statistic parameters are presented in Table 5, while Suppl. material 3 provides maps of individual ES.

Table 5.

Basic statistical parameters of the cultural ES*3.

Basic statistics	**CULTURAL ES**	**C1**	**C2**	**C3**
Minimum	0.00	0.00	0.00	0.00
Maximum	100.00	100.00	100.00	100.00
Range	100.00	100.00	100.00	100.00
Mean value	35.15	22.10	27.46	17.11
Median value	33.76	21.00	24.00	15.00
1st Quartile	14.20	7.00	15.00	5.00
3rd Quartile	52.70	33.00	37.00	26.00
St. deviation	23.34			

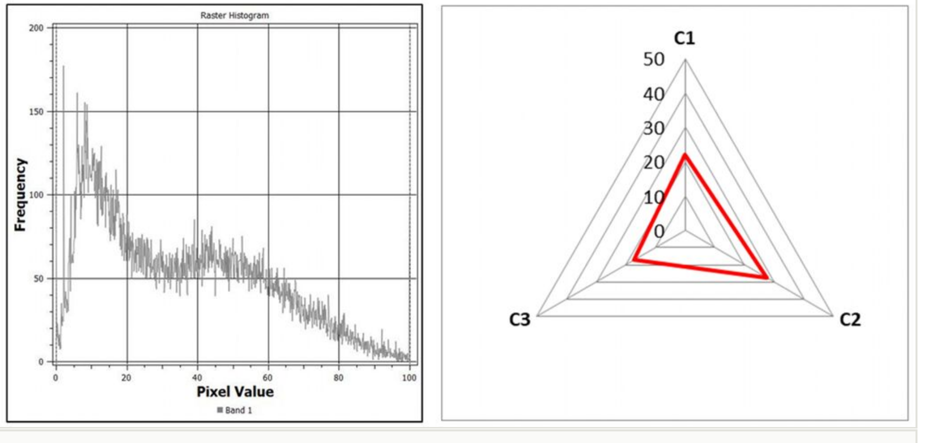

Figure 6.

Histogram and plot of the cultural ES values*3.

1. ES **Recreation and tourism.** The most obvious and apparent cultural ES. We evaluated it using available data on current landscape structure and the use and location of significant monuments and natural, historical and cultural sites of

interest. Information on protected areas and relevant data on tourist areas and routes and sport and leisure facilities also supplemented our assessment.

2. ES **Landscape aesthetics.** This ES express the visual quality of the landscape. We make our assessment on a reclassification of the aesthetics and attraction of land use classes, the occurrence of unique landscape structures under traditional land use and the attraction of the surrounding relief.
3. ES **Natural and cultural heritage.** This ES considers the importance of valuable natural and cultural sites for human existence. Here, we gave the special consideration to UNESCO sites, other historical and cultural monuments, protected areas and historical landscape structures under traditional management.

We expressed the landscape's overall capacity for cultural ES provision as the average of the three assessed ES (Fig. 7). They are closely related and have similar spatial distributions. The figure shows that the highest value is found for the high Carpathians and, especially, for the Tatra mountains. High values are also found for the mountain areas containing biosphere reserves and UNESCO sites, while most other Slovak mountain and sub-mountainous areas have medium- to high- capacity ES levels. Most of the lowlands and the central parts of the intra-mountain basins have low capacity values.

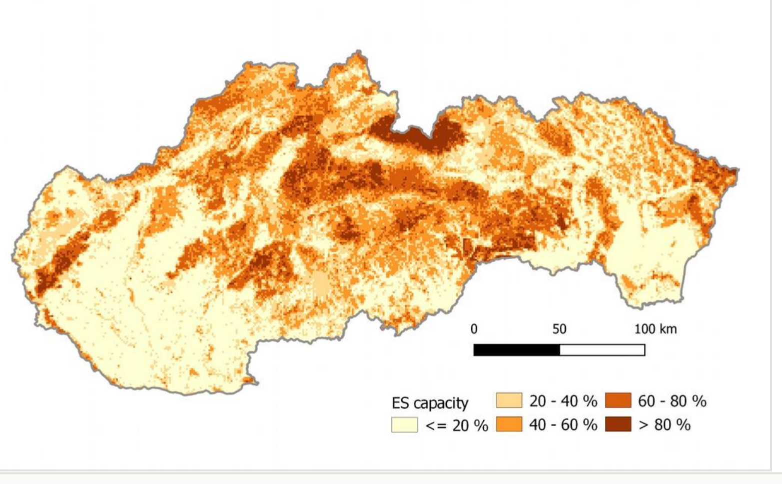

Figure 7.

The overall capacity of the landscape to provide cultural ES.

Overall ES assessment

As a synthesis of the first stage of our national ES assessment, we compiled the landscape's overall capacity for ES provision and calculated this value as the weighted average of values for the three assessed provisioning, regulatory/maintenance and cultural ES groups (see section Material and methods). Table 6 provides basic statistical parameters and Fig. 8 a histogram of these values.

Table 6.

Basic statistical parameters of the analysed ES groups*4.

Basic statistics	OVERALL ES ASSESSMENT
Minimum	5.51
Maximum	78.41
Range	72.90
Mean value	36.80
Median value	35.17
1st Quartile	21.19
3rd Quartile	51.59
St. deviation	16.56

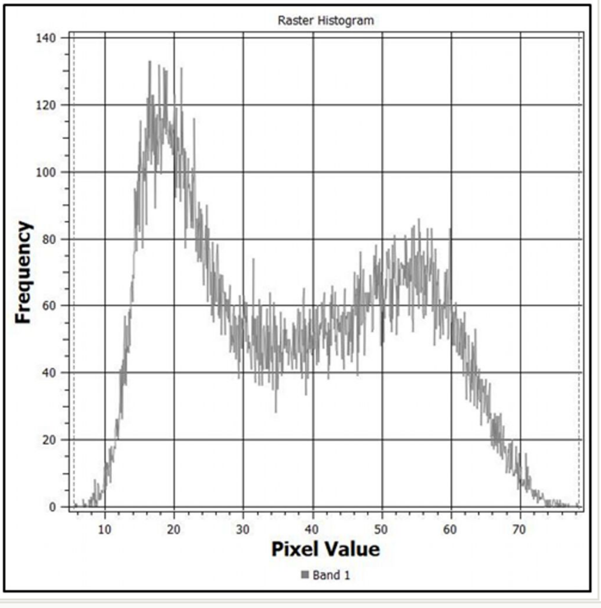

Figure 8.

Histogram of the overall ES values.

Fig. 9 gives the spatial distribution of the overall landscape capacity and highlights the fact that the most essential areas of Slovakia for overall ES provision capacity are the large areas of lower and medium-high mountains (which mostly have a capacity value of 50-60). In contrast, the areas at the lower end of the ES capacity scale are generally the broad Slovak lowlands and open basin areas (capacity value 15-25).

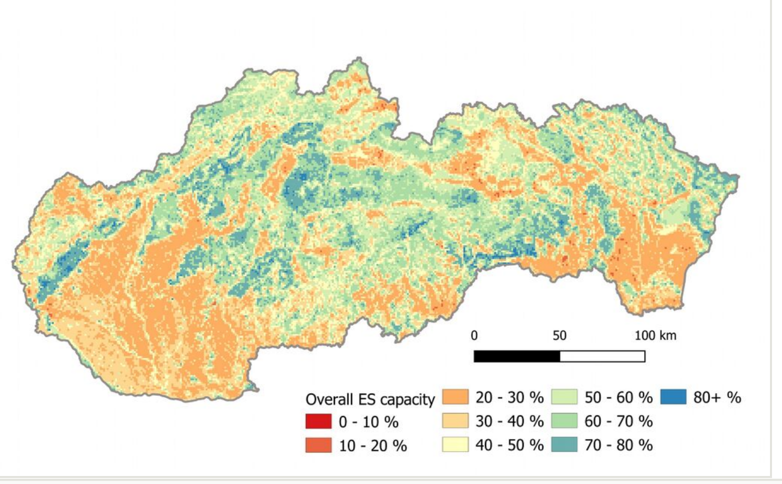

Figure 9.

The overall capacity of the landscape to provide ecosystem services.

Result interpretation

Ecosystem functions and related services are substantially based on the natural structure of the landscape and it is, therefore, useful to assess the main spatial units' capacity for ES provision. These basic Slovak landscape types are classified as the combination of the main Pannonian and Carpathians biogeographical regions and the geomorphological landscape types found in the area, which include the lowlands, river basins, the low and sub-mountainous regions and the mid-altitude and high mountain areas. Table 7 provides the capacity value calculations for ES provision of the main ES groups in these spatial units. The results verify that;

Table 7.

The capacity of the main landscape types of Slovakia for providing ecosystem services *4.

Main landscape types	Area (km2)	% of area	PROVISIONING ES	REGULATORY/ MAINTENANCE ES	CULTURAL ES	OVERALL CAPACITY FOR ES PROVISION
Lowlands and open river basins (Pannonian)	16,955	34.58	31.2	24.2	15.5	23.8
Intra-mountain river basins (Carpathians)	5,001	10.20	29.7	27.6	28.1	28.3
Low altitude mountains and sub-mountainous areas (Carpathians + Matricum)	15,078	30.75	37.2	49.2	42.6	44.5

Main landscape types	Area (km2)	% of area	PROVISIONING ES	REGULATORY/ MAINTENANCE ES	CULTURAL ES	OVERALL CAPACITY FOR ES PROVISION
Middle altitude mountains (Carpathians)	8,598	17.53	34.6	50.6	50.7	46.6
High altitude mountains (Carpathians)	3,403	6.94	40.5	52.6	69.8	53.9
Slovak Republic - average values	**49,035**	**100.0**	**34.2**	**38.9**	**35.1**	**36.8**

1. the ES capacity is significantly higher for the mountain areas than for the lowland and basin areas;
2. the capacity of the "core" Carpathians high altitude mountains is the highest for all ES groups;
3. the middle- and low altitude mountains have high significance because the former are essential for cultural and regulatory/maintenance ES and the latter have greater importance for provisioning ES and
4. river basin areas have higher ES capacity than lowlands, with the exception of provisioning ES.

Fig. 10 shows the distribution of the main landscape units of Slovakia and the overall ES capacity for the 84 geomorphological units (GU). The areas with the highest overall ES provision capacity values (1.5 times higher than the national average) are all mountainous; other mountain areas have lower, but still high values, while lowest-rated GU are lowlands and open river basins. Overall, these have 53-65% of the national average ES value.

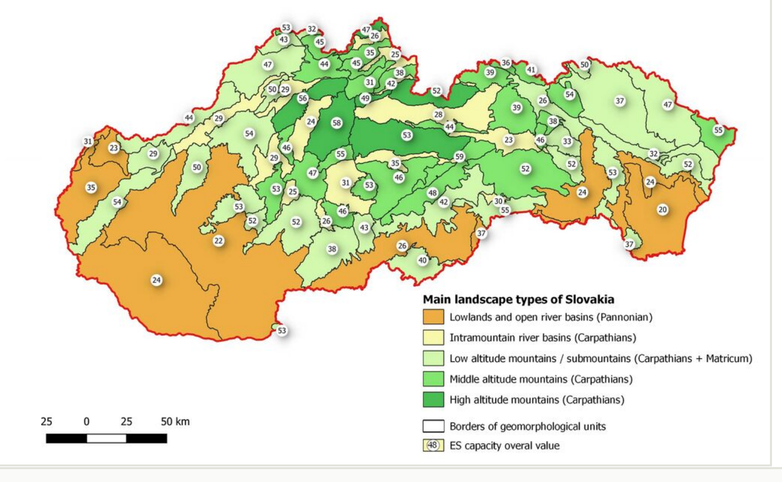

Figure 10.

The overall capacity of the landscape units to provide ecosystem services.

Fig. 11 shows the relationship between land use/land cover types and their overall capacity to provide ES. Here, the land use has been directly entered into the computational algorithms for most ES, so this assessment provides only a summary of the contribution of individual landscape categories to ES provision. The statistical results confirm the consensus that forests are the most essential ecosystems for ES provision and urbanised areas are the least important.

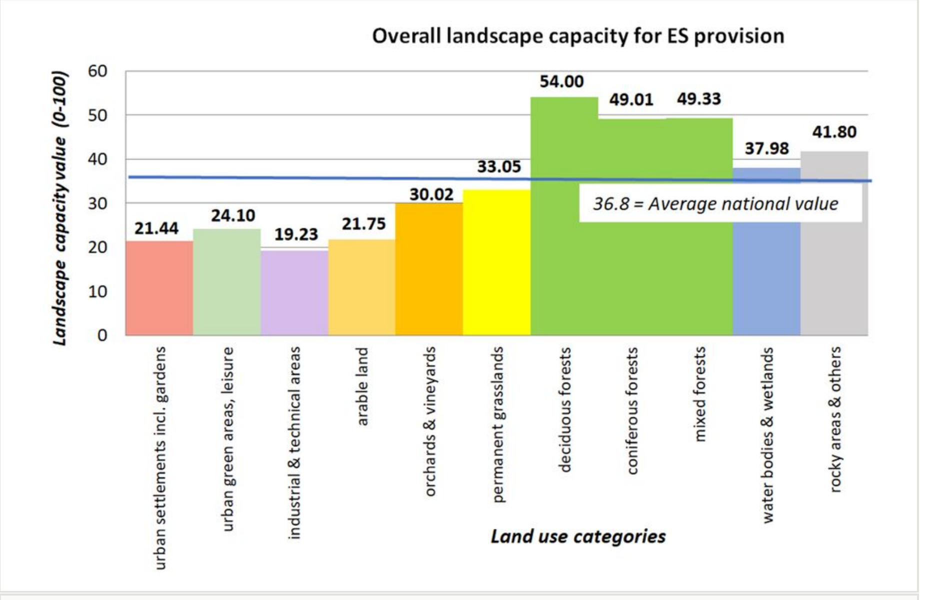

Figure 11.

The overall capacity of the landscape to provide ES for the main categories of land use*4.

The highest landscape capacity value for ES provision (1.5 times the average Slovak value) is found for deciduous forests, followed by mixed and coniferous forests. Rocks and screes have a very high capacity for cultural ES provision, while water bodies and wetlands have a high capacity for all ES groups. In contrast, permanent grasslands, orchards and vineyards have an average capacity for ES provision and arable land and urbanised areas have low to very low capacity.

Brink ten (2013) and other authors claim that NATURA 2000 protected areas have a crucial influence on the European Union's natural capital. We have, therefore, also focused on assessing the relationship between nature protection and the landscape's capacity for providing ES. The results show a clear correlation between these two indices for most ES. This fact is particularly evident for cultural ES and most regulatory and maintenance ES (Mederly and Černecký 2019). The highest capacity for providing these ES comes from natural and semi-natural ecosystems which are often involved in nature protection area systems. We found the most pronounced positive correlations for the following ES: Air quality regulation, Erosion and natural hazard regulation, Biodiversity promotion and Pest and disease control and we noted a clear positive correlation for all three assessed cultural

ES. These results emphasise the critical importance of nature and landscape protection for a healthy ecosystem state and the fulfilment of their functions and provision of services directly and indirectly used by humans.

Discussion

ES mapping and assessment has developed into a very mature scientific field in recent years (Burkhard and Maes 2017). ES maps are a powerful tool for communicating land use trade-offs and for transforming biodiversity, ecosystem and ES data into policy- and decision-making. However, comprehensive ES assessment must distinguish three essential aspects (Burkhard et al. 2014). These are, firstly, the landscape's capacity (supply) for ES provision; secondly, ES demands in a particular territory; and thirdly, ES actual use and balance as ES flow.

Analysis of national ES assessments (NEAs) finds that full implementation of ES in decision-making is still uncommon and Schröter et al. (2016) stress that the NEAs are highly context-specific for national policies and stakeholder interests and also for environmental settings and socio-economic characteristics. The design of the ES framework must, therefore, include country-specific adaptations.

Several countries have made significant progress in NEA research using a wide variety of approaches. Dimopoulos et al. (2017) The assessment is generally composed of two basic steps: the first involves mapping the ecosystem types and assessing ecosystem conditions and the second involves detailed ES mapping (e.g. Dimopoulos et al. (2017) in Greek ES assessment). Some approaches use GIS-based data and reclassification methods, for example, Denmark's spatial analysis of 11 ecosystem services in a 10 ×10 km grid (Turner et al. 2014). Assessment of ES capacity for Lithuania (Depellegrin et al. 2016) uses 31 CLC classes and 31 ES categorised into three main ES groups. Their expert-based ranking approach using a two-dimensional ES matrix and a geospatial analysis was then applied to determine the total ES potential and spatial patterns and the relationships between multiple ES. The Lotan et al. (2018) Israeli study considered potential pollination and genetic resources and the recreational use of the evaluated ES and Arany et al. (2018) conducted an integrated ES assessment in Hungary using the cascade model levels of ecosystem mapping to identify ES capacity and its use and contribution to human well-being. The NEA for the Czech Republic made an innovation in ES national monetary assessment of employing the "benefit transfer" method of converting the specified worldwide economic values for individual ES to national conditions (Frélichová et al. 2014, Vačkář et al. 2018). Finally, studies on advanced economic valuation methods have been performed in the United Kingdom (UK NEA 2011), Finland (Jäppinen and Heliölä 2015) and also in Spain (Santos-Martín et al. 2016).

As in other research, our results also point to existing trade-offs and some negative consequences of using different ES. The use of provisioning ES is tied to the consumption of matter and energy from the ecosystems. It is therefore very important to consider their recovery capacity and supply-demand balance while using ES (Ala-Hulkko et al. 2019).

Some ES, such as freshwater, are used almost constantly and have a continual ability to replenish themselves, while others, such as crops are seasonal or have a significantly longer recovery cycle (e.g. timber biomass). A further, related issue is the use of agricultural crops and forest biomass. Use of these ES largely limits the possibility of using other ES. On the other hand, some other provisioning ES, such as water, game and wild berries, do not threaten them. This imbalance causes trade-offs with conflicts of interests between provisioning ES and most regulatory/maintenance ES and cultural ES (Raudsepp-Hearne et al. 2010, Vallet et al. 2018).

The capacity to provide regulatory/maintenance ES depends mainly on the quality of a given ecosystem and its associated land use. In Slovakia, the frequent occurrence of wind- and bark-calamities and subsequent large-scale harvesting in the last 10-15 years have had negative impacts on the stability of forest ecosystems and this is undermining provision of the forest regulatory ES. Investigation of forests in Slovakia, affected by natural disturbances and changes in climate and land-use (e.g. Fleischer et al. 2017), shows declines mainly in cultural and provisioning services. Thom and Seidl 2015 analysed the impact of the most important disturbance agents and the effect on different ES and biodiversity of commonly used management approaches. They found that the disturbance impacts on ES are generally negative and the management approaches considered (e.g. salvage logging) do not mitigate adverse effects on ES nor enhance positive effects on biodiversity.

The importance of the agricultural and urban landscape in the provision of cultural ES has increased in recent years. This is mainly due to the development of agri-tourism and the current emphasis on healthy lifestyles which makes use of, for example, urban parks and vegetation for leisure activities (Santos-Martín et al. 2016). On the other hand, the use of cultural ES is limited by the effects of stress factors including environmental contamination from radiation, polluted air and water, damaged forest ecosystems and noise (Santarém et al. 2020) - all of which are related to the demand for regulatory and maintenance services.

Our results also confirm the importance of mountains for ES delivery, as has been found by other NEA (e.g. Skre 2017,Crouzat et al. 2019). Some authors find differences between mountain areas where demand and supply are well balanced and areas where demand and supply are unbalanced (Grêt-Regamey et al. 2012). It must also be taken into account that the spatial flows of ES from and to mountain regions extend far beyond the regional level (Schirpke et al. 2019).

It is apparent from our assessment process that we have not tried to evaluate the capacity of the landscape for ES provision in biophysical or monetary values. Instead, we have employed a relative scale which provides the percentages of maximum capacity and suitability value for the area. The advantage of this method is that these values can then be further processed, based on available data from relevant research and studies. The minimum and maximum values can then be replaced by specific biophysical units and monetary values using advanced analysis or the value-benefit transfer method from relevant ES valuation studies. This approach is most promising for further assessment of the capacity of the landscape to provide ES and the detailed mapping of ecosystem and habitat types which we have also prepared (Černecký et al. 2019) will be invaluable for it.

Most other national ES assessment studies have focused on identifying ecosystems, assessing their state and then assigning a monetary value to ES (e.g. Vačkář et al. 2018) or examining biophysical indicators (Jäppinen and Heliölä 2015, NEPA 2017, Rabe et al. 2016). They usually use and create map layers with varying accuracy and scale. Our approach, combining a variety of landscape parameters into one consolidated scale, is thus rather unique. Overall, it highlights the importance of other landscape parameters for ES provision in addition to the recognised ecosystems types and land use. One of its greatest strengths is the use of a comprehensive approach for 18 ES, with a single methodological framework, a shared database and use of the same spatial scale – features which enable detailed comparison of individual ES. Nevertheless, in the case of cultural ES, additional work is necessary to ensure more appropriate overall ES assessment by incorporating later or more accurate data from state statistical surveys; especially at the municipality level.

We consider the expression of the landscape's overall capacity for ES provision a particular problem. Most studies at a national or regional scale remain at the level of individual ES or their groups. Within this context, they evaluate synergies and trade-offs and rarely consider the overall capacity of the main ES groups (e.g. Jäppinen and Heliölä 2015). We have not found another national study presenting an overall ES assessment on a relative scale (suitability scale, %). Nevertheless, the situation is different in the case of monetary ES valuation, where the calculated financial values could simply be summarised - which is, incidentally, the case for estimating the ES global value (e.g. Costanza et al. 2014) and the national-level case of the Czech study (Frélichová et al. 2014). Looking for an appropriate synthesis of ES capacity biophysical values and linking it with economic valuation is undoubtedly one of the main challenges for our further research.

It is clear, that our approach is "science-driven" and not "policy-driven" because the views and attitudes of different stakeholders are not considered. This is a shortcoming compared to certain other national studies (e.g. Spain, Finland, Norway, Flanders and the United Kingdom) which, according to the review by Schröter et al. 2016, have incorporated stakeholder participation, collaboration and cross-sector communication into the assessment process. The next step, therefore, should be an integration of our results with policy-relevant questions and policy-impact assessments. It should also include assessment of other aspects of ES provision, including their current flow in the landscape, the demand for individual ES and monetary assessment of the benefits that ecosystems provide, as stressed by, for example, Braat and de Groot (2012).

Spatial ES flows and their inter-relationships in different scales also offer an interesting direction for future research. These topics cover ES flows from the mountains to the lowlands (Schirpke et al. 2019) and also in trans-boundary and conflicting regions (Santarém et al. 2020) which include urban and rural areas (Haberman and Bennett 2019). The increasing evidence of the natural environment's positive impact on mental health also mandates the need for such an assessment (Bratman et al. 2019). Here, quantification of the effects of land use and climate change on ES is possible through scenarios and modelling of both current and future potential ES status (Krkoška Lorencová et al. 2017). These are, also, further challenges for our ongoing research.

Conclusions

The main aim of our research was to conduct a pilot assessment of those ES, which are most relevant for the territory of Slovakia. While other national studies have inspired our research, we have herein introduced an original methodology, based on an individual computational algorithm for assessment of the ES using a database of 41 natural and societal landscape parameters. Evaluation of the 18 individual ES is followed by assessment of provisioning, regulatory/maintenance and cultural ES.

The highest capacity to provide ES comes from natural and semi-natural ecosystems, especially the deciduous, coniferous and mixed forests which cover more than 38% of Slovak territory. Other ecosystems, particularly those in the Carpathians, proved very valuable for the provision of many different ES. Moreover, this paper highlights the crucial importance of the high mountain areas of Slovakia for ES provision.

The results of the Slovak national ES assessment have been published as a comprehensive scientific publication (Mederly and Černecký 2019). The intent is for these results to be distributed and used in the field of nature protection, management of natural resources, spatial planning at different spatial levels and, last but not least, as a textbook for university studies of environmental sciences. We now intend further research which will more precisely examine selected socio-economic parameters which affect demand for most ES. In addition to population, human activities and resource use, our research will focus on the quality of the environment as a primary indicator for regulatory/maintenance ES. Further work will then centre on the current ES flow in the landscape and economic and financial ES assessment at the national level, followed by evaluation of spatial and functional mismatches and trade-offs of the ES over the entire territory of Slovakia.

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Author contributions

This paper was designed and implemented as a result of collaborative research by the State Nature Conservancy of Slovakia, Constantine the Philosopher University in Nitra and the Institute of Landscape Ecology of SAS. All co-authors prepared and analysed the data concerning individual ecosystem services and their ES assessment; Peter Mederly and Ján Černecký edited the results; P.M., J.Č., J.Šp., V.Ď., Z.I., R.P. and J.Šv. wrote the final paper.

Conflicts of interest

The authors reported no potential conflict of interest.

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Supplementary materials

Suppl. material 1: Specification of data used and legend of all used spatial layers doi

Authors: Peter Mederly, Matej Močko
Data type: Text file
Brief description: Full description of data layers used for ES assessment - Data source, Accuracy, Units, Min/Max values, Legend.
Download file (773.61 kb)

Suppl. material 2: Computational algorithms for 18 ES doi

Authors: Peter Mederly et al.
Data type: excel file - formulas
Brief description: Computational algorithms for all 18 ES - data sources, values, formulas
Download file (81.50 kb)

Suppl. material 3: Individual ES graphical outputs doi

Authors: Peter Mederly, Matej Močko
Data type: Figures
Brief description: Box plots, histograms and maps of 18 individual ES
Download file (7.43 MB)

Endnotes

*1 *P1-P5 – Individual provisioning ES: P1 Biomass - Agricultural crops; P2 Timber and fibre; P3 Drinking water; P4 Freshwater; P5 Fish & Game/Wildfood. The values are in the 0– 100 range; where 0 is the minimum value and 100 is the maximum for ES provision.*

*2 *R1-R10 – Individual regulatory/maintenance ES: R1 Air quality regulation; R2 Water quality regulation; R3 Erosion & natural hazard regulation; R4 Water flow regulation; R5 Local climate regulation; R6 Global climate regulation; R7 Biodiversity promotion; R8 Pollination; R9 Pest and disease control; R10 Soil formation. T he values are in the 0– 100 range; where 0 is the minimum value and 100 is the maximum for ES provision .*

*3 *C1-C3 – Individual cultural ES: C1 Recreation and tourism; C2 Landscape aesthetics; C3 Natural and cultural heritage. The values are in the 0– 100 range; where 0 is the minimum value and 100 is the maximum for ES provision.*

*4 *The values are in the 0 – 100 range, where 0 is the minimum value for the provision of individual ES categories and 100 is the maximum.*