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Assessing landscape services as foundation for Green Infrastructure functionality: the case of the Wienerwald Biosphere Reserve

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Abstract

Biosphere Reserves are considered as means for the people who live and work within them to attain a balanced relationship with the natural and semi-natural environment. Moreover, they contribute to the needs of society by showing a way to a more sustainable future. The Wienerwald Biosphere Reserve partly surrounds the city of Vienna and other minor settlements, representing a well-developed example of Green Infrastructure (GI) of great cultural and natural value. Its heterogeneous landscape offers a variety of landscape services (LS).

In this work, we quantified and mapped the capacity of LS offered by the open land elements of Wienerwald. Starting from a high-resolution dataset, we selected suitable indicator classes, and scored each ecological and socio-cultural service through an expert-based capacity matrix. The subsequent analyses with Geographical Information Systems (GIS) focused on the intensity and density of LS capacities by developing an index useful for mapping GI functionality.

The work provides an effective monitoring tool for the Reserve's both ecological and socio-cultural sustainability performance. It also allows detecting resilient areas, by considering both the spatial distribution and the abundance of landscape elements.

Keywords:
Wienerwald Biosphere Reserve, landscape services, ecosystem services, green infrastructure, capacity matrix

1 Introduction

1.1 Motivation

It is nowadays globally recognized that biodiversity sustains human life by means of the so-called ecosystem services (e.g. Isbell et al. 2015). Ecosystem services are defined as 'the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life' (Daily 1997). They arise when a biophysical structure (e.g. vegetation cover) or function (e.g. slow passage of water) directly or indirectly contributes towards meeting a human need or demand. Such services (e.g. flood protection) generate benefits (e.g. serving health and safety) that contribute to overall well-being and can be valued by people (e.g. willingness to pay for protection) (Haines-Young et al. 2010; MEA 2005). In this study we address a variation of the concept of ecosystem services, i.e. landscape services. This means defining functions, services and benefits at landscape scale to integrate the concept into land management decisions (Bastian et al. 1999; de Groot et al. 2010; Willemen et al. 2010). Landscape services are the contributions of landscapes and landscape elements to human well-being (Bastian et al. 2014), and they include potentials, materials and processes of the nature (e.g. raw materials, biomass, biodiversity etc.) and services of cultural elements and constructions that come into being through human creation (e.g. buildings, settlements, infrastructure etc.) (Konkoly-Gyuró 2011; Hermann et al. 2011). Important reasons to consider landscape services include the prominent role of spatial aspects, the reference to spatial elements and to the landscape character, and the relevance of landscape services for spatial planning (Bastian et al. 2014). The pattern of multi-functional landscapes is the basis for interactions, synergies and conflicts between landscape elements (Willemen et al. 2012). Moreover, the provision of services does not always depend on the properties of an ecosystem patch, but rather on the spatial interaction among these patches (Termorshuizen et al. 2009). Last, as local people define their environment more as a "landscape" than as an "ecosystem" the term "landscape services" is preferred as a specification (rather than an alternative) of ecosystem services (Termorshuizen et al. 2009). Landscape services can be supplied by those landscape elements comprised in the so-called Green Infrastructure (GI), such as areas of high biodiversity value, land managed in a sustainable fashion, green urban and peri-urban features (parks, gardens, small woodlands, cemeteries and the like), but also artificial connectivity features, such as green bridges over road corridors, tunnels underneath transport corridors and fish passes where natural migration/ movement is hindered by development (Mazza et al. 2011). In the European Commission communication (2013) GI is defined as '*a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services.*'

To provide benefits to society, GI shall be adequately planned and maintained (European Commission 2016). GI is in fact an approach that brings together both the need for strategic planning of green and open spaces and the science of landscape services (European Commission 2011). It promotes the multifunctional nature of space and the benefits that appropriate management approaches can deliver. As GI recognises and promotes the multifunctional nature of green and blue spaces and is underpinned by the science of landscape services, it has a natural affinity with the commonly accepted three pillars of sustainable development: society, economy and the environment (Purvis et al. 2018).

Biosphere Reserves are protected areas where people who live and work within them seek to attain a balanced relationship with the natural and semi-natural environment (UNESCO 2002). Moreover, they contribute to the needs of society by showing a way to a more sustainable future. They provide an example of an integrated sustainability framework, which explicitly acknowledges that complex socio-economic and ecological systems are inextricably linked (Levrel et al. 2008). For these reasons, they have a primary role in coupling nature conservation practices with sustainable socio-cultural development (Lotze-Campen et al. 2008). Being a living laboratory for the fruitful coexistence of human activities and nature protection, they may represent a suitable example of how to plan GI so to maximize the benefits to humans without depleting natural resources.

Since Biosphere Reserves are seen as models for sustainable development (UNESCO 2002), they need a rapid toolset for the assessment of their sustainability over time. The sustainability performance can be expressed by an assessment of GI multi-functionality, which implies that the whole range of landscape services, from socio-cultural to ecological, is simultaneously evaluated. Examples of benefits supported by GI through its landscape services are health and well-being, enhanced efficiency of natural resources, water management, tourism and recreation, conservation benefits, climate change mitigation, and resilience (European Commission 2013). Despite the recognition at EU level of the pivotal role of GI in meeting the EU 2020 Biodiversity Strategy's targets (European Commission 2013), the concept is yet not so well established in national, regional and local planning. This is probably due to the still ongoing difficulty in interpreting the term GI in a univocal way (John et al. 2019). Also, Slätmo et al. (2019) stressed that GI in spatial planning needs to cover many different policy sectors and that its implementation is an on-going process dependent on political willingness. Consequently, tools for implementing the assessment of the multi-functionality of landscape elements are still under progress. Examples of development of toolsets for the assessment of GI multi-functionality include the combination of spatial data with the knowledge of both experts and regional and local actors (Kopperoinen et al. 2014), the creation of performance indicators of GI (Pakzad and Osmond 2016), and the use of field questionnaire surveys to explore the perceived benefits (e.g. Qureshi et al. 2010). Nevertheless, a holistic LS point of view to address the evaluations is rarely employed.

This study aims at filling the above-mentioned gaps by providing a framework for the rapid assessment and mapping of the capacity of all the LS offered by the open land landscape elements, taking the Wienerwald Biosphere Reserve (AT) as pilot study area. The Wienerwald Biosphere Reserve is an important part of an international GI network of protected areas, but it also comprises landscape elements of natural and semi-natural areas forming a local GI offering a vast range of landscape services. Since Wienerwald partly surrounds the city of Vienna (AT), it represents an excellent training ground for developing a well-founded basis for the sustainable planning of GI in the peri-urban and rural areas around Vienna.

1.2 Goals of the study

The main objective of the study was the development and provision of technical and methodological framework for the regional assessment and mapping of landscape services provided by the open land landscape elements of the Wienerwald Biosphere Reserve, that would contribute to a replicable monitoring of the Biosphere Reserve's GI functionality performance.

In order to achieve our goal, we set out to answer the following research questions: (i) which landscape elements are suitable for representing the landscape services of the open land taking into consideration the availability of spatial data; (ii) and how to simultaneously assess and spatially represent ecological and socio-cultural landscape services.

2 Methods

2.1 Study area

The Wienerwald Biosphere Reserve (designated as Biosphere Reserve by UNESCO in 2005) encompasses an area of 105 645 hectares within the Austrian provinces Lower Austria and Vienna (Figure 1). Influenced by the easternmost part of the Alps, it is characterized by a hilly terrain (sea-level from 160 m up to 893 m). Geologically the Biosphere Reserve can be divided into the northern part consisting mostly of flysch rock ("Sandstein-Wienerwald") and the southern part, primarily limestone ("Kalk-Wienerwald") that appears near the so-called "Thermenlinie". As a stepping stone within the biotope network the Wienerwald is of superregional importance (Reimoser et al. 2008; Reimoser et al. 2012).

Together, the meadows and pastures have a share of 12% of the Wienerwald Biosphere Reserve area. The climatic, geological and biogeographical border location, special habitats as well as close interaction between areas of forest and open land (like meadows, pastures, cultivated fields, vineyards etc., including elements like single trees, orchards, hedge

Figure 1: Study area: the open land of the Wienerwald Biosphere Reserve.
Source: NUTS – EUROSTAT (2018); Staudinger et al. (2014).

and tree rows) allow for a diverse mosaic display of the Wienerwald landscape, increasing the ecological and nature conservation value of the Biosphere Reserve (Reimoser et al. 2008; Reimoser et al. 2012; Drozdowski et al. 2018). More than 60% of the Biosphere Reserve area is covered by forest (Loiskandl 2005; Brenner et al. 2015). In the Wienerwald Biosphere Reserve nature conservation, economic and social development as well as preservation of cultural values play an important role. It includes 27 core areas with particularly valuable forests, which equate 5% of the Biosphere Reserve area. The buffer areas, 19% of the Biosphere Reserve surface, contain valuable cultural landscape of meadows and grassland (Biosphärenpark Wienerwald Management GmbH n.d.)

The Wienerwald Biosphere Reserve intersects with seven municipal districts of Vienna as well as 51 municipalities in Lower Austria: whereas in three municipalities in Lower Austria live more than 20 000 inhabitants each, 60% of the municipalities have less than 5 000 inhabitants; altogether the Biosphere Reserve region hosts 815 000 inhabitants (Biosphärenpark Wienerwald Management GmbH n.d.). Beside the agricultural and forestry-used area, there is pressure from settlements, infrastructure and recreation. Because of the settlement areas, the proximity to Vienna and the characteristic landscape, the Biosphere Reserve is strongly used by recreationists. The area offers possibilities for various recreational activities and sports and is further enriched by a broad range of tourist attractions of cultural value (Loiskandl 2005; Reimoser et al. 2008; Reimoser et al. 2012).

The focus of the study was the open land areas of the Wienerwald Biosphere Reserve exclusively (Figure 1), which corresponds to an area of 27 831.5 hectares within the Biosphere Reserve. Due to its high potential for a wide spectrum of services, the forest was included by integrating the forest edges into the analysis. Furthermore, since the focus was more on the pull factors of recreation users within the open land, rather than push factors, settlements were excluded from the analysis. A difference in age and accuracy of the geodata underlying the project analyses required a quality-based selection of data within the south eastern region along the border of the Wienerwald Biosphere Reserve. On these grounds, part of the south eastern region of the Biosphere Reserve was excluded (about 3 000 hectares – 2.8% of the overall Biosphere Reserve area), fact that shall be considered in the valuation of the regional assessment of the landscape services.

2.2 *Definition of landscape services*

We defined the landscape service classification based on the definitions developed by de Groot (2002; 2006), thereby following the projects BIOS-ERV (Biodiversity and Ecosystem Services as scientific foundation for the sustainable implementation of the Redesigned Biosphere Reserve Neusiedler See; Hermann et al. 2014) and CCR (Climate Change Response of Ecosystem Services in the sensitive area of

Neusiedler See - Seewinkel; Hainz-Renetzeder et al. 2014) in the Austrian-Hungarian Biosphere Reserve Neusiedler See. The concept of landscape services refers strongly to the cultural landscape and landscape elements incorporating natural and cultural aspects of the Wienerwald Biosphere Reserve (Bastian et al. 2014). The classification proposed by de Groot (2002; 2006) includes 25 landscape services distinguished into five service categories: Regulation, Habitat, Provisioning, Carrier and Information (Table 1). We adapted the list of landscape services definitions to the properties of the study area, as follows. The Raw material service includes the provision of sand and gravel e.g. by periodic brooks. The Cultivation service refers only to the provision of substrate for the cultivation of food or fodder, not for ornamental cultivation (e.g. gardening). Furthermore, in comparison to the service Food, it refers to cultivated fields (producing crops and fodder), vineyards and orchards as well as managed meadows (fodder production). Consequently, the service Food refers to all food produced for human use (wild and cultivated) and includes all animal related farming (aquaculture, cattle etc.). Genetic resources are extended to forestry and agriculture. Waste disposal includes the landscape elements providing wastewater disposal. We discarded the service Energy conversion, due to lack of reliable data. Regarding the service Transportation, the potential transportation on waterways was not included in the evaluation as there are no suitable waterways in the project region. Tourism facilities, as a carrier service, address exclusively transformed (man-made) landscape elements, which provide touristic infrastructure such as accommodation and gastronomy. Recreation mainly refer to natural landscape elements used for recreational purpose. Furthermore, following de Groots' inclusion of eco-tourism within the Recreation service, recreation infrastructural elements such as educational trails were also included in the service (de Groot 2006; Table 1).

In order to link our conceptual approach to the EU standardized classification CICES (Common International Classification of Ecosystem Services; Haines-Young et al. 2018), we compared our landscape services definitions with the ecosystem service classification CICES V5.1 (Haines-Young et al. 2018). As an element for comparing the definitions implemented for each service, we decided to adopt the column "Simple descriptor" available in the classification CICES V5.1, since such descriptor provides an unambiguous and clear explanation for most of the services (Table 1). For the comparison we adopted a multiple correspondence approach. The selective, multiple correspondence approach allows for more than one CICES ecosystem service to be linked to different landscape services without the need of assigning a landscape service to every CICES ecosystem service.

The comparison of our landscape services classification with the CICES ecosystem services classification indicated that the Carrier services are underrepresented in CICES, which instead emphasises the natural environment and assigns less importance to the transformed landscape elements and to the socio-cultural aspects. On the other hand, CICES proved to be more detailed in distinguishing the Regulating and Provisioning services, like for instance Disturbance prevention, to which four simple descriptors could be linked, and Food, to which seven simple descriptors could be linked (Table 1).

2.3 Data sources and landscape elements classification

The study main data source is the open land data of the Wienerwald Biosphere Reserve, originating from a detailed mapping of open land habitat types performed in the field mapping project "Offenlanderhebung Biosphärenpark Wienerwald" (Staudinger et al. 2014) for the open land of the whole Biosphere Reserve in Lower Austria and Vienna. The geometries are based both on cadastral maps with high accuracy and remote sensing with the accuracy ranging between 10-30 m (Schranz 2018, pers. comm.). We relied on the open land data as the study prime data source and included data from other data sources solely when additional information was needed to address a service more fully or if it provided more detailed information on transformed landscape elements than the natural element-focussed open land data. All additional data was customised to the spatial projection of the open land (EPSG: 31259) using ArcGIS 10.5.1 (ESRI, Redlands). Most of the additional spatial data (from now onwards Additional Spatial Indicators - ASI) was downloaded from Open-

Table 1: Definitions of the landscape services addressed in this study and correspondence with CICES V5.1 (Haines-Young et al. 2018). The examples are the authors' adaptation of de Groot (2006); de Groot, Wilson, and Boumans (2002) and Haines-Young and Potschin (2018).

Service category	Code	Service	Definition	Simple descriptor (CICES V5.1)	Examples goods and benefits
Regulation Services	RS1	Local climate and air regulation	Maintenance of a favourable local climate (temperature, humidity, precipitation, radiation) and air regulation by filtering wastes	Filtering wastes; Regulating the physical quality of air for people	Favourable local climate; Filtering effects from trees
	RS2	Disturbance prevention	Mitigation of environmental disturbances (flood prevention/mitigation; storm protection; wind protection; fire protection)	Protecting people from winds; Protecting people from fire; Stopping landslides and avalanches harming people; Regulating the flows of water in our environment	Enhanced safety from natural extreme events
	RS3	Water regulation	Regulation of runoff and river discharge	Regulating the flows of water in our environment	Drainage and natural irrigation
	RS4	Water supply	Filtering, retention and storage of fresh water for drinking, irrigation and industrial use	Controlling the chemical quality of freshwater	Pure water for drinking
	RS5	Soil retention	Role of vegetation root matrix and soil biota in holding soil (mitigation of erosion)	Controlling or preventing soil loss	Mitigated effects of erosion
	RS6	Soil formation	Weathering of rock, accumulation of organic matter	Ensuring soils form and develop	Maintenance of natural productive soils
	RS7	Nutrient regulation	Role of biota in storage and recycling of nutrients (e.g. N, P and S)	Ensuring the organic matter in our soils is maintained; Controlling the chemical quality of freshwater	Maintenance of healthy and productive ecosystems
	RS8	Pollination	Role of biota in movement of floral gametes	Pollinating our fruit trees and other plants	Edible fruits
Habitat Services	HS1	Refugium	Suitable living space for wild plants and animals	Providing habitats for wild plants and animals that can be useful to us	Forest edge for rodents; church towers for falcons
	HS2	Nursery	Suitable reproduction habitat	Providing habitats for wild plants and animals that can be useful to us	Extensive meadow for bird breeding
Provisioning Services	PS1	Food	Conversion of solar energy into wild and cultivated edible plants and animals	Any crops and fruits grown by humans for food; food crops; Plants that are cultivated in fresh or salt water that we eat; Livestock raised in housing and/or grazed outdoors; Animals that are cultivated in fresh or salt water that we eat; Food from wild plants, Food from wild animals	Edible wild plants, crops, fungi, livestock and fish
	PS2	Raw materials	Conversion of solar energy into biomass	Material from plants, fungi, algae or bacterial that we can use; Material from animals that we can use; Plant materials used as a source of energy; Materials from wild plants; Materials from wild animals; Seed collection	Material for human construction (building, roofing material and manufacturing) like fuel and energy wood; sand and gravel;

Provisioning Services	PS3	Genetic resources	Genetic material and evolution in wild plants and animals	Seed collection; Plants, fungi or algae that we can use for breeding; Genetic material from wild plants, fungi or algae that we can use; Animals used for replenishing stock; Wild animals that we can use for breeding; The genetic information that is stored in wild animals that we can use	Improve crop quality
	PS4	Medicinal resources	Variety in chemical substances in natural biota	Materials from wild animals and from wild plants for non-nutritional uses	Drugs and pharmaceuticals
Carrier Services	CS1	Cultivation	Providing suitable substrate for cultivation	Any crops and fruits grown by humans for food; food crops;	Cultivated food and fodder
	CS2	Waste disposal	Providing suitable substrate for waste (including wastewater)	Decomposing wastes; filtering wastes	Space for waste disposal
	CS3	Habitation	Providing suitable space for human living	N/A	Living space
	CS4	Energy conversion	Providing suitable substrate or medium for energy conversion	N/A	Energy facilities
	CS5	Transporta-tion	Providing suitable substrate or medium for transportation	N/A	Main and side roads as well as railroad tracks
	CS6	Tourism facilities	Providing space and facilities for human activities related to tourism	N/A	Accommodation for touristic use
Information Services	IS1	Aesthetic information	Attractive landscape features and views	The beauty of nature	Appreciation of blooming trees or meadows
	IS2	Recreation	Variety in landscapes with (potential) recreational uses	Using the environment for sport and recreation; using nature to help stay fit; Watching plants and animals where they live; using nature to destress;	Use of meadows for leisure activities "Lagerwiesen"
	IS3	Cultural and artistic information	Variety in natural and cultural features with cultural and artistic value	the things in nature used to make films or to write books; The things in nature that help people identify with the history or culture of where they live or come from, Using nature to as a national or local emblem	Use of characteristic tree rows or single trees of cultural landscape in artistic display
	IS4	Spiritual and historic information	Variety in natural and cultural features with spiritual and historical value	The things in nature that help people identify with the history or culture of where they live or come from; Using nature to as a national or local emblem; the things in nature that have spiritual importance for people	Provision of religious and historic elements like churches and crucifixes
	IS5	Science and education	Variety in nature with scientific and educational value	Researching nature; studying nature	Possibility to experience, observe and learn about the environment e.g. species diversity, educational trails

StreetMap provided by Geofabrik (Geofabrik GmbH et al. 2019). This data was used to extract information on polylines as roads or railways and additional points as religious buildings and other religious elements. The recreational and educational trails (polylines) originate both from the detailed data of the OpenStreetMap as well as *gpx data available on the touristic website of the Wienerwald Tourismus GmbH (Wienerwald Tourismus GmbH 2018) for the mountain bike routes and educational trails. The data sources of the ASI are listed in Table A (Supplementary Material).

After having collated all the spatial data, we performed a quality check and then classified them into classes. We reclassified and aggregated the open land habitat types (Staudinger et al. 2014), so to obtain a list of open land classes at a level of detail adequate for both ecological and socio-cultural landscape services. The reclassification of open land habitat types into open land classes was achieved in three steps. First, in an ecological approach, the open land types were aggregated into classes, based on the following criteria: management level, nutrient level, moisture level, and ecosystem function. In a second step, taking socio-cultural aspects like recreational function or aesthetic aspects into account, we created a new aggregation of open land types. Finally, after an internal consultation involving both the experts in ecology and those in socio-cultural services, the two lists of classes evolved into one joint reclassification, consisting of 62 open land classes. The open land classes are available in the Supplementary Material (Table B). Similarly, we aggregated the ASI into 17 classes (Table A). The elements selected as ASI were classified based on their similarity and on their service provision capacity. Since settlements were excluded from the study area, the capacity of the service Habitation was expressed through the indicator “isolated buildings”. Due to the “layman” and inclusive nature of the OpenStreetMap data (OpenStreetMap Austria 2019), a deletion and ranking of the point data with congruent location and different name was indispensable. Expert decisions towards a double function of the element or towards its deletion were made. Hence part of the double-counted data was dismissed due to (i) redundancy (e.g. graveyards data was adopted from the open land class; “convenience stores” or “wind mill” were not included in the dataset); and (ii) ambiguity (the vague meaning of the name “attractions” was recessive). In case of “church” and “wayside cross” we decided in favour of the smaller element. We decided a picnic site to be an inclusive element for a bench or a waste basket. Other OpenStreetMap elements provided a double function; in these cases, both points were included in the further calculations for their double capacity (e.g. “guesthouse” and “restaurant”, “bench” and “viewpoint”, “restaurant” and “viewpoint”, “church” and “artwork”, “hiking” and “cycling trail”).

The reclassification of the open land habitats into 62 open land classes and the selection and classification of ASI into 17 classes led to a joint collection of 79 indicator classes (including altogether 58 202 landscape elements), which, in a next step, were inserted in a capacity matrix for the landscape service capacity assessment.

2.4 Capacity matrix: assessing service capacities

This study focuses on landscape service capacity only, similarly to many of the currently available spatial ecosystem and landscape service studies (for instance Crossman et al. 2013; Martínez-Harms et al. 2012; Egoh et al. 2012; Kopperoinen et al. 2014). Service capacity can be here defined as the hypothetical maximum yield provided by a service (Burkhard et al. 2012; Burkhard et al. 2014). Assessing the actual capability of ecosystems to provide services for human well-being needs information about their current conditions, which are induced by human activities (Burkhard et al. 2017). In this sense, nor the actual service capacity, neither the used stock of services is taken into account in this study. Other authors distinguish between ecosystem properties, potentials and services (Bastian et al. 2012), implying that ecosystems provide a certain potential to supply services based on their functioning (van Oudenhoven et al. 2012).

To define the LS capacity, we employed here the so-called capacity matrix. A capacity matrix links service providing units (definable at different spatial scales) to service supply capacities (Burkhard et al. 2009). In an assessment based on a capacity matrix, for each service providing unit a ranking proportional to the capacity for each service is assigned. Generally, expert evaluations are employed in order to gain an overview and see trends for ecosystem service assessments (e.g. Burkhard et al. 2009; Scolozzi et al. 2012). In subsequent analyses, the expert evaluation values could successively be replaced by data from monitoring, measurements, computer-based modelling, targeted interviews or statistics, although these techniques imply a much longer data processing.

Following the works of Burkhard et al. (2009; 2012; 2014), Hermann et al. (2014), and Hainz-Renetzeder et al. (2014), we applied the following scoring scheme, in a linear scale:

1: element presence, but no service capacity

2: low service capacity

3: moderate service capacity

4: high service capacity

5: very high service capacity

The 25 landscape services were split and assigned to the two teams of expertise (ecological and socio-cultural) involved in the study. First, both teams of experts assigned scores for their relevant services, producing a prefilled matrix. Then, through a dedicated workshop all experts contributed to the assessment of all the scores, both by discussing the scores of the services in their field of expertise and by providing comments and suggestions regarding services of the other discipline. Helpful within the workshop was the preparation of an approachable layout of the matrix in the software Microsoft Excel (2016). To ensure transparency, the matrix was projected on a screen, clearly visible for all people involved. We approached each class individually, discussing and comparing the scores vertically (to other classes) and horizontally (to other landscape services). When a consensus was necessary, we adjusted the scores directly on the screen, again aiming for high transparency. In many cases the provision of the definitions of landscape services and detailed information on the open land types were necessary, to avoid ambiguity and misunderstanding. Agreement on the definitions to describe each landscape service also helped to avoid issues of double counting, which refer rather to the service, than to the indicator. In case of similar aspects being valued within two services, values were split between the two (e.g. the ASI recreational infrastructure is valid both for the landscape service Tourism facilities and for Recreation). The possibility to examine the spatial location of the landscape elements and an orthophoto of the study area were also helpful to come to an agreement on the scores. The capacity matrix scoring gives no absolute values since the scores often refer to the specific characteristics of the Wienerwald Biosphere Reserve. Moreover, the comparison of indicators inside the area influences the score assigned. For instance, compared to dry grassland, other grassland classes have higher water supply; this means that peaks can be developed within the matrix.

After the evaluation, we linked the scores to the spatial data in Geographical Information Systems (ArcGIS 10.5.1; ESRI, Redlands), in order to obtain estimates of the capacity of landscape service supply and map them in spatially explicit units (Burkhard et al. 2009; Burkhard et al. 2012). The steps of the mapping procedure are detailed in the following sections.

2.5 Spatial data preparation and INDEC application

Simultaneously to the scoring of landscape service capacity, we prepared the spatial data so to later integrate the capacity matrix scores in the mapping process, using ArcGIS 10.5.1 (ESRI, Redlands). Figure 2 displays the workflow of the calculations, performed in Python (Python version 2.7.13). The forest-related classes of the open land dataset were transformed into polylines, since the forest was addressed as forest edge exclusively. We applied a buffer of 10 m to the data to secure the inclusion of all point and line features within or in direct proximity of the open land. By clipping the buffered data to the Wienerwald Biosphere Reserve's outline, we defined this as the outermost border of the project study area.

Due to the heterogeneity of data sources and data sets (spatial resolution and temporal variance) and the ambiguity in size for some of the ASI (e.g. streets, playgrounds, churches), we developed a methodology that would overlook both the size and the differences in data sources. The approach was based on two concepts: location of elements and the capacity scores retrieved directly from the capacity matrix. The location of the landscape elements was represented by points, meaning that line and polygon data types were transformed into point data. Then, we applied an innovative tool for mapping the landscape service capacity, which we named INDEC (analysis based on INtensity and DEnsity of service Capacity). Each passage of the workflow is described in the following paragraphs.

2.5.1 STEP A: Transformation of each landscape element into a point feature

Regarding the polygons, we transformed them into a point coinciding with the focal points of the polygons. Subsequently, the points generated from different geometrics (point, polyline, and polygon) and sources were merged into one "point feature class".

Based on the assumption that an ideal landscape services map would show an equally distributed

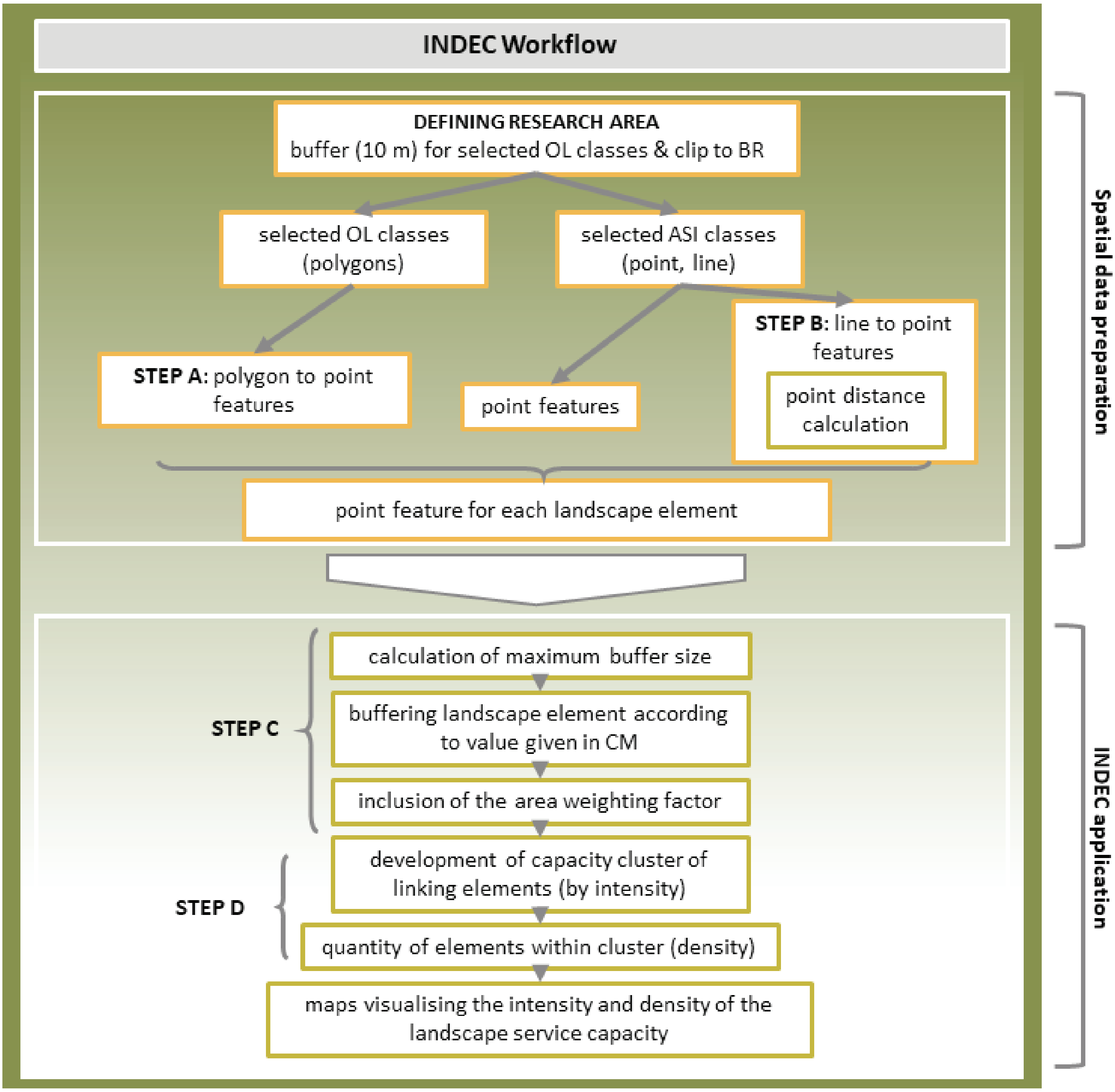

Figure 2: Workflow of the calculation steps, with spatial data preparation and INDEC (INtensity and DEnsity of service Capacity) application. OL: Open Land; ASI: Additional Spatial Indicators; CM: Capacity Matrix; BR: Biosphere Reserve.

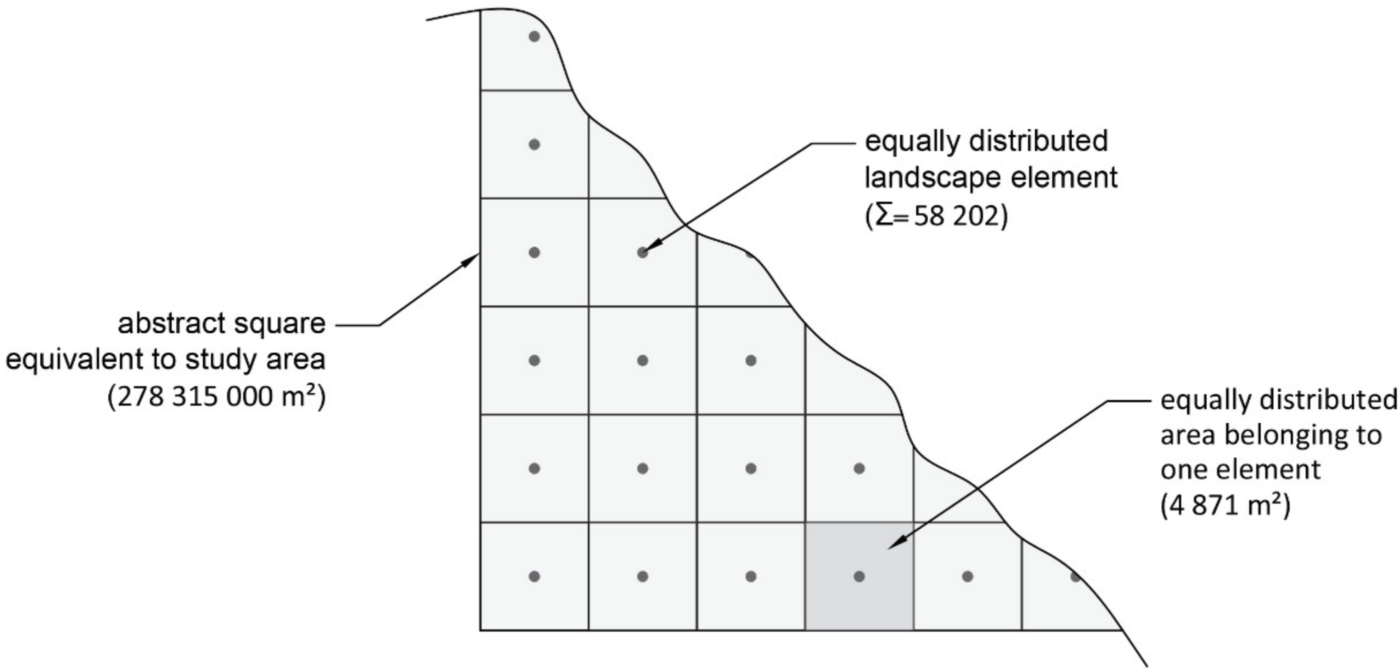

Figure 3 Graph showing the rationale behind the calculation of the equally distributed area of each point feature.

maximum capacity of the service (Figure 3), we computed the equally distributed area of each point data (4 871 m²) from the total study area (278 315 000 m²) and the number of landscape elements (58 202).

2.5.2 STEP B: Calculation of the distance of points along line features

In order to transform the polylines into points, we had to compute the point distance. In fact, no references for setting point distance could be found. For the line features the equivalent of the sum of the length of all the lines (5 027 130 m) within the area was equally distributed into an abstract quadrat of the study area size. Within this generated grid, we doubled the value of the side lengths of one grid cell (223 m), thereby prohibiting double counting mistakes leading to a misrepresentation of the line features. This value represents the ideal and equal distribution of points for the line features, similar to the method used for transforming polygons into points (Equation 1).

$$d_{points} = 2 * (2*A_{research} / (l_{total} - 2 * A_{research}{}^{1/2}) \qquad \text{Eq.1}$$

where

d_{points} = distance of points along polylines

$A_{research}$ = research area

l_{total} = total length of all polyline landscape elements

2.5.3 STEP C: Calculation of the buffer sizes of landscape elements

In the theoretical optimum described in the section above, each landscape element has the same maximum capacity to provide a landscape service and the elements are equally distributed across space. The calculated areas are perceived as circles (see Figure 4). The circles represent each landscape element with an equal range in all directions from one centre point, based on the assumption that the capacity of one landscape element potentially spreads equally in each direction. Therefore, the capacity of each point is represented by an outer buffer, whose radius is linked to the scores from the capacity matrix. The buffers express the potential intensity of the capacity. We computed the radius of the average circular area and adopted it as size of the maximum capacity buffer (equal to score 5 in the capacity matrix). At the maximum service capacity, the buffers (radius = 39 m) partially overlap. In this way the connectivity among the landscape services provided by each landscape element is guaranteed.

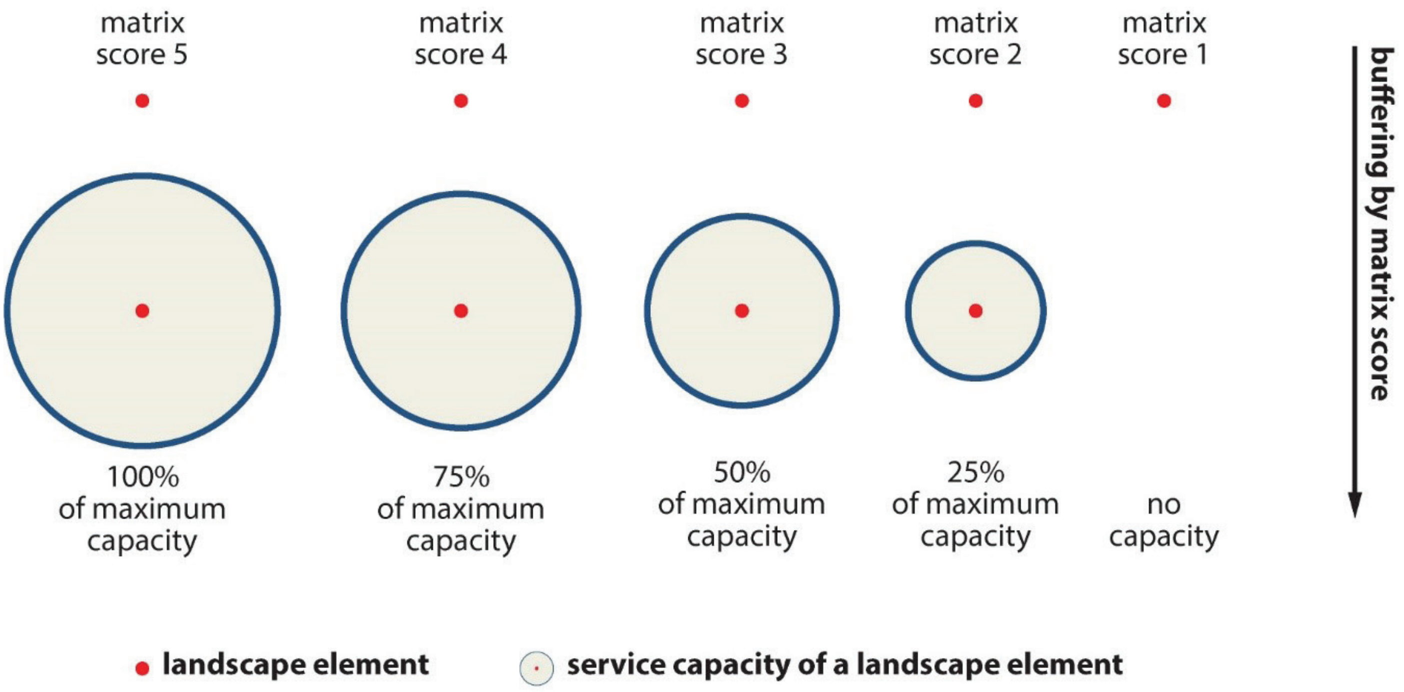

Figure 4 Graph exemplifying the theoretical assumption for defining the buffer sizes of the landscape service capacity of a landscape element.

For defining the intensity related to each point, we calculated the size of the buffer of the remaining capacity matrix scores (2-4) related to the maximum area (4 871 m²). For instance, 50% capacity (value 3) of maximum capacity (value 5) is equal to 50% (2 435.5 m²) area of maximum area (4 871 m²) (Figure 4).

The spatial data preparation provided two main outcomes: (i) the transformation of each landscape element into point data; and (ii) the definition of the buffer sizes according to the scores given the capacity matrix.

After the preparation of the spatial data and the transformation to point data for all landscape elements, we proceeded with the INDEC application (Figure 2). First, we linked the landscape elements to the scores they provide for each landscape service, taking them from the capacity matrix. In order to balance the representation of line elements (based on their nature of being represented by many points, in comparison with the polygons, which can only be represented by one point), we included a weighting factor (wf), which is based on the biggest (e.g. cultivated field ca. 400 000 m²) and smallest (e.g. single tree, a few m²) landscape element of the open land. The relative part of the maximum area within the study area became 1, and the relative part of the minimum area became 0. All the remaining landscape elements received relative values between 0 and 1, according to their area sizes (Equation 2) and were ranked accordingly.

$$rp_{LE\text{-}x} = (A_{LE\text{-}x} - A_{LE\text{-}min}) / (A_{LE\text{-}max} - A_{LE\text{-}min}) \qquad \text{Eq. 2}$$

where

$rp_{LE\text{-}x}$ = relative part of LE x (one open land LE e.g. meadow)

$A_{LE\text{-}x}$ = area of LE x

$A_{LE\text{-}min}$ = area of the smallest LE

$A_{LE\text{-}max}$ = area of the biggest LE

We defined wf=5 as maximum wf (wf [def as max]) (considering a balanced display of the landscape services addressed) and then for each landscape element whose rp was smaller than 1 we calculated the transformed wf (wf [transformed]) by linear correlation based on the rp of the landscape element.

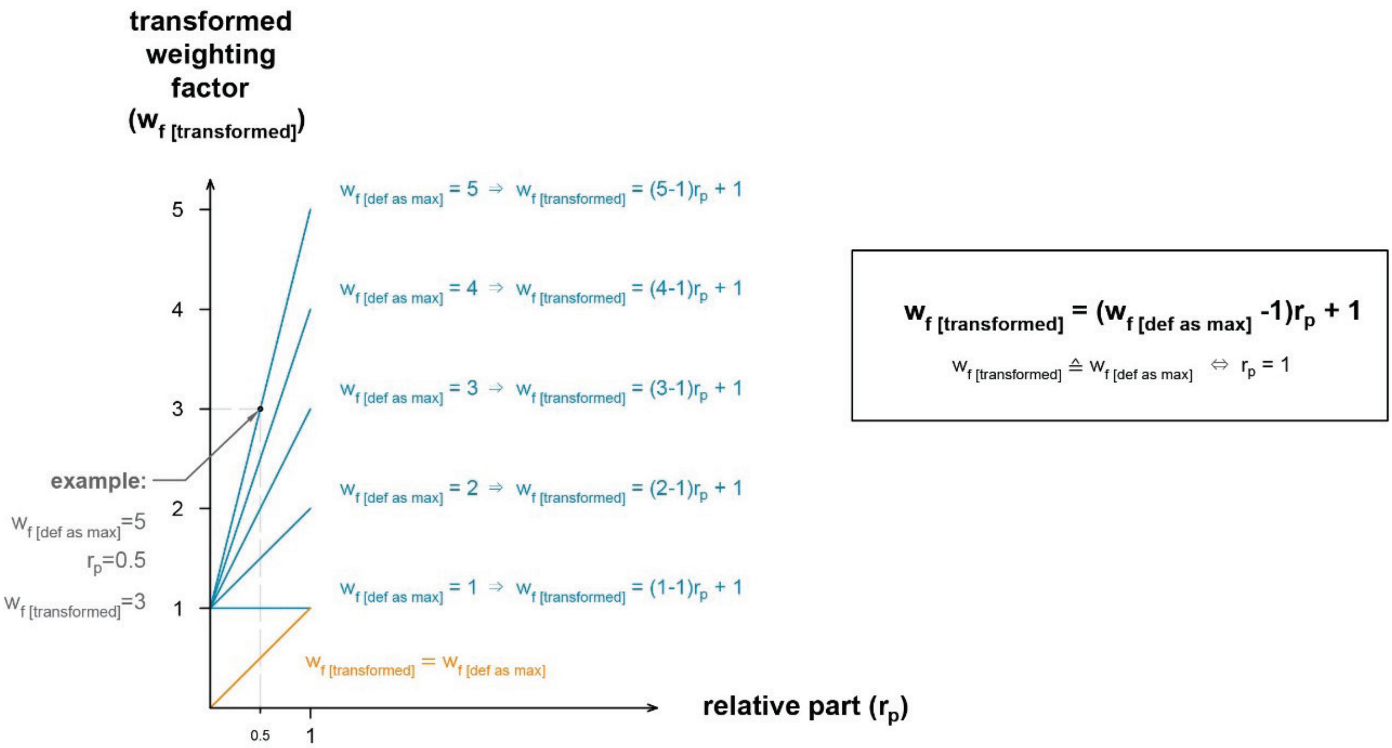

Figure 5 Calculation of transformed weighting factor (wf [transformed]) based on the relative part (rp) of each landscape element. The maximum weighting factor (wf [def as max]) =5.

As exemplified in Figure 5, depending on the relative part (0-1, with rp=1 equal to ranking position 1) and on the defined maximum wf, each landscape element received a transformed wf. For example, in case of rp=0.5 and wf [def as max]=5, the resulting wf [transformed]=3. Line elements also received a weighting factor independently of their length (see also Section 2.6.2).

2.5.4 STEP D: INDEC - final calculations

In a geoprocessing step, we buffered the landscape elements by multiplying the buffer value with the weighting factor of the line and polygon landscape elements. We merged the overlapping buffers by “spatial dissolve”, obtaining clusters (dissolved shapes) representing the cumulative *intensity* of service capacity. Subsequently we counted the number of landscape elements within each cluster by “spatial join”, using this number as an indicator of the *density* of service capacity. In this way we combined both intensity (the size of the cluster) and density (the number of elements within the cluster), creating our final INDEC. The INDEC itself has no unit and originates by 50% from the relative size and 50% from the relative amount of the landscape elements. All landscape service capacities are calculated through the same INDEC procedure, although for each landscape service only the landscape elements with service capacity >1 were included in the processing.

For the index of the intensity ($I_{IN\text{-}cl\text{-}x}$) of a cluster, the cluster area ($A_{cl\text{-}x}$) is divided by the normalized cluster area ($A_{cl\text{-}norm}$), which corresponds with the optimum area per landscape element ($A_{oALE} = bs_{max} = 4\ 871\ m^2$). This value refers to the value of the equally distributed area that is used to calculate the maximum buffer size and now allows for a normalisation as reference of the area size. In case the cluster size exceeds the optimum area per landscape element, it will produce a value higher than 1. In case of smaller clusters, a value lower than 1 will be produced. For clusters equal in size to the optimum area per landscape elements, the value 1 is assigned.

For the index of the density ($I_{DE\text{-}cl\text{-}x}$) the number of elements within the cluster ($n_{LE\text{-}cl\text{-}x}$) is divided by the number of elements per optimum area of landscape elements ($n_{LE\text{-}per\text{-}oaLE}$) equalling 1. The sum of the index of intensity ($I_{IN\text{-}cl\text{-}x}$) and the index of density ($I_{DE\text{-}cl\text{-}x}$) is the combined INDEC ($I_{INDEC\text{-}cl\text{-}x}$; Equation 3).

$$I_{INDEC\text{-}cl\text{-}x} = I_{ID\text{-}cl\text{-}x} + I_{DE\text{-}cl\text{-}}x \qquad \text{Eq. 3}$$

where

$I_{IN\text{-}cl\text{-}x} = A_{cl\text{-}x} / A_{cl\text{-}norm}$

$I_{DE\text{-}cl\text{-}x} = n_{LE\text{-}cl\text{-}x} / n_{LE\text{-}per\text{-}oaLE}$

and

$A_{cl\text{-}norm} = A_{oaLE}$ = optimum area per LE (bs_{max})

$n_{LE\text{-}per\text{-}oaLE}$ = 1= number of LE per optimum area of LE

$A_{cl\text{-}x}$ = size of cluster x

$I_{IN\text{-}cl\text{-}x}$ = Index of intensity of cluster x

$I_{DE\text{-}cl\text{-}x}$ =Index of density of cluster x

2.6 Validation of the workflow

2.6.1 Exclusion of landscape services

Data availability was a limiting aspect within the study. By using different data sources, we expanded our database to provide some indicators for all the services. However, after visualizing the preliminary capacity maps, two services had to be excluded from our list of landscape services, due to incomplete representativeness: Habitation and Waste disposal.

2.6.2 Validation of the plausibility of the landscape services capacity maps

The plausibility of landscape services capacity maps was validated through expert knowledge of the area during an internal workshop. The preliminary maps were displayed in Google Earth Pro (Google Earth Pro n.d.), and the two groups of experts (ecological and socio-cultural) were tasked to provide information on the areas of high and low capacity and on their location within the map of each landscape service. The discussion following the validation tasks revealed three main aspects in need of refinement. First, due to the spatially scattered nature of the study area, the weighting factor was further adjusted in order to enhance the visibility of the service capacities on the regional level. On account of a plausible and balanced display of the landscape services addressed, the final weighting factor was set to "6" for polygons and "3" for polylines. Second, since forest edges appeared spatially overrepresented in respect to the other landscape elements, creating a bias in the results, they received a final arbitrary wf = "1". Third, the scoring of the capacity matrix was revised to highlight some OL and ASI classes with respect to others. Changes affected 8% of the scores of the matrix, with 5% being upgraded to a higher score, and 3% being downgraded. The services Medicinal Resources, Disturbance prevention and Nutrient regulation faced the greatest changes with adjustments of 19% and 24% of the scores, respectively.

With these refinements we finalized our method and produced the final version of the service capacity maps.

3 Results

3.1 Capacity matrix

The capacity matrix consists of landscape elements classified into 79 classes, of which 62 are open land classes (Table B, Supplementary Material) and 17 are additional spatial indicators (Table A, Supplementary Material). Out of the 25 landscape services, 22 landscape services were selected. Altogether, we assigned 2000 scores.

The additional spatial indicators provide capacity for the landscape services categories Information services, Carrier services and Habitat services. The open land classes are addressed by all five service categories, but only marginally by the Carrier services. In the evaluation of some classes (e.g. trails, recreational infrastructure) the score within the matrix was split, due to the importance of the elements for both services. The capacity matrix is presented in the Supplementary Material (Tables C-H) groupwise, following the chronological order of the open land and additional spatial indicators classes.

3.2 Landscape service capacity maps: focus on three services

To exemplify the outcome of the INDEC application, the capacity service maps of three services are described here: Water supply (regulating service), Pollination (provisioning service), and Recreation (information service). These three services were chosen among 22 based on the following considerations: i) they were considered as either well or very well represented in the study area by the experts involved in the study; ii) they convey an unambiguous meaning; iii) and third, they are relevant services for the management of the Wienerwald Biosphere Reserve.

For the other service capacity maps and relevant descriptions, please refer to Drius et al. (2019).

The landscape service capacity maps are computed by the integration of the intensity (taken from the capacity matrix values) and the density of the selected landscape elements within the open land of the Wienerwald Biosphere Reserve. According to the INDEC the maps display clusters ranging from high (deep red) to low (light yellow) capacity of the open land. The colour grey symbolizes both areas of no capacity and the outline of the open land.

In the following sections the capacity map of each of the three selected landscape services is described by highlighting (i) the spatial distribution of the service capacity in the study area; (ii) the landscape elements showing the highest capacity in the capacity matrix; and (iii) the three clusters with the highest INDEC values. For the three highest capacity clusters, we provide a table showing the INDEC values, the frequency of landscape elements within each cluster, the size of each cluster and the distribution of landscape elements per classes within each cluster.

3.2.1 Landscape service Water supply

Spatial distribution: the service capacity is expressed through rather small clusters, with areas of highest capacity localized along streams and pools, such as south of Purkersdorf, and west of Liesing, and in the area of Pressbaum (Wienerwald See). Areas of high capacity are also visible in the dense mosaic of landscape elements south of Königstetten. The large north-eastern region of the Biosphere Reserve is dominated by cultivated fields and shows no capacity. Another area with many low, intermediate and high INDEC values is located in the north of Alternmarkt an der Triesting (Figure 6).

Landscape elements: The classes with the highest scores according to the capacity matrix are straight, seminatural streams, meandering, seminatural streams, channel/regulated streams, seminatural, nutrient-poor lakes and pools, nutrient-rich pools, artificial standing water connected to groundwater, springs, marshes, swamps, nutrient-poor fens, riparian woodland. A score “4” was assigned to periodic/small brooks, reed beds, forest edges, long-rotation woodland, hedgerows dominated by trees, and extensive orchards (Tables C-H).

Three clusters with highest INDEC: The first cluster (INDEC 86.6) is just south-east of Königstetten and includes 60 landscape elements distributed across 15 classes. The most frequent classes are forest edges, followed by intermediate managed meadows and hedgerows dominated by trees. Cluster 2 (INDEC 83.09) is a mosaic of meadows and lies west

Table 2: Three clusters with highest INDEC for Water supply. The INDEC value, the frequency of landscape elements (N LE), the area of the clusters and the distribution of landscape elements per class are reported. For the landscape element classes' code, refer to Table A and Table B.

CLUSTER	**INDEC** (adim)	**N-LE**	**Area** (m^2)	**Distribution of LE classes**										
Cluster 1	86.6	60	127218	TR31	MD23	TR44	TH12	SB41	MD13	B17	TR43	TR48	DR25	
				18	11	7	4	4	3	2	2	2	2	
				MG33	MG35	MG36	SB16							
				1	1	1	1							
Cluster 2	83.09	60	110431	MD13	MD22	TR31	MD23	TR44	MD14	WT9	MD24	SB41	TH12	WT11
				20	8	7	6	6	5	4	1	1	1	1
Cluster 3	56.24	40	77658	TR31	TR45	MD23	MD24	MD14	TH12	TR43	TR44	MG35	TH20	
				10	6	5	5	4	3	3	2	1	1	

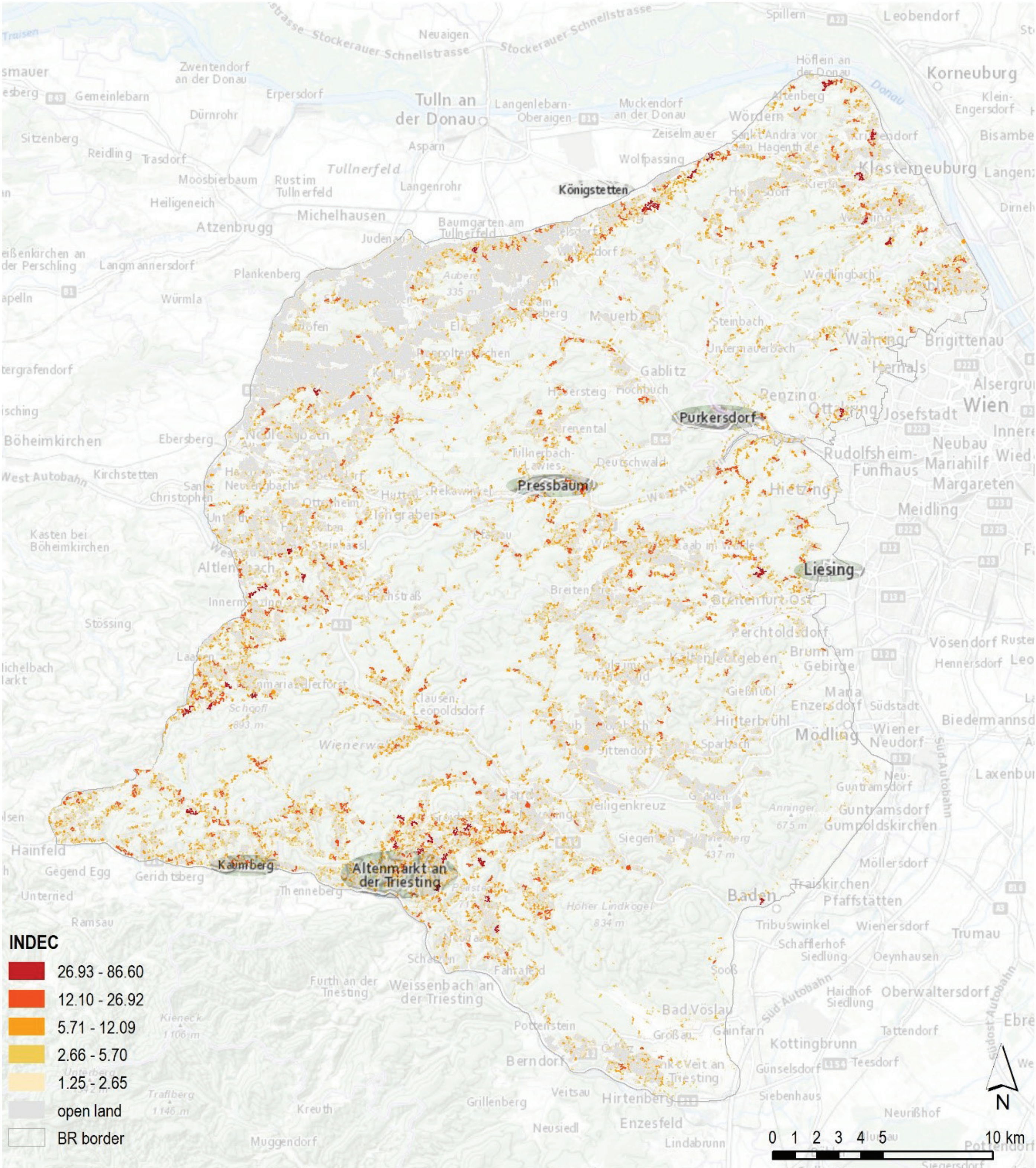

Figure 6: Water supply capacity in the Wienerwald Biosphere Reserve. The colour ramp distinguishes clusters of different INtensity and DEnsity Capacity (INDEC). Data sources: © OpenStreetMap (2018); Staudinger et al. (2014); Wienerwald Tourismus GmbH (2018); www.basemap.at (2018). EPSG: 31259

of Liesing; it has 60 landscape elements distributed across 11 classes. The most frequent classes are nutrient-poor extensive moist meadows, semidry managed meadows, and forest edges. Cluster 3 (INDEC 56.24) is situated in the southern area of the Biosphere Reserve, close to Obertriesting, in a mosaic of managed meadows, tree rows and hedges. It includes 40 landscape elements distributed across 10 classes, whose most frequent are forest edges, tree rows and single trees, and intermediate and intensively managed meadows (Table 2).

3.2.2 Landscape service Pollination

Spatial distribution: the service capacity is generally very high in the reserve, and more concentrated in the north of the Biosphere Reserve, particularly on the reserve border in the proximity of Baumgarten am Tullnerfeld, Königstetten, Klosterneuburg, and Döbling in the municipality of Vienna. Other areas for Pollination can be found in the southern part of the Biosphere Reserve, in the very large mosaic of meadows and fields just north of Altenmarkt an der Triesting (Figure 7).

Landscape elements: The classes with the highest score according to the capacity matrix are Nutrient-poor extensive moist meadow, Nutrient-poor managed meadows and pastures, Species-rich slopes and margins, and Extensive orchards. The classes with the score “4” according to the capacity matrix are nutrient-poor fens, nutrient-rich moist tall herbs, nutrient-poor moist shrub succession, shrubs on semi-moist grassland, semidry managed meadows, intermediate managed meadows, dry shrubland on limestone, thermophilous dry shrubland, semidry and dry grassland, dry forest edges, forest edges, *Pinus nigra* forests on dry grassland, hedges and shrubs, shrubs on moist soil, hedgerows dominated by trees, tree rows and single trees, larch dominated meadows/pastures, riparian woodland, gardens or parks, and greenery and planting (Tables C-H).

Three clusters with highest INDEC: The first cluster (INDEC 183.68) is a very large group of 121 landscape elements, distributed across 24 classes, and it is located close to Königstetten, on the reserve northern border. The three most frequent classes are forest edges (30 landscape elements), followed by intermediate managed meadows (17) and hedgerows dominated by trees (11). other frequent classes are gardens or parks, and semidry managed meadows. Cluster 2 (INDEC 132.7) lies quite close to Cluster 1, in the area of Baumgarten am Tullnerfeld. It includes 91 landscape elements, distributed in 17 classes. The most frequent class is cultivated fields, due to their density and small sizes in this cluster. Second most frequent class is Species-poor field margin, followed

Table 3: Three clusters with highest INDEC for Pollination. The INDEC value, the frequency of landscape elements (N LE), the area of the clusters and the distribution of landscape elements per class are reported. For the LE classes’ code, refer to Table A and Table B.

CLUSTER	**INDEC** (adim**)**	**N-LE**	**Area** (m^2)	**Distribution of LE classes**											
Cluster 1	183.68	121	299734	TR31	MD23	TR44	GD56	MD22	TH12	TR48	SB41	DR25	SB16	CU38	MD13
				30	17	11	9	9	7	7	6	3	3	2	2
				MG33	SB17	TR18	TR43	CU39	MG35	MG36	SB40	TR19	TR45	TR47	
				2	2	2	2	1	1	1	1	1	1	1	
Cluster 2	132.7	91	199398	CU37	MG35	MD23	TR48	TR44	CU38	DR25	GD56	SB41	MG33	TR49	
				15	10	9	8	7	6	6	5	5	4	4	
				MD22	MD24	TR45	SB42	TH12	TR43						
				3	3	3	1	1	1						
Cluster 3	108.81	73	171236	TR45	TR44	MD22	MD24	TR32	TR48	CU37	DR29	MD23	MG33	DR25	
				25	14	7	5	4	4	3	2	2	2	1	
				MD13	MD26	MG35	SB41								
				1	1	1	1								

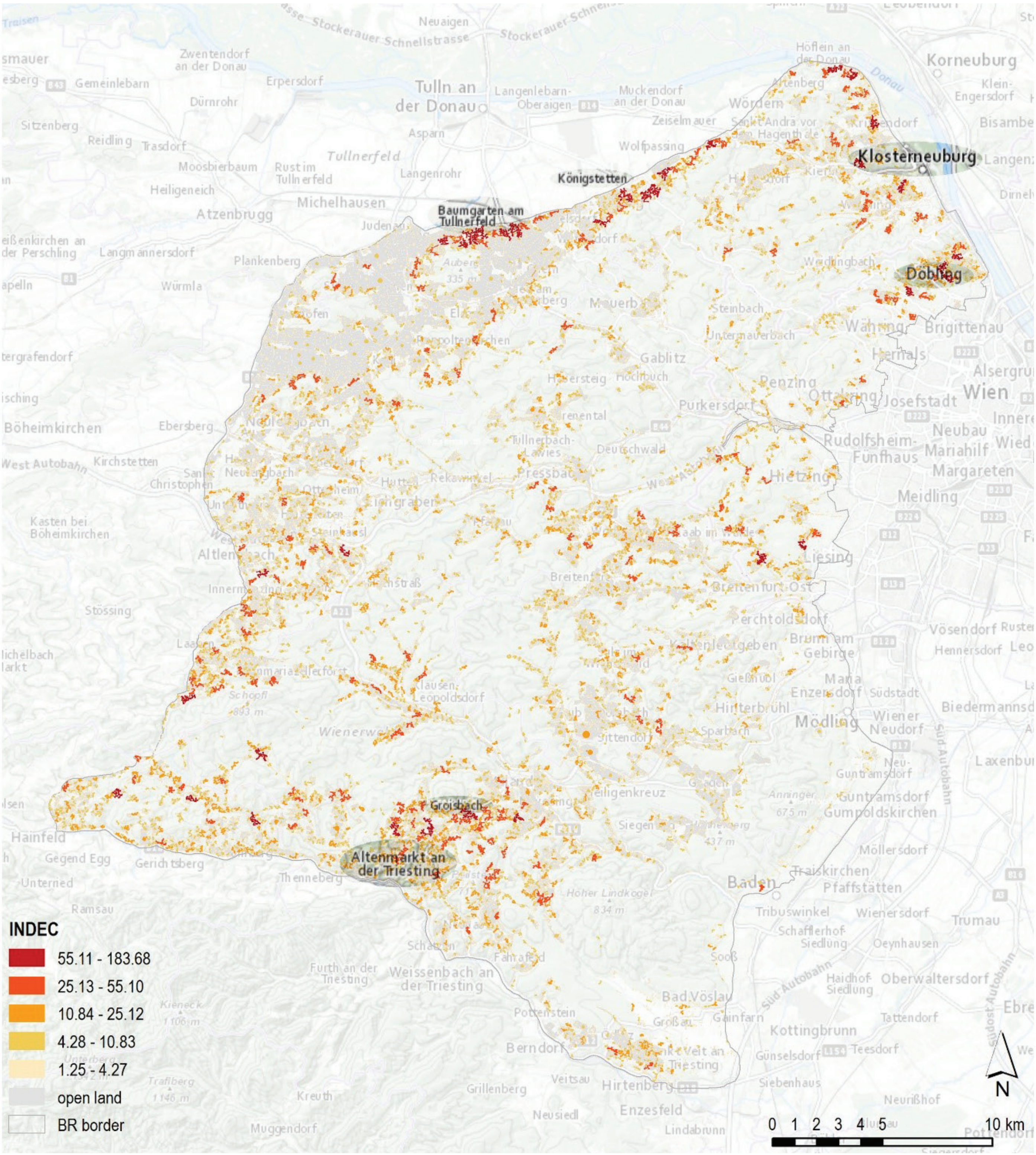

Figure 7: Pollination capacity in the Wienerwald Biosphere Reserve. The colour ramp distinguishes clusters of different INtensity and DEnsity Capacity (INDEC). Data sources: © OpenStreetMap (2018); Staudinger et al. (2014); Wienerwald Tourismus GmbH (2018); www.basemap.at (2018). EPSG: 31259

by intermediate managed meadow. The third cluster (INDEC 108.81) is again a large cluster including 73 landscape elements. Of these, 25 belong to tree rows and single trees, 14 to hedgerows dominated by trees, and 7 to semidry managed meadows. Other classes present in the cluster are extensive orchards, hedgerows dominated by trees, and forest edges. This cluster is located in the southern part of the Biosphere Reserve, in the proximity of Groisbach (Table 3).

3.2.3 Landscape service Recreation

Spatial distribution: For the LS Recreation capacities are shown throughout the area. Many high capacity areas are located in close proximity to settlements along the Biosphere Reserve, as Höflein an der Donau, Kritzendorf, Klosterneuburg and Vienna. In the south the hotspots are slightly more isolated with locations in Groisbach, Sankt Corona am Schöpfl and Obertriesting. In the north-west high capacities are revealed along the border of the Biosphere Reserve from Sieghartskirchen and Freundorf until Wolfpassing (Figure 8).

Landscape elements: The classes with the highest scores according to the capacity matrix are meandering, seminatural streams (4), artificial standing water connected to groundwater (4), chasm woodland (5), abandoned fruit trees (5), semidry managed meadows (4), semi-dry and dry fallow land of fields and vineyards (4), semidry and dry grassland (5), dry forest edges (5), forest edges (5), *Pinus nigra* forests on dry grassland (4), vineyard (4), tree rows and single trees(4), larch dominated meadows/pastures (5), riparian woodland (4), extensive orchards (5), cliffs (4), abandoned stone quarries (4), abandoned gravel pits (4), lawns (4), cemeteries (4), religious buildings (4), museums (5), castles and ruins (4) (Tables C-H).

Three clusters with highest INDEC: Cluster 1 (INDEC 152.62) is located close to Wolfpassing at the Dopplerhütte along the slopes of the Eichberg (394 m). 27 of the 102 landscape elements within this cluster are forest edges. Further 16 landscape elements are intermediate managed meadows and 10 hedgerows dominated by trees. Some gardens, dry meadows and extensive orchards are visible in the north and northwest of the cluster. Cluster 2 (INDEC 135.67) is located in the north of Vienna at the Kahlenberg. Vineyards, gardens or parks, forest edges and field margins dominate this cluster. Furthermore, it includes a view point and a recreational trail. Cluster 3 (INDEC 130.62) is located in the north of the Biosphere Reserve close to Höflein an der Donau and counts 87 landscape elements. Next to forest edges, extensive orchards, semidry meadows it includes gardens or parks, recreational trials, a cemetery, and altogether four religious buildings and elements (Table 4).

Table 4: Three clusters with highest INDEC for Recreation. The INDEC value, the frequency of landscape elements (N LE), the area of the clusters and the distribution of landscape elements per class are reported. For the LE classes' code, refer to Table A and Table B.

CLUSTER	INDEC (adim)	N-LE	Area (m^2)	Distribution of LE classes										
Cluster 1	152.62	102	242064	TR31	MD23	TR44	GD56	MD22	TR48	AR16	DR25	RTR7	CU38	MD13
				27	16	10	7	7	7	5	3	3	2	2
				SB17	TR18	TR43	MG33	MG35	MG36	REL10	TR19	TR45	TR47	
				2	2	2	1	1	1	1	1	1	1	
Cluster 2	135.67	91	213594	CU38	GD56	TR31	MG35	AR61	DR25	INF16	RC34	TR45		
				21	18	16	11	7	7	2	2	2		
				TR48	AR59	MD23	MG33	MG36	RTR7	SB17	VPS15	WT5		
				2	1	1	1	1	1	1	1	1		
Cluster 3	130.62	87	208608	TR31	TR48	MD22	GD56	RTR7	DR25	TR18	TR44	AR61	DR29	MD26
				14	14	12	6	6	4	4	4	3	3	3
				REL10	REL9	TR19	AR59	CU38	GD58	MD23	SB17	TR43	TR45	TR47
				2	2	2	1	1	1	1	1	1	1	1

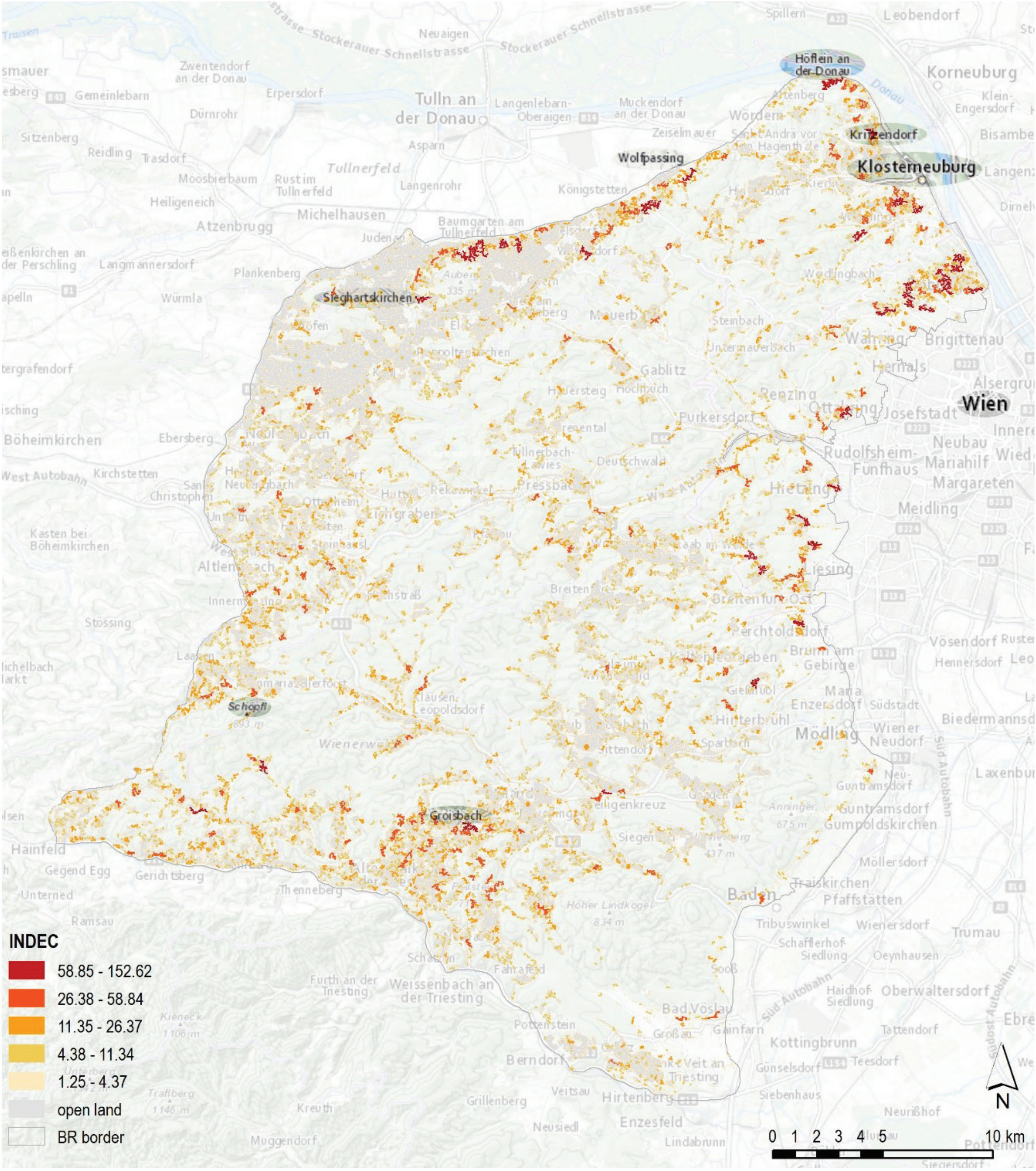

Figure 8: Recreation capacity in the Wienerwald Biosphere Reserve. The colour ramp distinguishes clusters of different INtensity and DEnsity Capacity (INDEC). Data sources: © OpenStreetMap (2018); Staudinger et al. (2014); Wienerwald Tourismus GmbH (2018); www.basemap.at (2018). EPSG: 31259

4 Discussion

In our study we aimed to address a broad range of landscape services to show the diversity of benefits the landscape provides for humans.

As faced in other studies (e.g. Wrbka et al. 2012) the availability and compatibility of spatial data was a main issue. Especially the assessment of the Carrier and Information services categories strongly depend on the availability of data additional to the mapping of the open land habitat types. Therefore, it was necessary to find a way to balance data varying in sources, age and level of accuracy. Nevertheless, the dismissal of landscape services was required for those cases where the provision of sufficient data was not accomplishable.

Another critical aspect was the classification of the data. The data of the open land is based on a mapping of the open land habitat types from an ecological point of view. On these grounds the open land habitat types referred to very detailed categorisation within the natural or semi-natural elements, whereas the other more anthropogenic classes provide broad information only. Since the further revision and amendment of the data was not possible, these broad classes (e.g. gardens or parks) or unvegetated open areas with compacted soil including parking areas and storage sites represent an imprecision in the evaluation progress as well as in the results. Other classes, like settlements, were excluded from the data selection.

Capacity matrices have proved to be a valuable method for the assessment and evaluation of landscape services (Hermann et al. 2014; Burkhard et al. 2012; Campagne and Roche 2018). They provide a flexible, integrative and time and cost-efficient approach to collect and integrate expert knowledge as a source of information (Campagne and Roche 2018; Jacobs et al. 2015). The attractiveness of the matrix approach results from its flexibility concerning level of detail and level of abstraction from rather simple to highly complex. Its potential to integrate all kinds of data, from expert-scores to statistics, interview data, measurements or high-end model outcomes makes it applicable in data-poor as well as data-rich environments. Results based on the flexible 0-5 ranking system and the linkage to geo-biophysical spatial units in ecosystem service maps provide wide application ranges in science and in decision making (Burkhard et al. 2014). The method has successfully been applied to quantify ecosystem and landscape services in several case studies (e.g. Kandziora et al. 2013; Kaiser et al. 2013; Vihervaara et al. 2010; Vihervaara et al. 2012; Hermann et al. 2014; Hainz-Renetzeder et al. 2014; Stoll et al. 2015). It has also inspired the development of ecosystem service mapping studies (e.g. Clerici et al. 2014; Baral et al. 2013). On the other hand, there are several uncertainties related to the matrix method applied for landscape analyses (Hou et al. 2013), which we could experience as well. First, in this study the expert knowledge emerged from the teams cooperating in the project. Therefore, the consensus approach provided productive input and discussion, minimizing ambiguities in the definitions and improving the development of the project. Furthermore, as also pointed out by Jacobs et al. (2015) the balancing effect of the consensus method allowed to progress on decisions where uncertainty (due to lack of data or knowledge) might have been blocking the individual. Nevertheless, an individual scoring beforehand to support the possibility of statistical analysis could be considered. Moreover, expanding the number of experts involved and thus optimizing scientific credibility shall also improve the method (Campagne et al. 2018; Jacobs et al. 2015). In fact, there is a high dependence on the observer's experience, knowledge and objectivity which services are supposed to be relevant and how to value them (Burkhard et al. 2012).

Although the issue of double counting of elements was avoided by agreement on distinct definitions or a splitting on values within strongly connected services (Wrbka et al. 2012), the distinction between the assessment of a general capacity of classes/elements while strongly referring to local/regional conditions and peculiarities of the Wienerwald Biosphere Reserve (also due to the Wienerwald explicit data of the open land habitat types) revealed contextual inconsistencies. The possibility of a direct transferability of the scores to other biosphere reserves or nature protection areas should be object of critical revision. Another limitation of the capacity matrix and of the study was that the actual condition of the landscape element and the influence of seasonal aspects were not addressed. In this sense the capacity score assigned wasn't adjusted with a qualifier factor, as done in other studies (e.g. Hermann et al. 2014; Hainz-Renetzeder et al. 2014).

In line with Campagne et al. (2018) the focus on the assessment of capacities does not allow for the consideration of trade-offs or neighbouring effects (positive or negative) within the matrix, therefore the complexity and multifunctionality of ecosystems is embodied insufficiently.

Finally, although careful preparation of the materials to assure transparency and time efficiency was aimed for within the capacity matrix workshop, the goal of scoring all 79 classes within one day in consensus could not be achieved. For which reason we see an accessible size of the matrix as well as and realistic time management throughout the scoring as key issues to avoid revisions, in the achievement of a consistent result. Based on this experience we are aware that no final solution for highly complex ecosystem and landscape service assessments has been found yet and that related challenges are still manifold.

Shifting from the capacity matrix assessment to the mapping methodology, our proposed method allowed us to overcome several issues related to data quality. In fact, through the INDEC application all landscape elements were treated at the same level, being all transformed into point data. The second advantage of the method is that it conveys multiple simultaneous information of density and of cumulative intensity, based on capacity score and the size of service capacity. The approach has also the great advantage of addressing very different services ranging from ecological to socio-cultural aspects. Indeed, the INDEC was very adequate for the combination of different data sources. Combining and merging data from different sources means having to deal with different resolution, age, spatial reference, different metadata and so on. The INDEC proved very efficient and successful in overcoming the data discrepancies and therefore it could be particularly useful in projects with limited financial resources. Thanks to the INDEC, there was no modification in the original data sets of open land data and in the additional spatial indicators. Moreover, our methodology highlighted the spatial connectivity of landscape elements, thanks to the creation of clusters equally dependent on the intensity of the capacity, assigned through the capacity matrix, and on the density of the landscape elements, i.e. their proximity. Therefore, the method allowed an appropriate balance among isolated and large landscape elements (e.g. cultivated fields, meadows) and small-scaled but numerous landscape elements, such as for instance forest edges, tree rows and benches. By adopting a method that applies a weighting factor to each polygon, most of the small-scaled elements would be overlooked. This is also important regarding the connectivity needed to guarantee a functioning GI within the Wienerwald Biosphere Reserve. Liquete et al. (2015) also proposed a methodology focusing on the connectivity of selected indicators for service provision as a way to define GI functionality. The authors stress that not all green areas qualify as GI elements, a fact which we took in consideration by employing the capacity matrix.

The INDEC clusters identified the spatial connectivity of GI within the Wienerwald Biosphere Reserve not only needed for the provision of landscape services, but also required for landscape service flow (Kukkala and Moilanen, 2017). Depending on the service assessed, the service provision and its demand need to be more or less in proximity, as highlighted by Cimon-Morin et al. (2013), who argued that in regions dominated by humans (which is the case for the Wienerwald Biosphere Reserve) demand is always nearby.

The INDEC is based on a tailored landscape service assessment. Nevertheless, the methodology could be efficiently transferred to other data sets, in any other region, provided that the capacity matrix scores are revised. As such, the method can also be used for a replicable monitoring needed in biosphere reserves to measure sustainable development performance, as recommended by the Seville Strategy (UNESCO, 1996). Chapman (2012) outlines that '*adaptive monitoring based on ecosystem services provides the best means to develop necessary information for informed decision-making*'. Concentrating on landscape elements as service providing units, they act as assessment endpoints in any adaptive monitoring program and can effectively identify the need for management actions. As such, the efficiency of the INDEC also makes it fruitful for applied analyses, such scenarios development. During the analyses, we carried out some exercises on scenarios development. For instance, we hypothesized the effects of management measures on the future provision of landscape services. Realistic measures might be extensive woodlets logging, change in the management of meadows, conversion of cultivated fields into vineyards or another cultivation, and so on. The INDEC might quite rapidly provide projections on the change of landscape service provision, based on each of such measures.

Last but not least, the INDEC is an approach fitting with the rationale behind the capacity matrix, since the size of landscape elements areas is not explicitly taken into account.

As regards the critical issues encountered in the development of the INDEC, we noticed that in some cases the density was a dominant factor over the intensity. This applies to the forest edges, which were so abundant that they were often included in the clusters of highest capacity. On the other hand, this method relies on the quality of the data set: in this study, we dealt with an "unbalanced" dataset, with high number of classes with few landscape elements (e.g. thermophilous dry shrubland with two landscape elements), and a low number of classes with many landscape elements: e.g. forest edges (11032 landscape elements); trails (7823); intermediate managed meadows (3283); hedgerows dominated by trees (3041).

A critical aspect in the development of the methodology was "translating" the difference in landscape services capacities into a buffer. In other words, what is the "spatial" proportion between a score "2" and a "5"? Another technical issue regarded the transformation into points: depending on the shape of the polygon, the focal points of polygons sometimes were outside the area of the polygon they belonged. This aspect remained unresolved.

The INDEC and the method employed in this work in general might be considered rather simplistic in the sense that they do not address disservices, i.e. conditions blocking the capacity of certain services, nor neighbouring aspects, i.e. influence of other landscape elements on the scoring for the service. Moreover, the INDEC is static: no temporal dynamism was considered.

As a further source of criticism, it is worth mentioning that the huge data set handled needs powerful hardware and software. However, this aspect is not limited to the INDEC.

5 Conclusions

The definition of GI in the European Commission communication (2013) implies two main aspects which are also taken up by other authors (e.g. Kopperoinen et al., 2014): (i) conservation of valuable natural areas and (ii) the enhancement of ES provision. By developing the innovative tool INDEC, we covered both aspects – the recognition of valuable natural and semi-natural landscape elements and their capacity to deliver a whole range of ecological and socio-cultural landscape services. Although the assessment performed through the capacity matrix has a local character, the tool might be transferable to other reserves and other regions.

Several aspects might be improved and further tested in the next studies. The most interesting one would be to analyse the spatial interaction among landscape services, in order to answer stimulating research questions like: can we see trade-offs when overlapping the selected services?

Since the study focuses on service capacity only, no information on service demand is currently available. A future project might focus on this aspect, finding gaps between supply and demand (Burkhard et al. 2012).

Another stimulating analysis might be the development of the INDEC for the whole area of the Wienerwald Biosphere Reserve, by including forest and settlements. The results would be comparable to those presented in this study. In addition to this, since the INDEC method was tailored for a regional approach, it would be fascinating to tune it at the local scale, by selecting a set of municipalities within the Reserve. In this way, communication and inclusion of stakeholders or the public might be desirable.

The implementation of GI into spatial planning seems a considerable effort (Slätmo et al., 2019). As a biosphere reserve, the Wienerwald represents an excellent training ground for developing a well-founded basis for the sustainable planning of GI in the peri-urban and rural areas around Vienna bringing all necessary actors (political and administrative) together.

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Supplementary material

Table A: Data sources of the Additional Spatial Indicators (ASI) classes, and the ASI types included in each class. The codes in brackets in the ASI types refer to the © OpenStreetMap 2018.

No	Code	ASI Classes	ASI Types
1	PUT2	Public transport	OSM: railways, bus stops
2	ROD3	Roads primary	OSM: Motorway, trunk, primary + all links
3	ROD4	Roads secondary	OSM: secondary, tertiary + all links
4	ROD5	Roads tertiary	OSM: unclassified
5	ROD6	Roads residential	OSM: residential, service roads
6	RTR7	Recreational trails	OSM: Bridleways; WWTourism: Nordic walking/jogging trails; Hiking - OSM: track all grades, path, footway, steps; WWTourism: Hiking trails, Cycling - OSM: cycle ways - paved; WWTourism: cycling/mtb trails
7	ETR8	Educational trails	WWTourism: \`Themenwege\`
8	REL9	Religious buildings	OSM: churches and chapels (3100+3102+3107)
9	REL10	Religious elements	OSM: wayside cross/shrine (2734+2735)
10	ART11	Monuments and artwork	OSM: memorial (2724), monument (2723), artwork (2725), fountain (2904)
11	ARC12	Archaeological sites	OSM: archaeological sites (2733)
12	MUS13	Museums	OSM: museum (2722)
13	CAS14	Castles	OSM: castles (2731), ruins (2732)
14	VPS15	View points	OSM: observation tower (2953), viewpoint (2742)
15	INF16	Recreational infrastructure	OSM: dog park (2206), playgrounds (2205), picnic site (2741), toilet (2901), drinking water facilities (2903), waste baskets (2906), bench (2902), tourist info (2701)
16	GST17	Gastronomy	OSM: biergarten (2307), restaurant (2301), cafe (2303), pub (2304), fast-food (2302), Bakery (2502), bar (2305)
17	ACC18	Accommodation	OSM: hotel (2401), guesthouse (2404), hostel (2405), campsite (2422), alpine hut (2423)

OSM: © OpenStreetMap contributors 2018. download 2.3.2019: https://download.geofabrik.de/europe/austria.html

WWTourism: Wienerwald Tourismus GmbH 2018. download (gpx) 20.8.2018: https://www.wienerwald.info/karte

Table B: Reclassification of the open land types (OL types) into open land classes (OL classes) of the Wienerwald Biosphere Reserve. OL types refer to the open land types available in Staudinger et al. (2014).

No	Code	OL class	OL type	
1	WT1	Straight, semi natural streams	2	
2	WT2	Meandering, semi natural streams	3, 4, 19	includes submerged vegetation in streams (19)
3	WT3	Channel/regulated streams	7, 8, 133	includes straight lowland streams (133)
4	WT4	Periodic/small brooks	9, 10	includes ditches (9)
5	WT5	Semi natural, nutrient-poor lakes and pools	11, 12, 14, 18	includes (meso) eutrophic pools (12), episodic pools (14), submerged vegetation in standing water (18)
6	WT6	Nutrient-rich pools	13, 15	includes nutrient-rich not natural pools connected to groundwater (15)
7	WT7	Artificial standing water connected to groundwater	17	
8	WT8	Artificial pools disconnected from groundwater	16	includes species-poor eutrophic pools
9	WT9	Springs, marshes, swamps	21, 23	
10	WT10	Nutrient-poor fens	24, 25	includes acidophilic and basophilic fens
11	WT11	Reed beds	26, 27, 28, 29, 31	
12	TH12	Nutrient-rich moist tall herbs	30, 33, 34, 35, 36, 44, 45, 46, 47, 48, 58	includes ruderal reed beds (30), corridors dominated by *Petasites hybridus* (33), corridors dominated by *Filipendula hydrophilous* (34), wet abandoned pastures dominated by umbellifers (35), corridors dominated by *Senecio sarracenicus* (36), moist fallow land dominated by *Petasites hybridus* (44), moist fallow land dominated by *Filipendula hydrophilou*s (45), moist fallow land dominated by umbellifers (46), abandoned reed beds (47), abandoned nutrient- rich wetlands (48), fallow land of damp (semi-moist) grasslands (58)
13	MD13	Nutrient-poor, extensive moist meadow	37, 38, 40, 42, 55	includes straw meadow dominated by *Molinia caerulea* (37), nutrient-poor fallow land of damp (semi-moist) and wet grasslands (38), nutrient-poor Molinia meadows (40), unfertilized marshy meadows (42), semi-humid oat grass meadows (Filipendulo vulgaris - Arrhenatheretum). It is part of EU habitat type: 6410 *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils, mire meadows, 6510 lowland hay meadows.
14	MD14	Nutrient-rich moist and wet meadow	41, 43, 207	includes fertilized moist and wet meadows. Typical species: *Cirsium rivulare*, *Holcus lanatus*, *Ranunculus acris*, *Festuca pratensis*, *Lychnis flos-cucculi*, *Carex panicea* (41); moist and wet pastures (43), regularly flooded prairies (207)
15	SB15	Nutrient-poor moist shrub succession	39	Secondary succession of fallow land of moist meadows
16	SB16	Nutrient-rich moist shrub succession	49, 108	Fallow Land of nutrient-rich moist meadows (49), shrub succession (108)
17	SB17	Shrubs on semi-moist grassland	59	shrubs on damp (moderate covering of moisture) grassland
18	TR18	Chasm woodland	132, 109	chasm woods (109) and abandoned fruit trees with shrub succession (132)
19	TR19	Abandoned fruit trees	140	
20	TH20	Nutrient-rich tall herbs	50, 52	includes Nettle meadows, neophytes like *Impatiens glandulifera* and *Reynoutria spp*.
21	TH21	Nutrient-rich herbs (blooming aspect)	51	*Solidago* sp. (Golderod)

22	MD22	Semidry managed meadows	54, 74, 75, 76	includes dry oat grass land (54), dry brome grass (74), semi-dry brome grass (75), secondary grazed semi-dry pastures (76). It is part of EU habitat type: 6510 Lowland hay meadows, 6210 Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia, important orchid sites)
23	MD23	Intermediate managed meadows	56, 57, 143, 204	includes oat grassland (56), damp meadows dominated by *Alopecurus* (57), grazed Pastinaco-Arrhenatheretum (143), mountainous Astrantio-Trisetetum (204). It is part of EU habitat type: 6510 Lowland hay meadows, rich pastures, 6520 Mountain hay meadows
24	MD24	Intensively managed meadows and pastures	60, 63, 67	includes intensively managed pastures (60)(67), field forage (63)
25	DR25	Semi-dry and dry fallow land of fields and vineyards	61, 62, 77	includes fallow land of semi-dry and dry grassland (77)
26	MD26	Nutrient-poor managed meadows and pastures	64, 65, 66	includes acidophilic (65) and basophilic (66) pastures, Red Fescue meadows (64)
27	DR27	Dry shrubland on limestone	69	
28	DR28	Thermophilous dry shrubland	70	EU habitat type: 40A0 Subcontinental peri-pannonic scrub
29	DR29	Semidry and dry grassland	72, 73, 78, 134	includes rupicolous dry grasslands (72), steppic grasslands (73), fallow land of semi-dry and dry grasslands (78), 6190 Rupicolous pannonic grasslands (Stipo-Festucetalia pallentis), 6240 Sub-Pannonic steppic grasslands, 6210 Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia, * important orchid sites), thermophilous scree vegetation (134)
30	DR30	Dry forest edges	79	
31	TR31	Forest edges	0_Wald, 135, 136, 199, 210-228	
32	TR32	*Pinus nigra* forests on dry grassland	200, 202	includes natural *Pinus nigra* stands in open land (202)
33	MG33	Species-rich slopes and margins	82, 83	includes field margins with pannonic shrub fringes (83)
34	RC34	Rock fragments and dry-stone walls	113	
35	MG35	Species-poor field margins	84, 85	includes ruderal species (84,85)
36	MG36	Ruderal Vegetation	80, 86	
37	CU37	Cultivated field	87	
38	CU38	Vineyard	88	
39	CU39	Intensively managed orchard	105	
40	SB40	Nitrophilous and neophytic edges and woodlets	89, 90, 93	
41	SB41	Hedges and shrubs	91	
42	SB42	Shrubs on moist soil	92	
43	TR43	Long-rotation woodland	94, 96, 103	includes *Robinia pseudoacaci*a (94), poplar, birch, spruce woodlands, non-natural hedges and windbreaks (96), copses of allochtonous species (103)
44	TR44	Hedgerows dominated by trees	95, 102	includes hedgerows (95), native and common deciduous trees (maple, cherry tree, linden, etc.) (102)

45	TR45	Tree rows and single trees	97, 101	
46	TR46	Larch dominated meadows/ pastures	205	
47	TR47	Riparian woodland	98, 99, 100	includes 91F0 Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*), non-natural riparian woodland
48	TR48	Extensive orchards	104	
49	TR49	Short-rotation plantations	106, 107	includes “energy forest”, tree nurseries
50	RC50	Cliffs	112	
51	RC51	Active gravel pits and quarries	115, 116	
52	RC52	Abandoned stone quarries	117	
53	RC53	Abandoned gravel pits	118	
54	AR54	Leisure and sport facilities	119	includes turf
55	AR55	Lawns	123	
56	GD56	Gardens or parks	120, 121	
57	GD57	Greenery and planting	122	
58	GD58	Cemeteries	124	
59	AR59	Unvegetated open areas with compacted soil including parking areas, storage sites	125	
60	AR60	Paved open areas including parking areas, storage sites	126	
61	AR61	Isolated buildings	127	
62	AR62	Waste sites	129	includes wastewater treatment sites

Table C: Capacity matrix of the open land (OL) classes 1-11

OL Code	**Open Land Class**		RS1	RS2	RS3	RS4	RS5	RS6	RS7	RS8		HS1	HS2		PS1	PS2	PS3	PS4		CS1	CS5	CS6		IS1	IS2	IS3	IS4	IS5
		Regulation services	Local climate regulation	Disturbance prevention	Water regulation	Water supply	Soil retention	Soil formation	Nutrient regulation	Pollination	**Habitat services**	Refugium	Nursery	**Provision services**	Food	Raw materials	Genetic resources	Medicinal resources	**Carrier services**	Cultivation	Transportation	Tourism facilities	**Information services**	Aesthetic Information	Recreation	Cultural and artistic info.	Spiritual and historic info.	Science and education
WT1	Straight, seminatural streams		5	5	5	5	1	2	5	2		4	5		3	2	2	1		1	1	1		3	2	2	4	4
WT2	Meandering, seminatural streams		5	5	5	5	1	2	5	2		4	5		3	2	2	1		1	1	1		5	4	3	4	5
WT3	Channel/regulated streams		5	4	2	5	1	1	4	1		3	3		2	1	2	1		1	1	1		3	2	2	2	3
WT4	Periodic/small brooks		4	5	4	4	1	2	4	1		4	4		2	2	1	1		1	1	1		3	3	2	2	3
WT5	Seminatural, nutrient-poor lakes and pools		5	4	4	5	1	1	4	2		4	5		3	1	2	1		1	1	1		4	3	3	3	4
WT6	Nutrient-rich pools		5	4	4	5	1	1	3	2		3	5		4	1	2	1		1	1	1		2	3	2	2	3
WT7	Artificial standing water connected to groundwater		5	4	4	5	1	1	4	2		3	4		3	1	2	1		1	1	1		2	4	2	2	3
WT8	Artificial pools disconnected from ground-water		5	3	2	3	1	1	3	2		3	4		3	1	2	1		1	1	1		2	3	2	2	3
WT9	Springs, marshes, swamps		4	4	5	5	2	4	5	3		5	4		2	1	1	3		1	1	1		3	1	1	2	3
WT10	Nutrient-poor fens		4	3	5	5	3	4	5	4		5	4		2	2	1	4		1	1	1		2	1	1	1	1
WT11	Reed beds		5	4	5	4	4	5	5	3		5	5		2	3	2	2		1	1	1		4	1	1	1	2

Table D: Capacity matrix of the open land (OL) classes 12-24

		Regulation services								Habitat services		Provision services				Carrier services			Information services				
OL Code	**Open Land Class**	RS1 Local climate regulation	RS2 Disturbance prevention	RS3 Water regulation	RS4 Water supply	RS5 Soil retention	RS6 Soil formation	RS7 Nutrient regulation	RS8 Pollination	HS1 Refugium	HS2 Nursery	PS1 Food	PS2 Raw materials	PS3 Genetic resources	PS4 Medicinal resources	CS1 Cultivation	CS5 Transportation	CS6 Tourism facilities	IS1 Aesthetic Information	IS2 Recreation	IS3 Cultural and artistic info.	IS4 Spiritual and historic info.	IS5 Science and education
TH12	Nutrient-rich moist tall herbs	4	4	4	3	5	5	5	4	4	4	2	1	1	3	1	1	1	3	1	1	1	2
MD13	Nutrient-poor, extensive moist meadow	3	4	4	3	4	4	4	5	5	4	3	3	3	5	1	1	1	4	2	1	1	4
MD14	Nutrient-rich moist and wet meadow	3	4	4	3	4	4	4	3	4	3	3	1	2	2	3	1	1	2	1	1	1	1
SB15	Nutrient-poor moist shrub succession	4	3	4	3	5	5	4	4	5	5	2	2	3	3	1	1	1	3	1	2	1	1
SB16	Nutrient-rich moist shrub succession	4	3	5	3	5	5	5	3	5	5	3	3	2	2	1	1	1	3	1	1	1	2
SB17	Shrubs on semi-moist grassland	4	4	3	3	5	5	5	4	5	5	3	3	2	3	1	1	1	3	3	1	1	2
TR18	Chasm woodland	5	4	4	3	4	4	4	3	5	5	3	3	2	3	1	1	1	5	5	3	5	4
TR19	Abandoned fruit trees	4	3	3	2	4	4	5	3	5	5	3	3	3	2	1	1	1	5	5	3	5	4
TH20	Nutrient-rich tall herbs	3	4	3	2	3	4	4	3	4	3	2	2	1	4	1	1	1	2	1	1	1	2
TH21	Nutrient-rich herbs (blooming aspect)	3	3	3	2	3	4	4	3	4	3	2	2	1	2	1	1	1	4	1	1	1	2
MD22	Semidry managed meadows	2	3	3	3	4	5	4	4	4	3	2	1	2	3	5	1	1	4	4	2	2	3
MD23	Intermediate managed meadows	2	4	3	3	4	5	4	4	4	3	2	1	2	3	5	1	1	3	3	2	2	3
MD24	Intensively managed meadows and pastures	2	3	3	2	3	3	3	3	3	2	1	1	1	1	5	1	1	2	1	2	2	2

Table E: Capacity matrix of the open land (OL) classes 25-36

		Regulation services								**Habitat services**		**Provision services**				**Carrier services**			**Information services**				
OL Code	**Open Land Class**	RS1 Local climate regulation	RS2 Disturbance prevention	RS3 Water regulation	RS4 Water supply	RS5 Soil retention	RS6 Soil formation	RS7 Nutrient regulation	RS8 Pollination	HS1 Refugium	HS2 Nursery	PS1 Food	PS2 Raw materials	PS3 Genetic resources	PS4 Medicinal resources	CS1 Cultivation	CS5 Transportation	CS6 Tourism facilities	IS1 Aesthetic Information	IS2 Recreation	IS3 Cultural and artistic info.	IS4 Spiritual and historic info.	IS5 Science and education
DR25	Semi-dry and dry fallow land of fields and vineyards	2	3	2	2	3	4	3	3	3	2	2	1	1	2	1	1	1	3	4	2	2	3
MD26	Nutrient-poor managed meadows and pastures	2	3	4	3	4	5	4	5	5	3	3	1	3	5	4	1	1	4	3	2	2	3
DR27	Dry shrubland on limestone	3	4	3	2	4	4	4	4	4	4	2	2	2	2	1	1	1	5	2	4	4	4
DR28	Thermophilous dry shrubland	3	4	3	2	4	4	4	4	4	4	2	2	2	3	1	1	1	5	2	3	3	4
DR29	Semidry and dry grassland	4	3	3	2	4	4	4	4	4	4	2	2	2	5	1	1	1	5	5	3	3	4
DR30	Dry forest edges	4	4	3	3	4	4	4	4	4	4	3	4	3	3	1	1	1	5	5	3	3	5
TR31	Forest edges	5	4	4	4	4	4	4	4	5	4	2	4	4	4	1	1	1	5	5	3	3	5
TR32	*Pinus nigra* forests on dry grassland	4	4	3	3	4	5	4	4	4	4	2	4	2	2	1	1	1	5	4	2	2	3
MG33	Species-rich slopes and margins	3	2	3	2	3	4	3	5	5	4	2	1	2	4	1	1	1	5	2	2	2	4
RC34	Rock fragments and dry-stone walls	1	2	2	2	1	1	1	1	4	4	1	1	1	1	1	1	1	5	2	5	5	5
MG35	Species-poor field margins	2	2	2	2	3	3	3	3	3	2	1	1	1	2	1	1	1	3	2	2	1	1
MG36	Ruderal vegetation	2	2	2	2	3	5	3	3	3	2	2	1	1	2	1	1	1	1	3	1	1	2

Table F: Capacity matrix of open land (OL) classes 37-50

OL Code	Open Land Class	**Regulation services**	RS1 Local climate regulation	RS2 Disturbance prevention	RS3 Water regulation	RS4 Water supply	RS5 Soil retention	RS6 Soil formation	RS7 Nutrient regulation	RS8 Pollination	**Habitat services**	HS1 Refugium	HS2 Nursery	**Provision services**	PS1 Food	PS2 Raw materials	PS3 Genetic resources	PS4 Medicinal resources	**Carrier services**	CS1 Cultivation	CS5 Transportation	CS6 Tourism facilities	**Information services**	IS1 Aesthetic Information	IS2 Recreation	IS3 Cultural and artistic info.	IS4 Spiritual and historic info.	IS5 Science and education
CU37	Cultivated field		1	1	2	1	1	2	2	2		2	1		5	1	1	1		5	1	1		2	2	2	2	2
CU38	Vineyard		1	1	2	1	2	2	2	2		2	1		4	2	2	1		4	1	1		5	4	5	5	4
CU39	Intensively managed orchard		2	2	3	2	3	4	2	2		2	1		5	2	1	1		5	1	1		2	1	1	1	1
SB40	Nitrophilous and neophytic edges and woodlets		3	2	4	3	3	5	3	3		3	2		2	2	2	2		1	1	1		3	1	1	1	2
SB41	Hedges and shrubs		3	4	4	3	5	5	5	4		4	4		3	3	2	2		1	1	1		4	1	2	2	4
SB42	Shrubs on moist soil		3	4	4	3	5	5	5	4		4	4		3	3	2	3		1	1	1		3	1	2	2	3
TR43	Long-rotation woodland		4	5	5	4	5	5	5	3		4	4		2	4	2	2		1	1	1		4	2	2	2	3
TR44	Hedgerows dominated by trees		4	5	4	4	5	5	5	4		4	4		2	4	2	2		1	1	1		5	3	2	2	4
TR45	Tree rows and single trees		3	3	3	3	3	3	3	4		4	2		2	2	1	1		1	1	1		5	4	5	5	5
TR46	Larch dominated meadows/pastures		3	4	3	3	5	5	4	4		4	3		2	2	2	3		2	1	1		5	5	5	5	5
TR47	Riparian woodland		5	5	5	5	5	5	5	4		5	5		3	4	3	4		1	1	1		5	4	2	3	4
TR48	Extensive orchards		3	4	3	4	5	5	4	5		5	4		4	3	5	3		4	1	1		5	5	5	5	5
TR49	Short-rotation plantations		3	3	3	2	4	4	4	3		3	3		1	4	2	2		1	1	1		1	1	1	1	1
RC50	Cliffs		1	1	1	1	1	2	1	1		4	3		1	1	1	1		1	1	1		5	4	2	3	4

Table G: Capacity matrix of the open land (OL) classes 51-62

OL Code	Open Land Class	**Regulation services**	RS1 Local climate regulation	RS2 Disturbance prevention	RS3 Water regulation	RS4 Water supply	RS5 Soil retention	RS6 Soil formation	RS7 Nutrient regulation	RS8 Pollination	**Habitat services**	HS1 Refugium	HS2 Nursery	**Provision services**	PS1 Food	PS2 Raw materials	PS3 Genetic resources	PS4 Medicinal resources	**Carrier services**	CS1 Cultivation	CS5 Transportation	CS6 Tourism facilities	**Information services**	IS1 Aesthetic Information	IS2 Recreation	IS3 Cultural and artistic info.	IS4 Spiritual and historic info.	IS5 Science and education
RC51	Active gravel pits and quarries		1	2	2	2	1	1	1	1		1	1		1	5	1	1		1	1	1		1	1	1	1	3
RC52	Abandoned stone quarries		1	2	2	1	1	1	1	1		3	3		1	1	1	1		1	1	1		2	4	3	3	3
RC53	Abandoned gravel pits		1	1	2	1	1	1	1	1		2	2		1	1	1	1		1	1	1		2	4	2	2	2
AR54	Leisure and sport facilities		1	1	1	1	1	1	1	1		1	1		1	1	1	1		1	1	3		3	3	2	1	1
AR55	Lawns		2	1	2	1	2	2	1	1		1	1		1	1	1	1		1	1	1		2	4	1	1	1
GD56	Gardens or parks		3	2	3	1	2	2	2	4		3	3		1	1	1	2		1	1	3		5	3	5	4	3
GD57	Greenery and planting		2	2	2	1	2	2	2	4		3	3		1	1	1	2		1	1	1		4	2	2	2	1
GD58	Cemeteries		2	2	2	1	2	2	2	3		3	3		1	1	1	1		1	1	1		3	4	5	5	3
AR59	Unvegetated open areas with compacted soil including parking areas, storage sites		1	1	2	1	1	1	1	1		2	1		1	1	1	1		1	3	3		1	2	1	1	1
AR60	Paved open areas including parking areas, storage sites		1	1	1	1	1	1	1	1		1	1		1	1	1	1		1	4	4		1	2	1	1	1
AR61	Isolated buildings		1	1	1	1	1	1	1	1		1	1		1	1	1	1		1	1	1		3	2	4	4	3
AR62	Waste sites		1	1	1	1	1	1	1	1		1	1		1	1	1	1		1	1	1		1	1	1	1	1

Table H: Capacity matrix of the Additional Spatial Indicators classes

		Regulation services								**Habitat services**		**Provision services**				**Carrier services**			**Information services**				
Code	**Additional Spatial Indicators**	RS1 Local climate regulation	RS2 Disturbance prevention	RS3 Water regulation	RS4 Water supply	RS5 Soil retention	RS6 Soil formation	RS7 Nutrient regulation	RS8 Pollination	HS1 Refugium	HS2 Nursery	PS1 Food	PS2 Raw materials	PS3 Genetic resources	PS4 Medicinal resources	CS1 Cultivation	CS5 Transportation	CS6 Tourism facilities	IS1 Aesthetic Information	IS2 Recreation	IS3 Cultural and artistic info.	IS4 Spiritual and historic info.	IS5 Science and education
PUT2	Public transport	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1
ROD3	Roads primary	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1
ROD4	Roads secondary	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1
ROD5	Roads tertiary	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1
ROD6	Roads residential	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1
RTR7	Trails	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	3	1	3	1	1	1
ETR8	Trails educational	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	3	1	3	4	3	4
REL9	Religious buildings	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	5	4	5	5	4
REL10	Religious elements	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	2	2	4	3
STA11	Artwork and monuments	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	2	5	4	3
ARC12	Archaeological sites	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	2	2	4	5	5
MUS13	Museums	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	5	5	5	5
CAS14	Castles and ruins	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	5	4	4	5	5
VPS15	Lookout towers and view points	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	3	1	1	1
INF16	Recreational infrastructure	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	3	1	1	1
GST17	Gastronomy	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1
ACC18	Accommodation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1