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Going local – Providing a highly detailed Green Infrastructure geodata set for assessing connectivity and functionality

Abstract

Green Infrastructure (GI) defined as a strategically planned network of natural and semi-natural areas is a key strategy in the European biodiversity strategy and the landscape connectivity agenda. To implement this approach in Central Europe's (CE) landscape planning policies the Interreg project MaGICLandscapes (ML) tried to operationalise the GI concept in CE as well as in nine case studies, to provide land-managers, policy makers and communities with tools and knowledge, at different spatial levels.

Based on the example of the Austrian case study area, the aim of this paper is to present an easy to use approach, as implemented in ML, for producing a highly-detailed regional GI database to overcome the difficulty of realising comprehensive biotope mapping surveys as well as the rather coarse resolution of CORINE Land Cover (CLC). By compiling regional cadastral and agricultural information, highly detailed data on the water network as well as Pan-European High Resolution Layers (HRL), this detailed representation of the regional GI network allows to enhance the regional applicability and acceptance of GI initiatives and provides a crucial foundation for assessing GI connectivity and functionality to develop evidence-based strategies and action plans through stakeholder involvement to direct future actions and investment in GI.

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1 Introduction

1.1 Motivation

Green Infrastructure (GI) as a term and concept is increasingly used among many design-, conservation- and planning-related disciplines. Due to these different application areas, conceptual differences are inherent to the broad approach of GI, depending on the context and spatial level.

When considering GI, the spectrum of elements of Green Infrastructure and scale are as diverse and varied as the involved stakeholders, which is also mirrored in the various definitions of GI, three of which are provided below:

> *"Green Infrastructure can be broadly defined as a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings. More specifically GI, being a spatial structure providing benefits from nature to people, aims to enhance nature's ability to deliver multiple valuable ecosystem goods and services, such as clean air or water."*
>
> European Union (2013)

Furthermore, other sources conclude, that Green Infrastructure…

> *"...includes established green spaces and new sites and should thread through and surround the built environment and connect the urban area to its wider rural hinterland. Consequently, it needs to be delivered at all spatial scales from sub-regional to local neighbourhood levels, accommodating both accessible natural green spaces within local communities and often much larger sites in the urban fringe and wider countryside."*
>
> Natural England (2009)
>
> *"...is 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. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings."*
>
> *BfN - German Federal Agency for Nature Conservation (2017)*

The requirement of incorporating green space elements at the state, regional, community and parcel scales (Benedict and McMahon 2002) emphasises the need for a profound data basis in terms of high spatial and thematic resolution geodata for local implementation of GI.

Recognising these principles, the Interreg Central Europe project Managing Green Infrastructure in Central European Landscapes – MaGICLandscapes (ML) addressed the operationalisation of the GI concept in Central Europe (CE) in general as well as in nine specific case studies, at transnational, regional and local level, providing land-managers, policy makers and communities with the tools and the knowledge they need to ensure the persistence of GI functionality and consequent benefits to society, at different spatial levels.

Among these nine multi-scale and multi-thematic case studies, the Austrian region "Eastern Waldviertel and Western Weinviertel" comprising the Thayatal National Park serves as a testing ground for the trans-disciplinary partner consortium of ML to identify and feedback best practice for assessment, thus creating transnational added value. Therefore, GI assessment methods that focus on functionality in terms of connectivity and provision of landscape services were developed to communicate and facilitate the adoption of those assessment methods by institutions through stakeholder involvement and participatory approaches.

1.2 Goals of the study

This study is primarily addressing the compelling necessity for a highly-detailed regional GI data basis to allow the implementation of the assessment methods and objectives stated above.

EU-wide available land-cover maps, such as CLC, can help in coarse assessments of GI connectivity and functionality, but they cannot provide exact information about the local-scale network of GI elements.

Therefore, more detailed tools like classifications of aerial photographs and field surveys are needed. High-quality biotope data is usually fragmentary or absent for most parts of Austria. We tested the use of a set of various regionally available data sources, such as digital cadastral data, agricultural data derived from the Austrian dataset on the implementation of the EU integrated administration and control system (IACS) and Land Parcel Identification System (LPIS), regional data on the waterways network and products of the Pan-European High Resolution Layers (HRL) to overcome the difficulty of realising comprehensive biotope mapping surveys as well as the rather coarse resolution of CLC. In this article, the Austrian case study area "Eastern Waldviertel and Western Weinviertel" will be used as a test area for applied GI mapping and further analysis of pattern, connectivity and functionality. This approach is applicable to the whole of Austria and could be adopted in a similar way to other regions owing to the availability of similar kinds of data sources. Thereby, we will

I. show how suitable highly-detailed regional GI data is for GI analysis, mapping and participatory processes to implement the concept of GI regionally, compared with other available data sets (such as CLC);
II. evaluate the improvements of highly-detailed regional GI data by comparing example sections of a landscape;
III. demonstrate the different results by a comparison of outputs of morphological spatial pattern analysis (MSPA).

2 Materials and Methods

2.1 Study area

Our Austrian case study area (CSA) "Eastern Waldviertel and Western Weinviertel" is located in north-east Austria and consists of parts of the Lower Austrian regions Waldviertel and Weinviertel (Figure 1), which border the Czech Republic. The Waldviertel part of the CSA in the west is shaped by the highlands of a shallow gneiss landscape and the river Thaya, which has carved characteristic canyons there. Due to the combination of loamy, clayey sediments and loess deposits this region is more fertile than other parts of the area and is therefore characterised by agriculture and forestry. The previously predominant wet meadows were drained and improved a long time ago, so that they are almost non-existent nowadays. The remaining meadow lands are mainly improved meadows dominated by foxtail grass (*Alopecurus pratensis*), tall oatgrass (*Arrhenatherum elatius*) or golden oat grass (*Trisetum flavescens*). Apart from the area of the Thayatal National Park, large sections of the forests in the Waldviertel part of the CSA are characterised by intermixed spruce mono-cultures with intensive forestry.

On the other hand, the Weinviertel part of the CSA in the east is characterised by wide open valleys and molasse sediments with rolling hills. The border between these two regions is formed by the Manhartsberg – a gneissic rock ridge – which constitutes the point of highest altitude in the Western Weinviertel. Due to the lack of rainfall there are no distinctive stream networks in the region. With a total annual precipitation between 450 and 600 mm, the Western Weinviertel represents one of the driest parts of Austria. Here, less meadows and wetlands - comprising an area of 1,238 ha respectively an area segment of 1.19% - can be found when compared to the Eastern Waldviertel, where meadows and wetlands cover 2,514 ha or 3.21% of the subregion. Due to the Pannonian climate and the loess soil this region was predestined for viticulture, in fact Weinviertel translates to "wine quarter" in English and the area is Austria's biggest wine growing region. The Western Weinviertel is dominated by intense agricultural use. River regulation and drainage associated with arable farming has meant that much of the previously widespread wet meadows and waterlogged habitats have been lost. On steeper hillsides and knolls the landscape becomes more structured with viticulture interspersed by patches of dry and xeric grassland as well as heathland. At slightly higher elevations warm temperate oak forest can be found. The vegetation in this area is unique and differs from the more westerly parts of Austria. Here, not only Pannonian species but also species which are usually widespread much further to the east can be found, representing the western limit of their distribution.

Climatically, the transition from the humid Atlantic climate dominating the highlands of the Waldviertel to the dry Pannonian climate of the Weinviertel is characteristic of the region.

Data Source:
Nomenclature of Territorial Units for Statistics (NUTS) 2016,
European Statistical Office (Eurostat)

Figure 1. Location of the Austrian case study area within the Interreg Central Europe Programme Area

2.2 Green Infrastructure in Austrian national/ regional law and policy

Green Infrastructure as a precise subject has not yet been established in the Austrian legislation. Nonetheless, legal matter referring to elements of Green Infrastructure appears in different national and regional jurisdiction. In Austria, most of the legislation regarding nature and landscape conservation, etc. lies within the responsibility of the federal states.

The only documents directly referring to GI are the Biodiversity Strategy Austria 2020+/Biodiversitäts-Strategie Österreich 2020+ (BMLFUW - Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management 2014) and the Lower Austrian Nature Protection Concept/Naturschutzkonzept Niederösterreich (Office of the Federal Government of Lower Austria 2015).

The Biodiversity Strategy Austria 2020+ is the national implementation of the EU 2020 Biodiversity Strategy and deals with the issues of the preservation of species and habitats as well as the support of biodiversity and ecosystem services by biotope networks and consequently (elements of) Green Infrastructure.

The Biodiversity Strategy Austria 2020+ aims to preserve the diversity of life in Austria, to slow down the loss of species, genetic diversity and habitats, and to minimise the sources of threats. With regard to GI the following targets are defined:

- Target 10: Establishment of a valuable, functional biotope network by acceleration and support of voluntary measures to create a biotope network as well as enhancement of biotope networks by
  - improving the quality of relevant areas and structural elements
- Target 11: Priority areas for ecological functions (Green Infrastructure) are considered or identified in local and regional spatial planning as well as the significant increase in ecological permeability in higher-ranking traffic routes by
  - regional planning of wildlife corridors/habitat networking axes/Green Infrastructure
  - identification of areas with increased need for Green Infrastructure and consideration in planning of different levels and sectors, such as zoning, regional planning, overall transport scheme and therefore coordinated establishment of green bridges and tunnels
  - development of nationwide strategies for habitat networking

In addition, the Lower Austrian Nature Protection Concept published in 2011 divides Lower Austria into several regions based on its natural landscape types and provides the basis for nature conservation in these regions. In 2015, the topic area “Green Infrastructure – wildlife corridors – habitat connectivity” has been added and aims to implement the targets of the Biodiversity Strategy Austria 2020+ at the state level.

2.3 Green Infrastructure definition

As already described in the introduction, in addition to the conceptual differences, the definition of GI is very much dependant on the context as well as the spatial level of implementation. Following the objectives and ideas of MaGICLandscapes, that of an integrated, cross-sectoral approach employing stakeholder involvement and participatory processes, our consortium defined an expert based classification of GI based on CLC classes for the whole of Central Europe as a first step, followed by a round of stakeholder validation in the form of workshops in the case study areas to adapt the definition regionally. Based on regional characteristics as well as the thematic resolution of local geodata, which was used to improve the CORINE Land Cover basic dataset, land use classes defined as "Green Infrastructure under specific circumstances or partly GI" on the CE level were assigned to the classes "Green Infrastructure" or "Not Green Infrastructure" unambiguously for the case study areas (Table 1).

2.4 GIS data sets and methods

Starting from the common, comparable data base of CLC, MaGICLandscapes partners supplemented individual geographic information system (GIS) projects by available national and regional data. For the Austrian case study this was obtained by compiling the following data sets:

- Copernicus High Resolution Layers (HRLs): High Resolution Layer - Forest Types (FTY) 2015, European Environmental Agency (EEA)
- Agricultural data of the Integrated Administration and Control System (IACS) and Land Parcel Identification System (LPIS): INVEKOS Schläge Österreich 2018, Agrarmarkt Austria (AMA)
- Digital cadastral data: Digitale Katastralmappe (DKM) 2018, Federal Office of Metrology and Surveying (BEV)
- Regional waterways network: Gesamtgewässernetz (GGN) 2014, Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW)

These data sets are available for the whole of Austria, but will most likely also exist in a similar form for other regions. The data sets were aggregated and reclassified according to the land cover classes of CORINE Land Cover using various GIS-based tools and sequenced according to their thematic coverage in order to obtain an accurate description of the local land cover.

Table 1. The applied Green Infrastructure definition based on the Central European consortium was regionally adapted to represent local characteristics adequately using CORINE Land Cover classes.

Green Infrastructure	
CLC code	*CLC description*
141	Green urban areas
231	Pastures
242	Complex cultivation patterns
243	Land principally occupied by agriculture, with significant areas of natural vegetation
244	Agro-forestry areas
311	Broad-leaved forest
312	Coniferous forest
313	Mixed forest
321	Natural grasslands
324	Transitional woodland-shrub
333	Sparsely vegetated areas
411	Inland marshes
511	Water courses
512	Water bodies
Green Infrastructure under specific circumstances or partly GI	
CLC code	*CLC description*
112	Discontinuous urban fabric[2]
122	Road and rail networks and associated land[2]
131	Mineral extraction sites[2]
142	Sport and leisure facilities[1]
211	Non-irrigated arable land[2]
221	Vineyards[1]
222	Fruit trees and berry plantations[1]
Not Green Infrastructure	
CLC code	*CLC description*
111	Continuous urban fabric
121	Industrial or commercial units

[1] assigned to GI regionally for the Austrian CSA

[2] assigned to "Not Green Infrastructure" regionally for the analysis of geometry and connectivity

2.5 Analysis of geometry and connectivity of GI

To evaluate the shape, connectivity and spatial arrangement of GI within the regionalised GI dataset and the CORINE Land Cover data, the Morphological Spatial Pattern Analysis (MSPA) as well as other types of analysis modules of GuidosToolbox were applied. GuidosToolbox is a free software collection by the Joint Research Centre of the European Commission and offers a variety of modules targeted to investigate several spatial aspects of raster image objects.

The MSPA is a generic and universal pattern analysis framework provided by a custom sequence of morphological operators (Soille and Vogt 2009). MSPA performs a segmentation on a binary image to identify and localise mutually exclusive morphometric feature classes describing the shape, connectivity and spatial arrangement of image objects by mapping and classifying them into categories (Vogt et al. 2017). The MSPA module automatically detects geometry and connectivity of the image components. Hence, the foreground area of a raster based binary image is partitioned into seven MSPA classes: Core, Islet, Perforation, Edge, Loop, Bridge, and Branch.

In terms of the assessment of Green Infrastructure connectivity, MSPA uses a series of image processing routines to identify hubs, links, and other features after reclassifying the raster land-cover map into foreground (GI) and background (all other classes) (Vogt et al. 2007). To align the terminology of GI, the category of core is equivalent to a hub, and bridge is synonymous to a link (corridor). First, the MSPA processing identifies the category core which is based on the connectivity rule used to define neighbours and the value used to define edge width (Soille and Vogt 2009).

In the basic settings of MSPA connectivity can be set to either four (cardinal directions only) or eight neighbours. The minimum size of core and the number of pixels classified as core is affected by the settings of the edge width. By increasing the edge width, the minimum size of core increases and thereby reduces the number of pixels defined as core areas. The decrease of core areas that results from increasing edge width arise in gains for all other classes, not just for edge class. By increasing the edge width it can shift core to islet if the area of core is small and core to bridge if the area of core is narrow (Wickham et al. 2010).

Since the application of MSPA is sensitive to changes of scale as defined by the pixel size and the MSPA size parameter, it is crucial to use the highest possible spatial resolution of the input data and applying the smallest possible MSPA size parameter to obtain the maximum structural detail of landscape objects (Ostapowicz et al. 2008).

To ideally represent the concept of GI and its comprehensive network, based on a pixel size of five metres, eight-neighbour connectivity and size parameter of four were used resulting in 20 metres of edge width in the application of MSPA in MaGICLandscapes. According to the regionalised definition of GI (Table 1) the input maps were reclassified regarding the data classes Foreground (Green Infrastructure including classes indicated by [1]) and Background (Not Green Infrastructure including classes indicated by [2]).

3 Results

3.1 Mapping of regionalised GI geodata versus CLC data

The use of detailed regionalised GI geodata revealed differences in the representation of a landscapes' structure and fragmentation as well as land use patterns and landscape features (Figures 2 and 3). The Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena of CORINE Land Cover and the associated generalisation of landscape, small-scale structures and complex landscape formations did not allow for realistic mapping.

When comparing detail sections of both map products, the aforementioned differences are even more apparent (Figures 4 and 5). The regionalised geodata set shows much more detail in the actual fragmentation but also excessive branching of the GI network. What appeared to be large coherent areas, such as vineyards or urban fabric for example at the CLC scale, are partially highly fragmented cultural landscapes. In contrast to this, areas where large-scale arable land seemed to be nearly featureless and free of elements of GI, interspersed island-like elements like woodlots, shelter belts and water bodies became more visible.

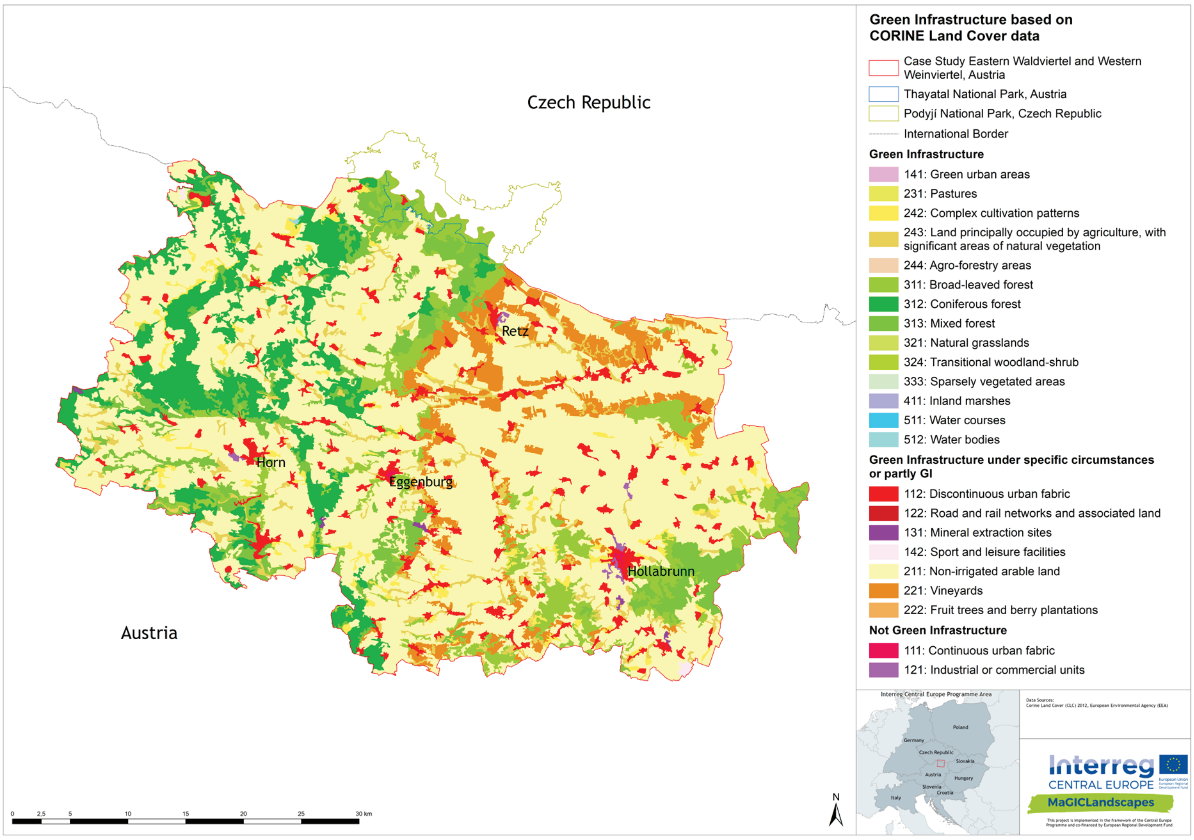

Figure 2. Map of Green Infrastructure of the Austrian case study based on CORINE Land Cover data

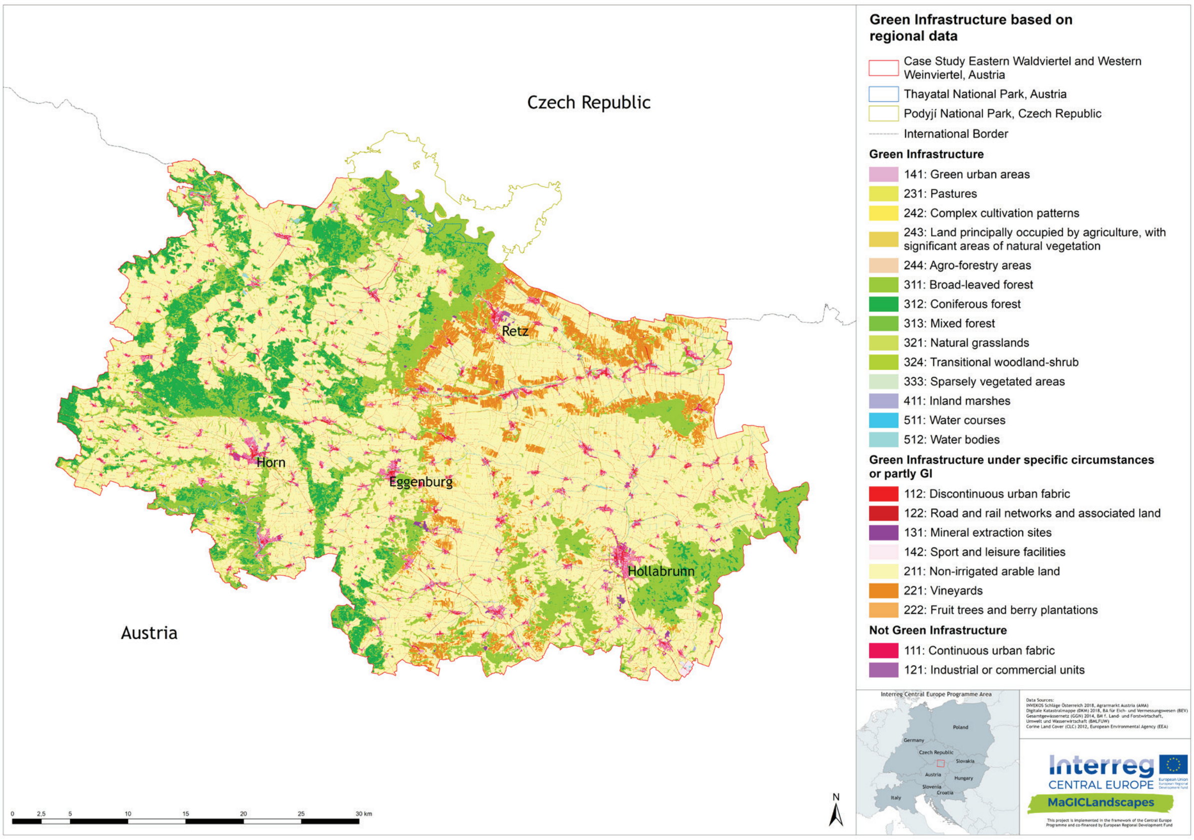

Figure 3. Map of Green Infrastructure of the Austrian case study based on regional geodata

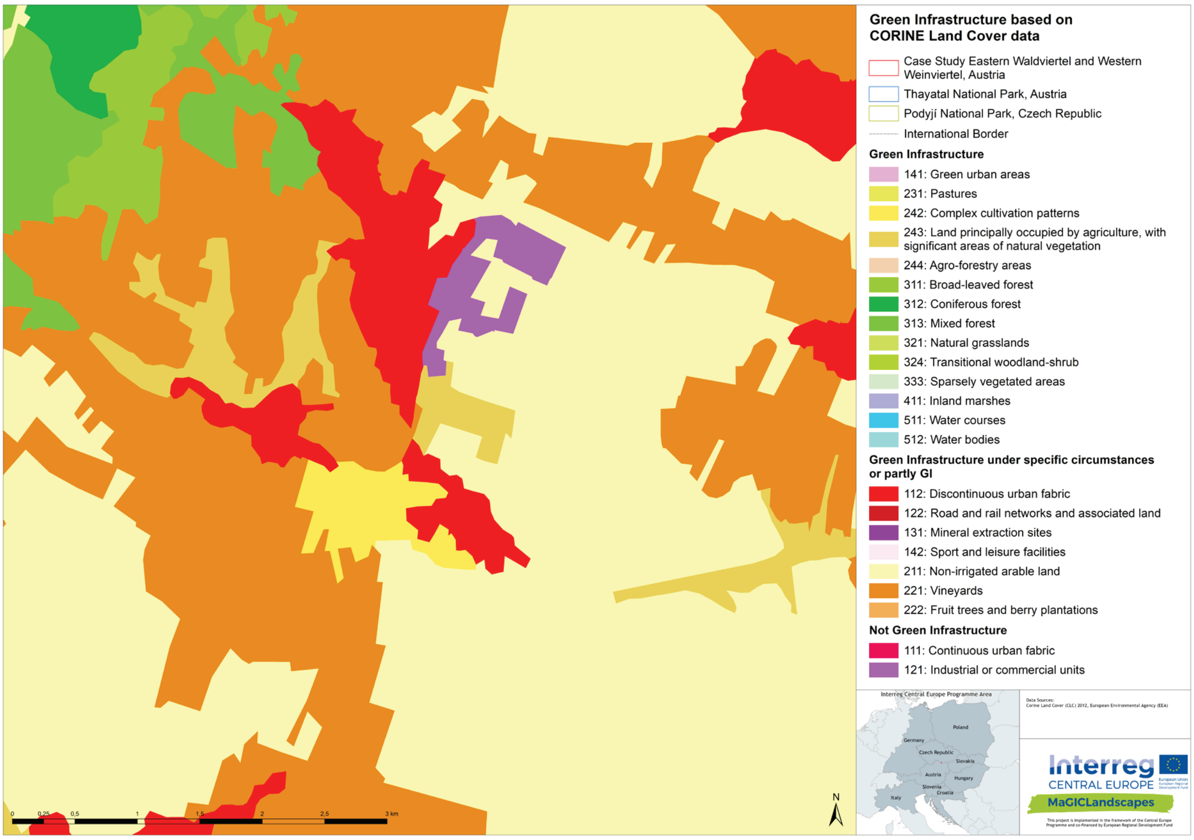

Figure 4. Exemplary detail section map of Green Infrastructure based on CORINE Land Cover data

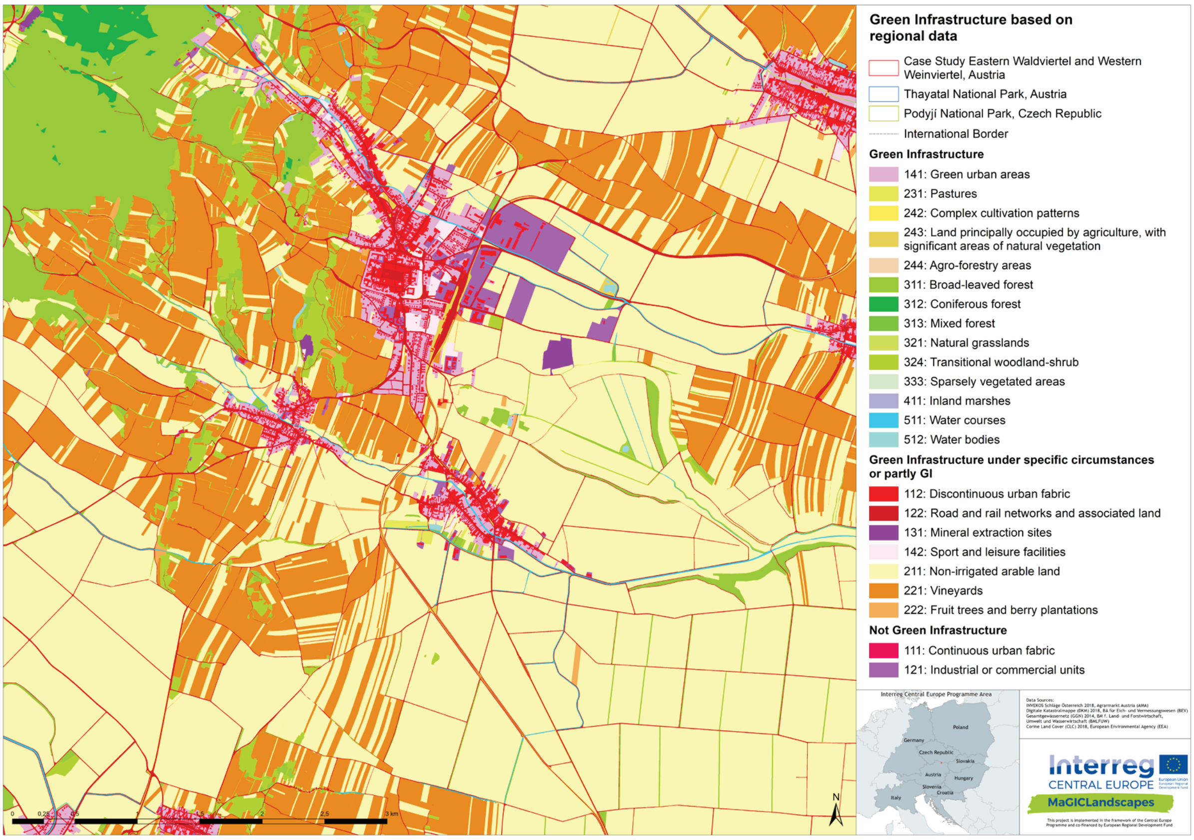

Figure 5. Exemplary detail section map of Green Infrastructure based on regional geodata

3.2 Comparison of land area shares of regional GI geodata versus CLC data

When comparing the land area shares, the above-mentioned differences in the representation of land cover and the case study area's landscape composition are evident (Table 2). While the enhanced thematic resolution is indicated by providing 19 instead of just 15 different land cover classes in the regionalised geodata set, also the actual area ratio based on the clustered Green Infrastructure definition shows an overestimation in the provision of GI respectively an underestimation of the group "Not Green Infrastructure", when assessing CLC data. This over- and underestimation based on the generalisation of landscape by CLC is also reflected when comparing individual CLC classes and analysing outliers. The discrepancies in the class of "311 Broad-leaved forest", for example, with a total of 13,419.61 ha in the CLC data set versus 29,519.49 ha regionalised geodata set, representing an 8.97% difference in the area of the case study area, can be explained by the complete absence of small

Table 2. Comparison of land area shares in the case study area based on CORINE Land Cover data and regionalised geodata set.

		CORINE Land Cover data		**Regionalised geodata set**		**Difference**
		Total area (ha)	*Percentage of the study area (%)*	*Total area (ha)*	*Percentage of the study area (%)*	*Percentage of the study area (%)*
Green Infrastructure		66,224.08	36.9	63,376.01	35.31	**-1.59**
Code	*CLC description*					
141	Green urban areas	0.00	0.00	3,385.55	1.89	**1.89**
142	Sport and leisure facilities1	148.55	0.08	454.65	0.25	0.17
221	Vineyards1	11,329.77	6.31	8,323.80	4.64	**-1.67**
222	Fruit trees and berry plantations1	0.00	0.00	414.26	0.23	0.23
231	Pastures	69.49	0.04	2,420.31	1.35	1.31
242	Complex cultivation patterns	3,999.15	2.23	0.00	0.00	**-2.23**
243	Land principally occupied by agriculture. with significant areas of natural vegetation	7,262.79	4.05	1,227.64	0.68	**-3.37**
244	Agro-forestry areas	0.00	0.00	47.17	0.03	0.03
311	Broad-leaved forest	13,419.61	7.48	29,519.49	16.45	**8.97**
312	Coniferous forest	17,402.25	9.69	14,428.50	8.04	-1.65
313	Mixed forest	12,386.24	6.90	0.00	0.00	**-6.9**
321	Natural grasslands	0.00	0.00	0.00	0.00	0
324	Transitional woodland-shrub	174.02	0.10	1,818.63	1.01	0.91
333	Sparsely vegetated areas	0.00	0.00	4.42	0.00	0
411	Inland marshes	0.00	0.00	18.17	0.01	0.01
511	Water courses	0.00	0.00	1,073.24	0.60	0.6
512	Water bodies	32.21	0.02	240.20	0.13	0.11
Not Green Infrastructure		113,276.76	63.1	116,124.83	64.69	**1.59**
Code	*CLC description*					
111	Continuous urban fabric	89.73	0.05	0.00	0.00	-0.05
112	Discontinuous urban fabric	8,509.29	4.74	1,877.04	1.04	**-3.7**
121	Industrial or commercial units	311.06	0.17	767.44	0.43	0.26
122	Road and rail networks and associated land	0.00	0.00	5,430.43	3.02	**3.02**
131	Mineral extraction sites	177.60	0.10	195.56	0.11	0.01
211	Non-irrigated arable land	104,189.08	58.04	107,854.35	60.09	**2.05**

woodlots, copses, hedges, riparian woods and strips for example as well as field trees due to the large Minimum Mapping Unit of the CLC dataset.

On the one hand, due to the high spatial resolution of the Copernicus High Resolution Layer product Forest Types (FTY) 2015, differentiating between broad-leaved and coniferous trees based on the dominant leaf type at small-scale, the class “313 Mixed forest” is not represented in the enriched regional geodata set. On the other hand, the class “122 Road and rail networks and associated land” is not present in the CLC data set, due to its comparatively small and very detailed formation. Yet, roads, parking spaces and other sealed traffic surfaces constitute about 3.02% of the area of the regionalised geodata set.

In contrast, the agricultural data of the INVEKOS dataset and the detailed crop data contained therein, allowed for a much better, more realistic allocation of agricultural land especially for the classes “221 Vineyards”, “242 Complex cultivation patterns”, “243 Land principally occupied by agriculture, with significant areas of natural vegetation” and “211 Non-irrigated arable land”.

Finally, the regionalised geodata set also offers a highly differentiated representation of urban and rural settlement areas, which becomes evident by considering the notable differences in the land area balance of the classes “141 Green urban areas”, “112 Discontinuous urban fabric” and “122 Road and rail networks and associated land” as well as the visual comparison (Figures 4 and 5).

3.3 Comparison of geometry and connectivity of GI

When evaluating the shape, connectivity and spatial arrangement of GI elements by applying MSPA and analysing the image components represented by the MSPA classes, the different levels of detail of the compared map products become apparent (Table 3).

Due to the associated generalisation inherent in CORINE Land Cover, the class core for example, which constitutes interior areas of GI and comprises about 33% of the case study area in total and almost 90% of the GI elements, is represented by only 392 individual coherent elements. The difference is clearly noticeable when comparing to the regionalised data, where core accounts for only about 23% of the total area and nearly 66% of GI, but consists of a much larger number of single continuous components, 11,604, over 29 times the amount. The strongest differences appear in the detection of branches, which represent discontinuous extensions of GI, and islets, which represent disjointed elements of GI too small to contain cores. A total number of 4,487 branches and 21 islets, when analysing the CORINE Land Cover data, contrasts greatly with 62,028 and 43,425 self-contained elements respectively, when analysing the regionalised geodata set.

Table 3. Comparison of results of MSPA in the case study area based on CORINE Land Cover data and regionalised geodata set.

	CORINE Land Cover data			**Regionalised geodata set**			**Difference**		
MSPA class	*Percentage of the study area (%)*	*Percentage of GI (%)*	*Total number of coherent elements*	*Percentage of the study area (%)*	*Percentage of GI (%)*	*Total number of coherent elements*	*Percentage of the study area (%)*	*Percentage of GI (%)*	*Total number of coherent elements*
Core	**33.04**	89.53	392	23.3	65.99	11,604	-9.74	**-23.54**	**11,212**
Islet	*0.00*	0.00	21	1.72	4.88	43,425	1.72	4.88	**43,404**
Perforation	0.30	0.82	28	0.14	0.39	395	-0.16	-0.43	367
Edge	3.42	9.28	252	7.3	20.68	7,869	3.88	11.4	7,617
Loop	0.00	0.00	8	0.45	1.28	6,048	0.45	1.28	6,040
Bridge	0.01	0.04	119	1.25	3.55	12,822	1.24	3.51	12,703
Branch	0.12	0.33	4,487	1.14	3.23	62,028	1.02	2.9	**57,541**
Background (not GI)	63.10		120	64.69		66,648	1.59		66,528

4 Discussion

4.1 Suitability of datasets for GI mapping

The use of the highly detailed geodata set revealed differences in the realistic representation of landscapes' provision with a comprehensive and finely spun network of GI. On the one hand, due to the classification and generalisation inherent in CORINE Land Cover data, the extent of fragmentation is distinctly underrepresented in large continuous areas and elements of GI, like woods or vineyards. On the other hand, apparently featureless areas of e.g. arable land or urban fabric are greatly underrated in terms of their provision of GI, landscape features as well as linear and punctiform elements. Therefore, the regionalised geodata set enhanced the evaluation of the GI network in natural and semi-natural areas as well as in rural and urban settings, which allows the operationalisation of the GI concept locally in the first place. Still, the availability and thus, comparability in most European countries is one major benefit of the CLC classification.

We argue that by using regionalised highly detailed geodata, the mapping quality of GI can be enhanced for all types of landscapes and constitutes a precondition to develop stakeholder-based strategies and action plans for future actions and investment in GI. The present methodology to compile local datasets allows to address the local network of GI precisely in the specific field of action of land-managers, policy-makers and communities. This way, MaGICLandscapes exemplarily encouraged an association of local authorities and an additional municipality in the Austrian case study area to implement the GI concept as an informal aid for spatial planning. This was achieved by producing customised local GI maps at the community level highlighting the local needs and opportunities for GI and providing information to support decision-making on where to invest in GI.

Furthermore, this dataset provides an ideal basis to enhance the specific analyses of connectivity, by an additional assessment of functionality in terms of provision of landscape services (De Groot et al. 2002, 2006 and 2010), which was conducted in MaGICLandscapes subsequently, but will not be considered in detail here. In comparison to ecosystem services, landscape services focus more on spatial patterns, resulting from human and natural processes, as well as social dimensions (Vallés-Planells et al. 2014). This makes the broader concept of landscape services better applicable and thus is commonly used in landscape planning. Hence, potential points of conflict can be revealed beforehand by clearly mapping out synergies among various stakeholders and institutions operating in the region, as well as the spatial comparison in the provision of ecosystem services, respectively landscape services in our case, on which they depend (Vihervaara et al. 2010). This could help to consider cross-sectoral policy and planning objectives and avoid inappropriate and unsustainable land use planning.

As an alternative to the approach discussed here, similar detailed datasets could be produced by using multi-spectral, high-resolution remote sensing data, since the acquisition is not necessarily slow or costly nowadays. Together with LiDAR data (Digital Elevation Models, DEM and Digital Surface Model, DSM), satellite imageries are available below 0.5 m resolution and can be used for forest habitat delineation, for example, delineation of age structures based on tree heights (Vihervaara et al. 2012) as well as various other elements of GI.

This approach could be further improved by taking biodiversity into account, using additional data layers derived from biotope mapping surveys. In the present case study area, relevant resources are not freely accessible to third parties by legal means and therefore could not be used.

4.2 Representation of geometry and connectivity of GI

When analysing and comparing shape, connectivity and spatial arrangement of GI, using GuidosToolbox' MSPA, of the CLC and regionalised dataset, the underlying differences in spatial resolution were particularly pronounced. This could be shown when contrasting the area shares of the resulting partitioned MSPA classes in total, the total number of coherent elements and regarding the composition of GI. The detection of GI or rather the differentiation of land cover between GI and non-GI stands out as well, resulting in an increase of 1.59% of GI elements in relation to the entire case study area starting from the analysis of the CLC dataset. This is reflected in the substantial reduction in the amount of large, coherent cores of GI as well as an increase of islets, bridges, and branches and hence also by edges associated with rather small elements of GI.

The total number of individual MSPA elements of 5,427 in the CLC dataset versus 210,839 in regionalised geodata illustrates the difference more clearly, indicating that the case study area is more affected by landscape fragmentation, but also provides a high number of stepping stones represented by small-scale structures and landscape features, which do not appear in the CLC dataset.

In view of the current situation of wild areas and semi-natural habitats becoming scarcer, especially in industrialised countries, upstream protection strategies, which identify and protect the land, or in this case rather critical GI, which must not be lost if we wish to maintain viable species populations and ecological corridors to allow the necessary mobility to their survival, need to be implemented (Bergès et al. 2020).

Through the ongoing conversion of land, it is fragmented into isolated patches of open space, substantially changing the functions of its natural systems by increasing edge habitats and isolating patches, reducing the number and diversity of native species (Benedict and McMahon 2002). With regard to the 1970s approach of ‘ecological networks’ and the proposed creation of corridors and stepping stones for the dispersal and migration of species between core areas in addition to the restoration of habitats, as a further development beyond simply protecting important wildlife sites, these small-scale structures and landscape features reduce isolation and improve the coherence of natural systems (Benedict and McMahon 2012).

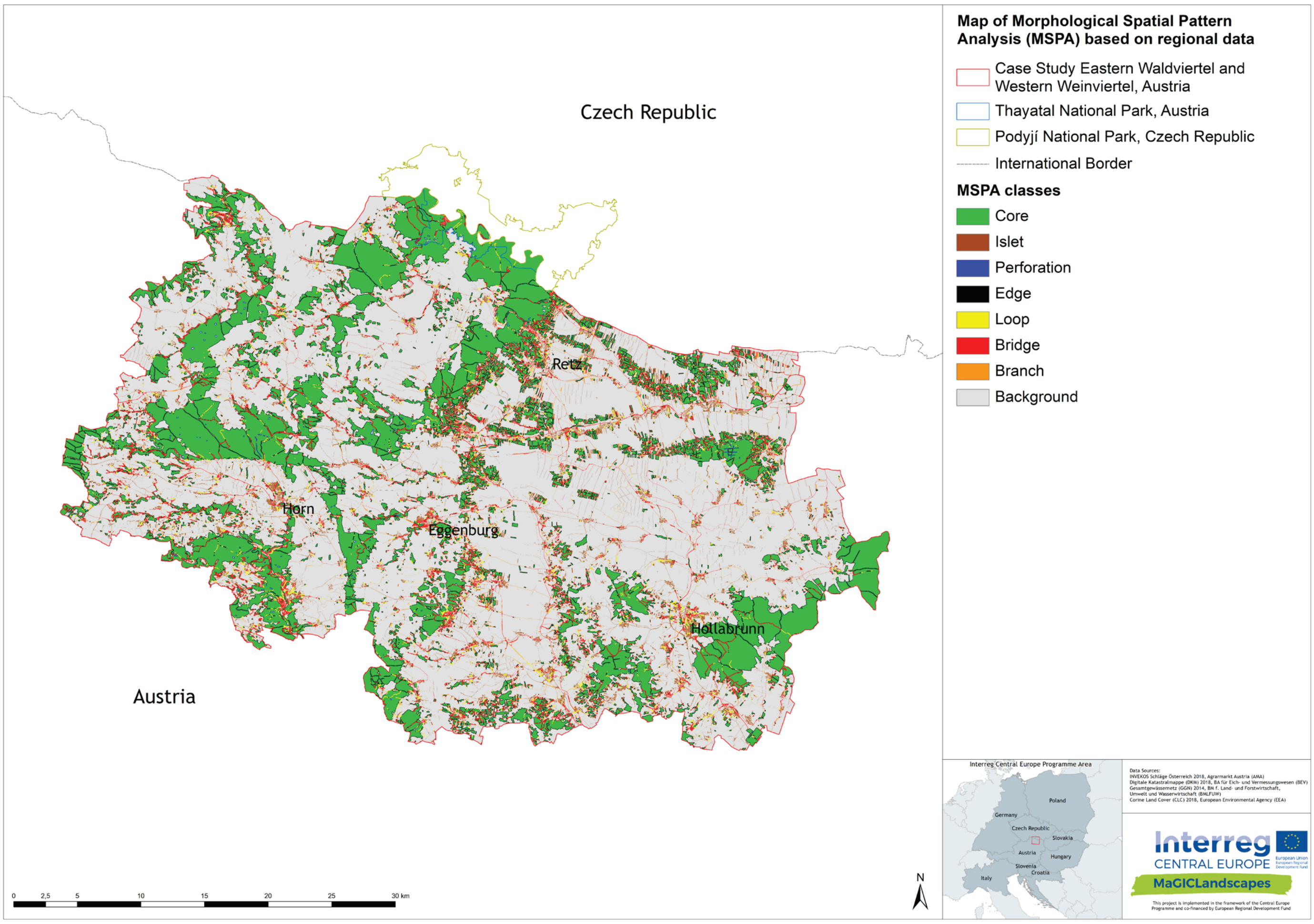

Figure 6. Map of Morphological Spatial Pattern Analysis (MSPA) of GI in the Austrian case study based on regionalised geodata

However, if these indicators are to be meaningful, they must give a sufficiently accurate picture of the actual state in a certain region to meet these challenges and counteract negative developments. The proposed method for providing a highly detailed Green Infrastructure geodata set offers spatially explicit information allowing for the highlighting of hotspots of highly fragmented areas or those dominated by well-established GI networks. Additionally, the simple, yet intuitive analysis scheme of the MSPA and other analysis schemes of the GuidosToolbox are easy to communicate and can be related to a variety of spatial planning measures by illustrating the degree of fragmentation or intactness and allowing direct comparisons with results among the case study areas (Figure 6).

For instance, the analysis methodology of Euclidean Distance, which was conducted in MaGICLandscapes in addition to the MSPA, offers a practical and effective method of implementation. The module of Euclidean Distance analysis scheme is also available in GuidosToolbox and uses the same input data as the MSPA described above. This application creates maps of objects of interest showing the Euclidean distance inside and outside those objects (Figure 7). To illustrate the influence zones of each object and to derive the pairwise proximity between neighbouring image objects, this type of analysis may be further pursued. For the establishment of cost-efficient reconnecting corridors in restoration planning proximity may be used to locate close encounters of existing objects (Vogt and Riitters 2017). The spatial information of these distance maps of GI in combination with the results of the MSPA may be of high importance for monitoring, planning and risk assessment.

As for land use planning, in addition to the proximity of public and private land parcels to the existing network of GI, especially those with high values for GI with regard to species' distribution, landscape struc-

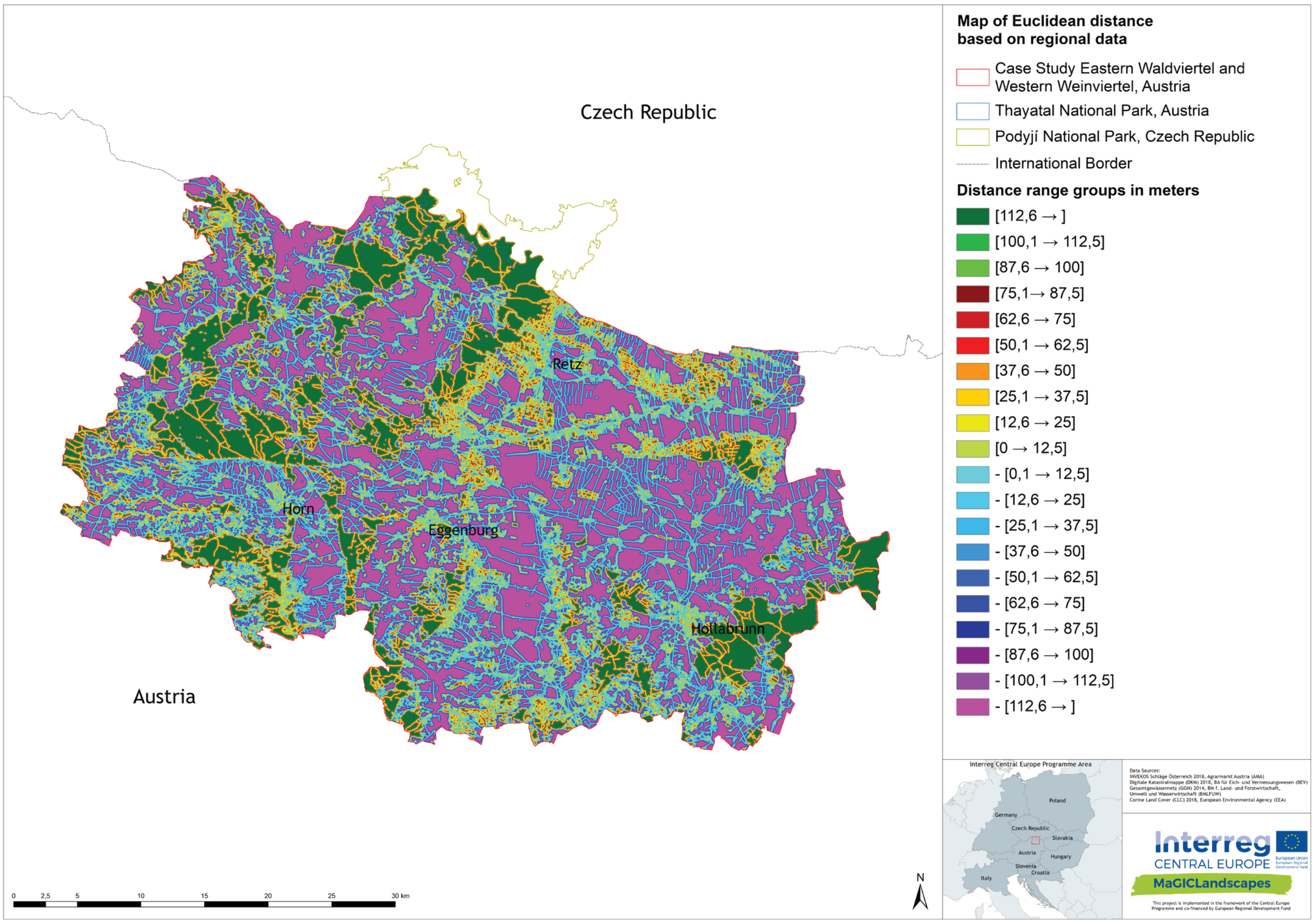

Figure 7. Map of Euclidean distance of GI in the Austrian case study based on regionalised geodata

tures and networks as well as ecosystem services, may require specific incentives to maintain their desirable characteristics, as they are more likely to be degraded than areas with more building restrictions (Honeck et al. 2020).

By using regionalised geodata, the importance of the highly complex and substantially-greened urban as well as rural settlement areas could be highlighted. In particular green urban areas, such as parks, public and private gardens, and street trees, complement the network of GI substantially and therefore underline the urgent need to implement the GI concept as an informal aid for spatial planning and not to forget urban planning. Moreover, it has been shown that the integration of high-density urban landscape nodes into the network of GI will not only promote the protection of the ecological diversity of green spaces around the city and the health of the ecosystem, but will also be beneficial to the health and service capabilities of green space within the city (Huang et al. 2020).

In this respect, the real dimension of transport infrastructure in the case study area could be demonstrated by using regionalised geodata, which on the one hand could serve as a proxy for the fragmentation of the GI network, on the other hand indicates potential sites for the greening of so-called Grey Infrastructure. Therefore, road verges constitute a substantial opportunity to mitigate the negative ecological effects of roads and to address demand for ecosystem services in urban and agricultural landscapes (Phillips et al. 2020), the same might also apply to railway embankments and other land associated with transport infrastructure. If those areas were strategically designed and managed for environmental outcomes, namely by optimising the selection, position and management of plant species and habitats, their capacity to provide ecosystem services might be enhanced considerably (Phillips et al. 2020).

In contrast, rural agricultural landscapes, representing the dominant type of landscape of the case study area presented here, are facing different challenges to the implementation of a well-connected and functional GI. In these intensively farmed arable-land matrices elements of GI are very often limited to linear structures and are therefore particularly important linking elements, hence crucial to the GI network. Whilst at the same time GI improves the overall environmental resilience of farmed landscapes towards climate change and extreme environmental events (Tóth 2016).

With regard to the interconnectedness of such agricultural landscapes it is recognised that connectivity depends not only on the distance between habitat patches, but also on the presence of corridors and stepping stones and on the resistance of the surrounding matrix (Moilanen and Hanski 1998; Ricketts 2001). In the mosaic of crops and uncultivated patches those corridors and stepping stones are represented, inter alia, by woodlots, orchards, shelter belts, ditches, field margins, heathland, wetlands and hedgerows.

To improve GI and its benefits to rural agricultural landscapes these detected linkages and buffer zones call for active management with respect to landscape connectivity criteria, by creating positive synergies between instruments for nature conservation and sectoral policies. Thus, also the appropriate management of agricultural and forestry holdings within this network is fundamental, given that they cover and often maintain large parts of the GI in farmed landscapes (Gurrutxaga et al. 2010).

Therefore, we strongly argue for the production of customised local GI maps on community level to highlight the local needs and opportunities for GI and to provide decision support for investment in GI, since the visualisation of priority conservation areas in a spatially explicit manner could support decision-makers to optimally allocate limited resources for ecosystem preservation (Honeck et al. 2020).

5 Conclusions

In this article, the use of detailed regionalised geodata for mapping GI in Austria has been presented, using the case study area “Eastern Waldviertel and Western Weinviertel” comprising the Thayatal National Park as an example. This approach could be adopted all over Europe, owing to the availability of similar kinds of detailed datasets (e.g. agricultural, digital cadastral and hydrographical data).

Three results can be summarised: Firstly, the mapping approach and methodology based on detailed regionalised data sets can be used for comparing distribution and fragmentation of GI. Secondly, even though the main point of this article was not to make a full assessment of connectivity and pattern of GI, the results showed that elements of GI, especially small-scale structures and landscape features representing islets, bridges and branches could be displayed considerably better than by using data from CORINE Land Cover. Finally, the regionalised GI map and its various analysis products can be related to a variety of spatial planning measures, enabling politicians, planners, land users/managers and communities to invest in GI by highlighting hotspots of highly fragmented areas or those dominated by well-established networks of GI.

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