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Territorial System of Ecological Stability as a regional example for Green Infrastructure planning in the Czech Republic

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Abstract

The concept of Green Infrastructure (GI) is still relatively new in the Czech Republic. When looking at the definition of GI, one can recognise a relationship with the Czech Territorial System of Ecological Stability (TSES), which is defined as "an interconnected system of natural as well as modified semi-natural ecosystems keeping the natural balance". TSES is a designed system and is an integral part of territorial plans. This article focuses on TSES and its relationship to GI, how it is implemented in a Czech case study representing intensively used agricultural region in South Moravia, what the main obstacles are to its implementation and how TSES can contribute to the connectivity of the landscape. Our results show that nearly two thirds of the planned TSES in the case study area already exist to some degree. There is a difference between the number and the area of existing TSES elements: the area of existing elements shows higher relative values than the number. This is mainly due to bio-centres that exist in large forest complexes and their pre-set minimal parameters. Creation of TSES elements increases connectivity of GI, especially those characterised as core areas and bridges.

Keywords:
Green Infrastructure, Territorial System of Ecological Stability, connectivity, Czech Republic, South Moravia

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1 Introduction

The concept of Green Infrastructure (GI) has gained more attention worldwide in the last decade, although it has already been known especially among planners in America since 1990s (Benedict and McMahon 2002). The concept considers natural systems important to achieve both economic and social well-being in the same way as man-made/artificial infrastructure, so called Grey Infrastructure (da Silva and Wheeler 2017), often at a lower cost and with additional benefits. GI aims to foster connectivity between natural and semi-natural habitats, thus making the landscape more permeable for migrating species while simultaneously enabling sustainable land use and planning (Schmidt and Hauck 2018).

The spread of the GI concept in European countries gained momentum with the EC report "Green Infrastructure – Enhancing Europe's Natural Capital" (European Commission 2013a) and its "Technical Information on Green Infrastructure" (European Commission 2013b). GI is researched mainly in urban areas (e.g. Ioja et al. 2018, Gradinaru and Hersperger 2019, Hansen et al. 2019) where it can be seen as a way to conceptualise connected greenspace (Davies and Lafortezza 2017), combat climate change manifestations (Emmanuel and Loconsole 2015, De la Sota et al. 2019) or even control urban sprawl (Gavrilidis et al. 2019).

In rural landscapes, GI is usually studied in the framework of ecological networks. Indeed, some believe that GI concept has roots in the former hierarchical system of ecological networks (Mander et al. 2018) and often use existing ecological networks, usually in the form of protected areas, as a stepping stone in mapping GI, especially its connectivity (e.g. Liquete et al. 2015). It is logical, since the ecological networks are broadly defined as networks of areas that are connected to enhance biodiversity conservation (Boitani et al. 2007) or as systems of nature reserves and their interconnections that make a fragmented natural system coherent, so as to support more biological diversity than in its non-connected form (Jongman and Pungetti 2004). The concept of ecological networks stems from the principle that intensively used landscapes are balanced by natural zones that function as a coherent self-regulating whole (Bennett and Mulongoy 2006).

GI is defined according to European Commission (European Commission 2013a) 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. Unlike ecological networks, GI can be understood in a broader sense, since it includes "other environmental features" (such as urban parks, green roofs, roadside vegetation) and is designed with humans as the main focus (in ecological networks, the main focus is wildlife). Still, these two concepts are interlinked and this fact can be taken advantage of because there are countries where the concept of ecological networks is already integrated into legislation while the concept of green infrastructure seems to be a "new term". One such country is the Czech Republic, where the legislation operates with a concept based on ecological networks called the Territorial System of Ecological Stability (TSES). This concept is integrated not only in environmental legislation but also in the planning, which to some degree fulfils some of the main terms in GI definition.

The article focuses on TSES and its relationship to GI, how it is implemented in an intensively used agricultural landscape and how it can contribute to the connectivity of the landscape's GI. Therefore, it will be divided into three parts: the first part, rather theoretical, will focus on definition and rationale behind TSES, the second and third part will be more practical – the second part will show a state of TSES implementation in a case study area and the third part will show how complete implementation of the whole TSES can improve connectivity of the existing GI.

2 Methods

The Territorial System of Ecological Stability (TSES) is defined as an interconnected system of natural as well as modified but semi-natural ecosystems keeping the natural balance (Act No. 114/1992). TSES is supposed to provide sources of natural genetic material, support ecological stability of the landscape and support landscape-forming functions and landscape multifunctionality (Bínová et al. 2017).

It is a designed network and is an integral part of municipalities' spatial plans. Effective TSES design should:

- delineate areas large enough to support survival of species,
- delineate routes with relatively undisturbed species movement,
- create optimal spatial distribution of ecologically more stable areas, and
- divide ecologically less stable areas and ensure connectivity between them and ecologically more stable areas.

Delineation of TSES is based on many different ecological and landscape ecology theories. These include theory of ecological stability and homeostasis (Míchal 1994), landscape matrix-patch-corridor model (Forman and Godron 1986), biogeographic island theory (MacArthur and Wilson 1963), metapopulation theory (Levins 1969), sink-source theory (Pulliam 1988), theories dealing with organism movements (daily movements, dispersal, migration) and barriers (natural, anthropogenic), etc.

There are also several principles for designing TSES. They include:

- biogeographical representativeness (according to potential natural ecosystems),
- ecosystems functional links (natural migration routes with minimal barriers),
- adequate space requirements (minimal size, shape, length, width and density),
- taking into account the current state of the landscape (preference to include already existing valuable natural GI elements),
- taking into account other limits and interests in the landscape, and
- following continuity of hierarchical level of TSES (see below).

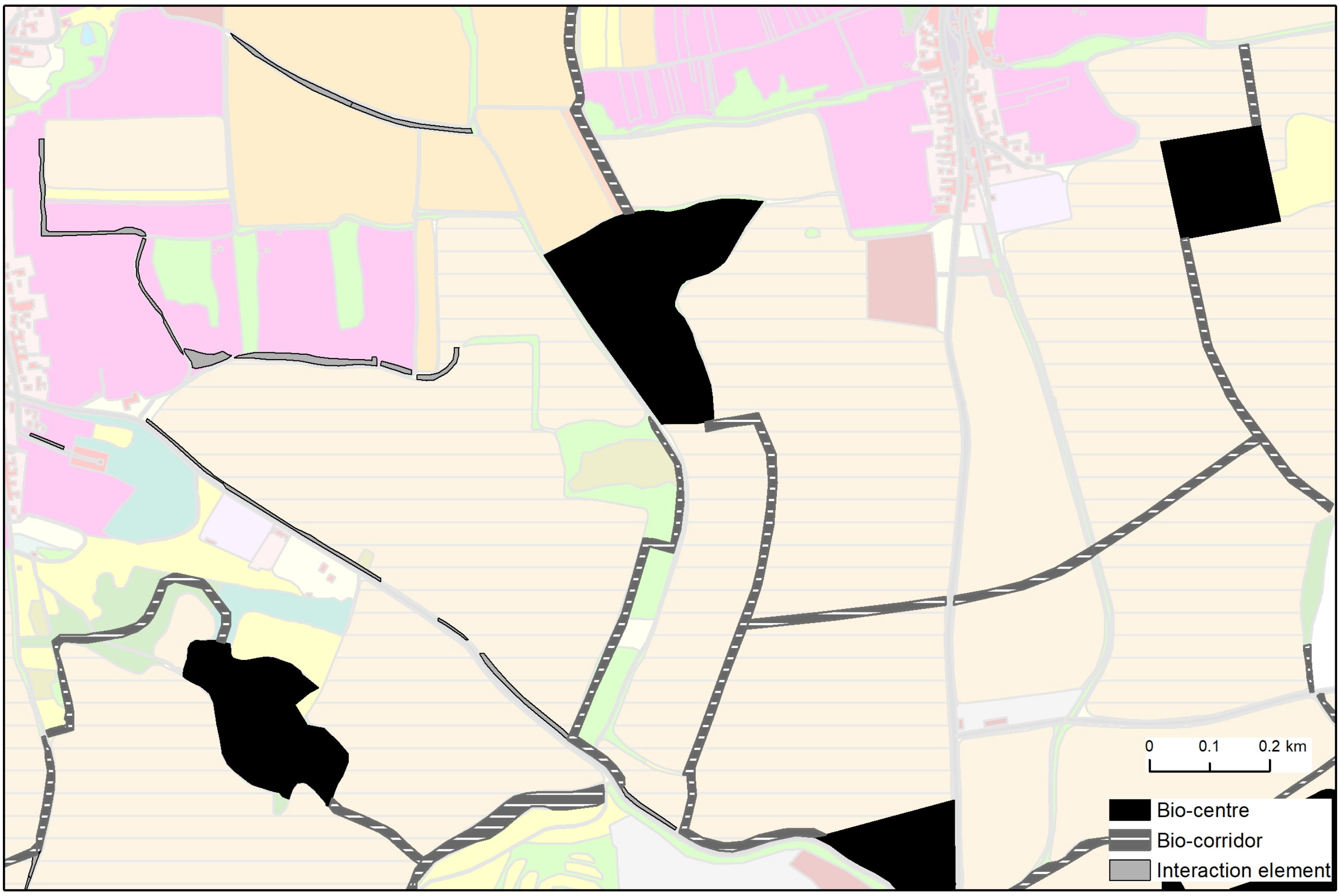


Figure 1: Example of designed Territorial System of Ecological stability with its three parts, bio-centres, bio-corridors and interaction elements; sources: municipality plans of Syrovín, Těmice and Žeravice, Czech Republic

Table 1: Minimal spatial parameters for bio-centres according to spatial level and habitat type

Level	**Type of habitat**	**Minimum size in ha**
Local	Forest	3
	Wetland	1
	Meadow	3
Regional	Forest	20-40*
	Wetland	10
	Meadow	30
Supra-regional	Forest	1,000

* Depending on vegetation zone and type of biogeographic unit/biochore, which depicts a unique combination of landscape potential and actual habitat (Culek et al. 2005)

Table 2: Spatial parameters for bio-corridors according to spatial level and habitat type

Level	**Type of habitat**	**Minimum width in m**	**Maximum length in m**
Local	Forest	15	2,000
	Wetland	20	2,000
	Meadow	20	15,000
Regional	Forest	40	700
	Wetland	40	1,00
	Meadow	50	500-700
Supra-regional	Forest	40	8,000

The TSES is a hierarchical system and we can distinguish different types of TSES, based on relevant criteria:

I. according to biogeographic significance and hierarchical level
   i. local
   ii. regional
   iii. supra-regional
II. according to the degree of anthropogenic impact
   i. natural (e.g. forests in areas with potential natural vegetation of forests)
   ii. dependent on anthropogenic activities (e.g. meadows in areas with potential natural vegetation of forests)
III. according to types of natural environment
   i. terrestrial
   ii. water

Similar to ecological networks, TSES distinguishes core areas, so called bio-centres, and biotic corridors, so called bio-corridors. Furthermore, it adds a third part, so called interaction elements (Figure 1). Bio-centres are areas that due to their size and state of ecological conditions enable the permanent existence of species and their communities. Bio-corridors are defined as elongated areas or corridors that enable movement of organisms between bio-centres, which they physically connect. Interaction elements can be seen as stepping stones for migration or the permanent existence of organisms. They are usually smaller than the previous two categories, do not fulfil pre-set criteria for bio-centres (Table 1) and bio-corridors (Table 2), can be designed only on local level and do not have to be directly connected to bio-centres and bio-corridors but should have a positive influence on surrounding ecologically less stable landscape sensu Míchal (1994). Ecological stability of the landscape (ecosystem) in Míchal's understanding is an ability of the landscape (ecosystem) to persist even under the influence of external disturbances and to reproduce its essential characteristics in these conditions with the help of the landscape's (ecosystem's) auto-regulation processes. Natural and semi-natural ecosystems provide higher ecological stability (Bínová et al. 2017).

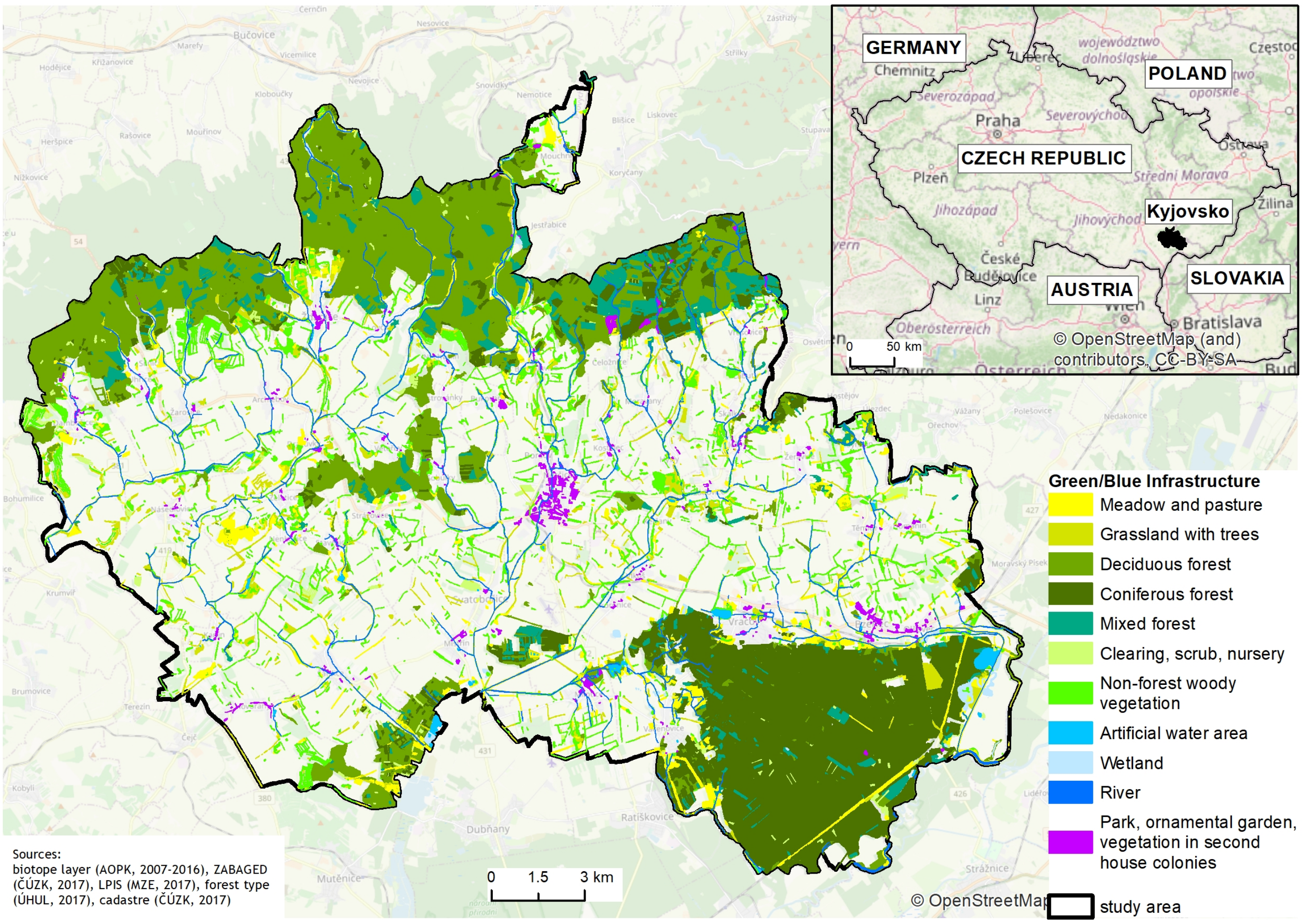
In order bio-centres and bio-corridors to be functional they must have minimum and maximum spatial parameters. It includes a minimum size of bio-centre and minimum width and maximum length in the case of bio-corridors. Maximum length represents the maximum distance between two bio-centres interconnected by particular bio-corridor. These parameters differ according to spatial level and type of habitat (Table 1 and Table 2).

As mentioned previously, TSES is an integral part of spatial plans according to legislation and there is an updated handbook (Bínová et al. 2017) on how to design it. It is designed not only in open landscape, but also in forests and urban areas. As stated above, it should include already existing GI elements that fulfil prescribed criteria (namely representativeness, but also adequate spatial requirements) but it usually also includes new elements that will be created/planted after the spatial plan is approved by municipalities.

3 Case study region

TSES implementation and its contribution to connectivity has been researched in the case study region of Kyjovsko, located in South Moravia, Czech Republic (Figure 2). This region covers 470 km^2 containing 42 municipalities. It is situated in the lowlands with an elevation of 200-300 m ASL. Most of the region (49 %) is intensively used, especially for agriculture, resulting in very large, impermeable blocks of arable fields that suffer from wind and water erosion. Due to its warm and dry climate (average annual temperature is around 9 °C and average annual precipitation around 450-500 mm), the region is known for its vineyards and to a lesser extent also for its orchards, which are, however, quickly disappearing. Larger forest complexes cover 29 % of the whole territory. They can be found in the north (mostly broadleaved, dominated by oak and hornbeam) and in the south of Kyjovsko (predominantly coniferous – pine forests on sandy soils). There are also some remnants of dry grasslands and other types of grassland with scattered trees (3 % of the territory). One of the unique but rapidly disappearing features of the landscape is the mosaic of smallholdings (5 % of the territory) – a mixture of vineyards, orchards, arable fields and grasslands, usually associated with settlements.

GI in the case study region includes forests, non-forest woody vegetation, meadows and pastures, rivers, wetlands, water bodies and urban greenery in the form of parks (Figure 2) and it covers 36 % of the whole territory.



Sources:
biotope layer (AOPK, 2007-2016), ZABAGED (ČÚZK, 2017), LPIS (MZE, 2017), forest type (ÚHUL, 2017), cadastre (ČÚZK, 2017)

Figure 2: Green infrastructure in the case study region Kyjovsko in the Czech Republic

4 Materials and methods

4.1 TSES

There are several sources for acquiring information about TSES, dependant on hierarchical level. Bio-centres on supra-regional level can be obtained in a digital vector form from the Czech Nature Conservation Agency (AOPK) and are available for the whole country. TSES on supra-regional and regional level in digital vector form can be also obtained from regional administrations, in particular from spatial analytical data, which are used for creating regional spatial plans. Data on the local TSES are an integral part of municipal spatial plans. They can be found in a digital vector form as a separate layer, however, they are often only in digital raster format as a part of the whole plan and therefore have to be extracted.

In the Kyjovsko case study region, we obtained TSES elements at supra-regional and regional level as a digital vector layer from the regional administration in Kyjov. Concerning the local TSES, only six municipalities had separate digital vector layers for TSES. For verification purposes, each vector layer was compared with the main spatial plan. Spatial plans for the other municipalities had to be georeferenced and the TSES layer had to be manually extracted/digitized. All TSES layers on the municipal level were combined in order to create a single layer for the whole Kyjovsko region. Based on the spatial plan each TSES element was classified as to whether it was existing or planned. Furthermore, where available, information about target ecosystems (forest, grassland, wetland/water, mosaics – in case where several ecosystems are considered) was also added.

Due to the fact that municipal spatial plans were created over the last twenty years, the information provided about local TSES could be outdated. Therefore the local TSES was compared with current (2017-2018) orthophotos. Based on the visual interpretation of orthophotos, TSES elements were divided into three categories: existing (element is as described in the municipality plan and at the same time can be seen in orthophoto), partly existing (element is present in the orthophoto to some degree but doesn't fulfil all the required criteria, e.g. a bio-centre that has been planted on half of its intended area, a line of trees in a grassland strip in an intended bio-corridor), and non-existent (element is planned in a municipality plan but is not present in the orthophoto). The same analysis was done also for regional and supra-regional TSES.

Besides checking actual state of TSES, we have also checked connectivity at the municipality borders among TSES elements, namely bio-centres and bio-corridors. This analysis stemmed from the fact that TSES for one municipality is often created without considering surrounding municipalities (Matuška and Jelínek 2005).

4.2 Connectivity

One of key principles of GI is its connectivity (Lafortezza et al. 2013). In this study we understood connectivity as physical connectedness of GI elements in the landscape. Therefore, we calculated connectivity using Morphological Spatial Pattern Analysis (MSPA), which was carried out in GUIDOS Toolbox, version 2.7 (Vogt and Riitters 2017). MSPA conducts a segmentation of a binary image to detect and localize mutually exclusive morphometric feature classes describing the shape, connectivity and spatial arrangement of image objects. It distinguishes seven feature classes: cores, islets, bridges, loops, branches, edges and perforations. Cores are defined as areas that enable broad movement of organisms, while islets are isolated patches. Islets do not directly affect degree of connectivity, however, they can be considered as stepping stones and if connected, they can then increase the physical connectivity of GI. Both bridges and loops can be considered as connectors. Bridges connect two different cores, loops emanate from the same core and return to it. Branches originate from and facilitate movement outside cores, loops or bridges but do not connect other features (Soille and Vogt 2009). As such they can be considered as potential features for extension and subsequently transformation into bridges or loops, thus increasing physical connectivity. Edges and perforations represent boundaries: edges are the outer boundaries of cores and perforations are inner boundaries of holes in a core area.

To assess whether implementation of TSES can affect GI connectivity, we first had to derive a GI map of the Kyjovsko region. We combined available data from different sources, namely Forest type map from Forest Management Institute (ÚHUL), Biotope layer from Czech Nature Conservation Agency (AOPK), Land Parcel Information System (LPIS) from Ministry of Agriculture, Fundamental Base of Geographic Data on the Czech Republic (ZABAGED) and Cadastre data from Czech State Administration of Land Surveying and Cadastre (ČÚZK). We further used orthophotos from 2017 to manually digitise GI elements that were not captured by existing datasets.

We considered GI as forests, non-forest woody vegetation, grasslands (meadows and pastures), and grasslands with woody vegetation, urban parks, wetlands, water bodies and water courses.

Since MSPA uses only a binary raster, both GI and TSES layers were converted to this format. The pixel size was set to 2 m. MSPA settings were set to foreground connectivity 8 (all neighbouring pixels are connected), and the edge width defining the width/thickness of the non-core classes in pixels was set to 10, i.e. 20 m.

Connectivity based on MSPA results was assessed within the framework of graph theory (Saura and Rubio 2010). Cores were considered as nodes and bridges served as links. Cores in this context represented a space where connectivity exists; bigger cores mean more connected area (Saura et al. 2011b). With the help of GUIDOS software, we calculated an Equivalent Connected Area (ECA) which represents a summary of overall connectivity. It is defined as the size that a single habitat patch should have in order to provide maximum connection (Saura et al. 2011a).

To find out how TSES implementation can affect overall connectivity, we conducted MSPA and calculated ECA separately for the GI layer and combined GI and TSES layer.

5 Results

5.1 TSES

Results show that there are in total 1,790 TSES elements in the Kyjovsko region on supra-regional (28), regional (75) and local (1,687) level. Bio-corridors dominate in number at all levels (Figure 3).

If we consider the area of individual TSES categories at all levels, the category of bio-centres dominates. In the case of supra-regional and regional TSES, the bio-centres cover more than 90 % of the delineated TSES area. This is logical due to their type of habitat (forest) and therefore pre-set minimum size (20-40 ha for regional and 1,000 ha for supra-regional). In the case of local TSES, bio-centres also dominate spatially but the dominance is not so profound (bio-centres occupy 59 % of the total TSES area, bio-corridors 29 % and interaction elements 12 %).

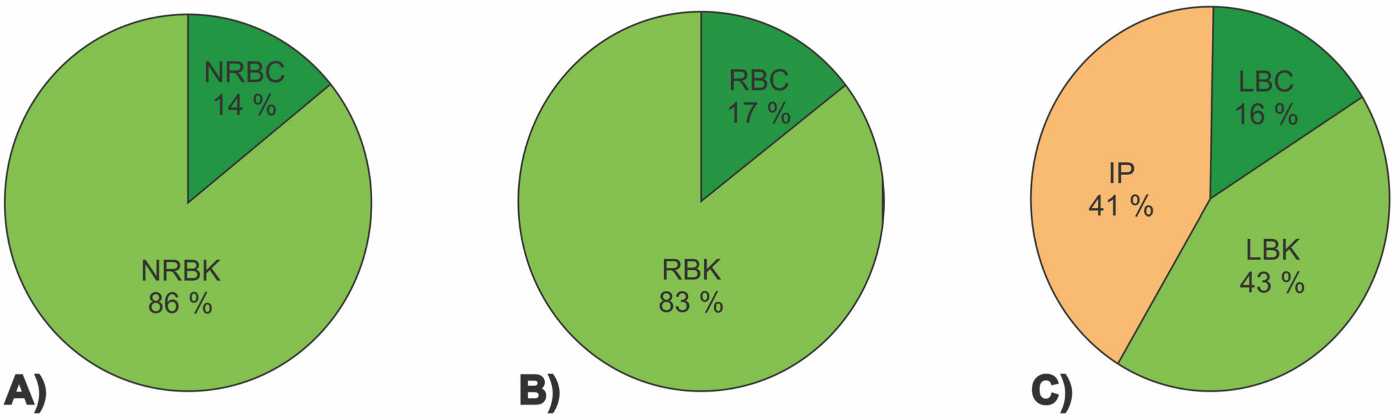


Figure 3: Number of TSES (Territorial System of Ecological Stability) elements in the case study region Kyjovsko in the Czech Republic shown as the share of A) supra-regional bio-corridors (NRBK) and supra-regional bio-centres (NRBC), B) regional bio-corridors (RBK) and regional bio-centres (RBC), and C) local bio-corridors (LBK), local bio-centres (LBC) and interaction elements (IP)

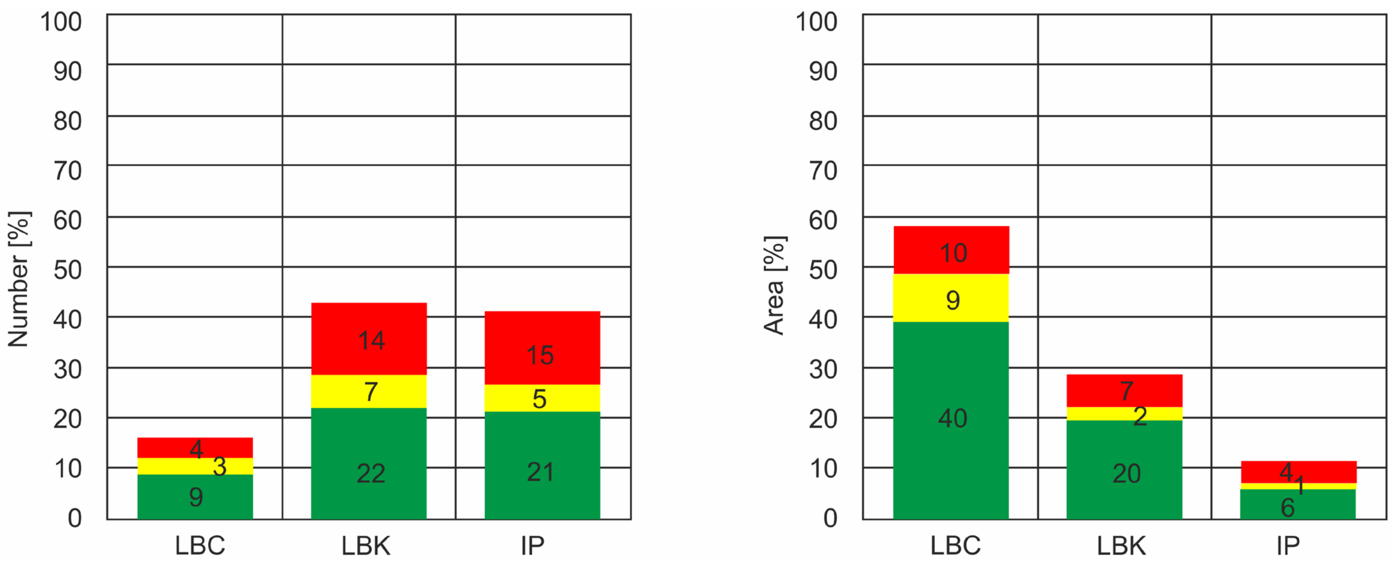


Figure 4: Proportions of existing (green), partly existing (yellow) and non-existent (red) local bio-corridors (LBK), local bio-centres (LBC) and interaction elements (IP) expressed in terms of numbers (left) and size (right)

All supra-regional TSES elements are present in the landscape. There are some parts of one forest bio-centre that cover a narrow valley, which is dominated by arable land, however, since there is no major road going through the valley, it does not represent a hard barrier for forest species crossing this valley. At the regional level, there are several missing bio-corridors or their parts. These bio-corridors are delineated in the agricultural landscape with dominant large arable fields and are supposed to connect local bio-centres; therefore their realisation should be priority.

In case of local TSES, the situation is a bit different. One third of delineated TSES elements do not exist and even though they cover only 21 % of the total TSES area, they are usually situated inside or at the edges of large arable fields and thus if realised would serve also as an erosion control measure. It is mainly local bio-corridors and interaction elements that already exist (Figure 4 left), although in terms of size, existing bio-centres dominate (Figure 4 right). If we consider presence of local TSES in individual categories, it is mainly bio-centres where the situation is

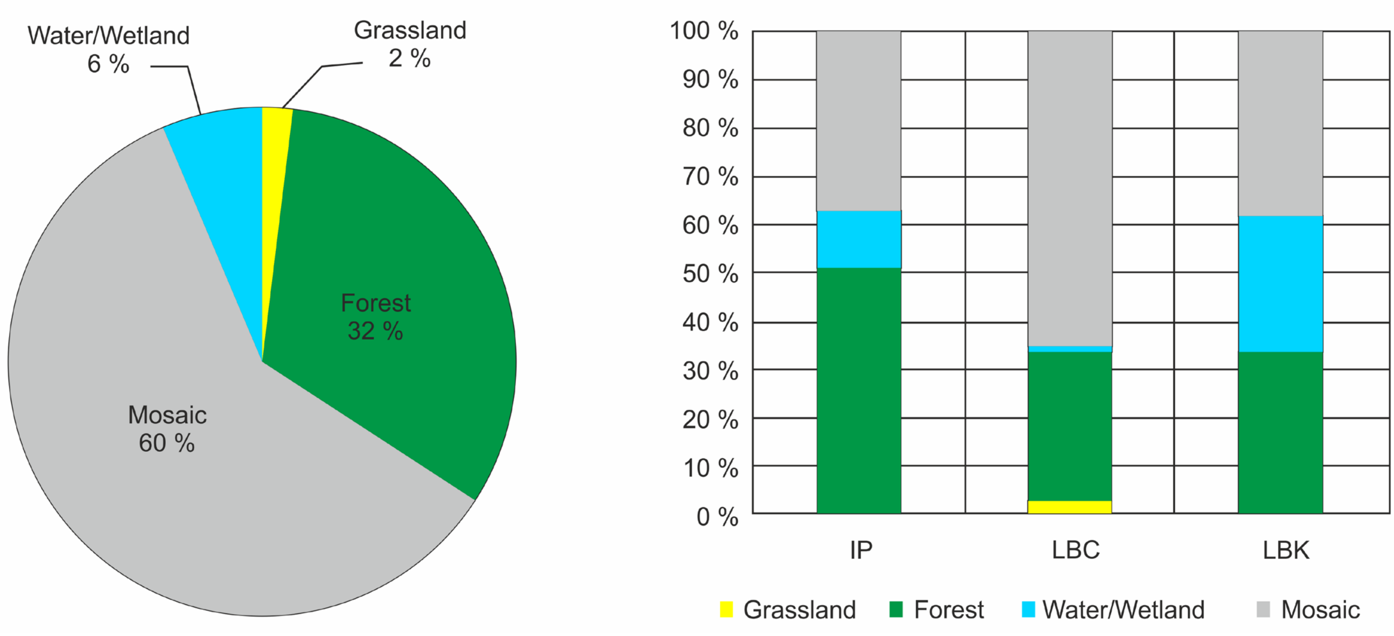


Figure 5: Proportions of target ecosystems in local TSES elements as total (left) and its components (right)

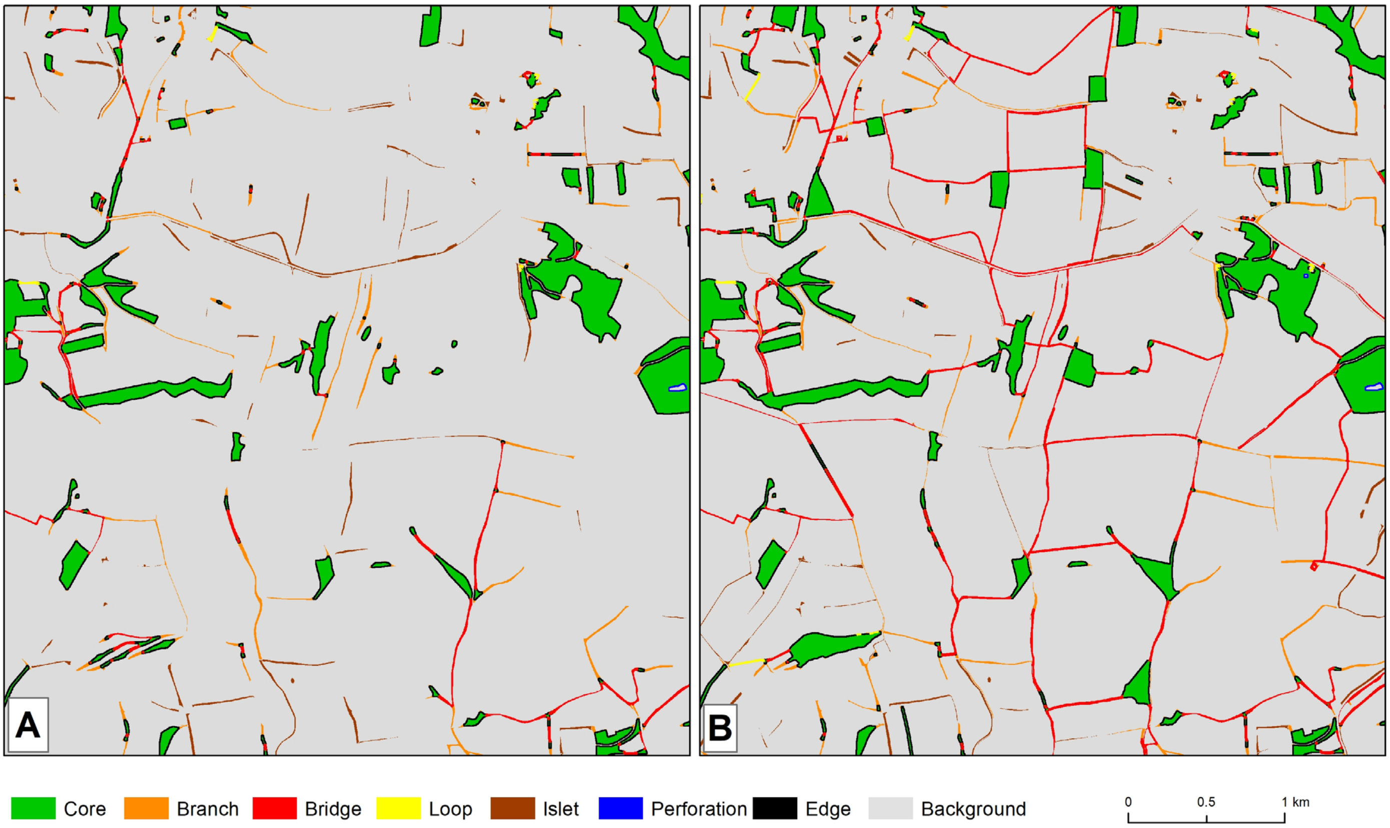


Figure 6: Subset of the resulting Morphological Spatial Pattern Analysis (MSPA) of green infrastructure (GI) without adding elements of Territorial System of Ecological Stability (A) and with added elements (B) in the Kyjovsko region

quite good: 75 % of bio-centres exist fully or in part; in the case of bio-corridors, this is true for 67 %, and in case of interaction elements, 64 % exist fully or partially.

Information about target ecosystems was available only at the local level and only for 36 % of the total number of TSES elements. The majority of information was available for bio-centres (91.5 %), followed by bio-corridors (42.6 %) and interaction elements (4.5 %). Mosaics of various ecosystems were the most common target group, followed by forests, water or wetland ecosystems and grasslands (Figure 5 left). Mosaic ecosystems included mainly a mixture of forests and grasslands or forests, grasslands and water ecosystems and were typical for bio-centres (Figure 5 right). Bio-centres were also the only TSES element, which included pure grasslands as a target ecosystem. Bio-corridors also displayed a large share of water or wetland ecosystems. This is logical, since many bio-corridors can be found along watercourses. Forests were predominant in the interaction elements as these are usually too small to have more than one target ecosystem.

Visual analysis of local TSES connections revealed that there are 34 irregularities. They include a shift of bio-corridors at the municipality borders (disconnection), parallel routes of bio-corridors, bio-corridors ending at the municipality border without their counterpart in other municipality or missing connections inside settlements.

5.2 Connectivity

Morphological spatial pattern analysis revealed quite a high fragmentation of GI (Figure 6 A), expressed by high numbers of branches, cores and islets and smaller numbers of bridges and loops. Equivalent Connected Area (ECA) was calculated as 150 ha of GI being fully connected. Adding the TSES layer resulted in a significant increase of connectivity (Figure 6 B), expressed by increase in ECA (1,239 ha). This is mainly result of an increase in number of bridges (from 1,466 to 2,071) and in the area of cores (from 28 % to 31 %).

6 Discussion and conclusions

6.1 TSES

Here the presented results show that implementation of TSES in the landscape of Kyjovsko region is not so bleak as one could imagine. The supra-regional and regional levels are usually planned in order to include already existing habitats. Two thirds of the local TSES also exist either fully or partly, showing massive effort of municipalities to make landscape in their regions more resilient. However, we should be aware that the presented results only refer to the existence/non-existence of the TSES elements and omit their functionality in terms of quality, especially concerning species composition and predefined spatial criteria (Slach and Skokanová 2019).

The implementation of TSES focuses mainly on bio-centres and bio-corridors, i.e. elements with clearly defined parameters regarding their size, shape, etc. Therefore, these two types of the TSES can be easily planned and implemented. Vague description of interaction elements in the TSES methodology and their ambiguity (Lacina 2018) can result in their underrepresentation as shown in the Kyjovsko region. On the other hand, this ambiguity might help in easier implementation of such type of TSES, especially in cases, which show lack of land with suitable size parameters.

Results from the Kyjovsko region also show the lack of data in the municipalities' plans regarding targeted ecosystems of individual TSES elements. This might be a problem during TSES implementation since lack of such data might cause diminishing of the potential functionality of the TSES elements.

Visual analysis of the connectedness of TSES among municipalities confirmed a lack of its consideration in the spatial plans of surrounding municipalities during its design as was observed by Matuška and Jelínek (2005). This type of mistake might be reduced by creating an information system where all local TSES plans would be stored and be accessible to TSES designers and planners (Glos and Kocián 2003); however, fulfilling of such system is quite difficult, especially on national level, mainly due to administrative problems. Still, we believe that creation of such information system at regional level (such as Kyjovsko) is feasible.

6.2 TSES and GI

The TSES definition at first glance shows similar features with the definition of GI – inter-connected system/network (European Commision 13a; Skokanová et al. 2020); natural and semi-natural ecosystems/areas; and supporting the multifunctionality of the landscape (Hansen et al. 2019). However, while GI can be seen as a rather broad concept (Snäll et al. 2016), TSES is more narrowly focused on the need to protect (or create) a minimum area for potential natural biota which will then positively affect its surrounding landscape and could be used for specific ecosystem services (Lacina 2018).

We can argue that TSES is unquestioningly part of GI and its full implementation in the landscape can lead into increase of GI's connectivity as was demonstrated in Figure 6, and subsequently also to the increase of GI's multifunctionality. TSES considers many of the benefits mentioned in Technical information on Green Infrastructure (European Commission 2013b), mainly conservation benefits and resilience, but also enhanced efficiency of natural resources, disaster prevention, land and soil management, climate change mitigation and adaptation or water management. It can also contribute to better agriculture by enhancing pollination and pest control. Since many of TSES elements have to be newly created and maintained for the next five years (before they are more resilient), it creates opportunities for employment.

Unlike GI, TSES is a concept with strict set of rules, which is true especially for bio-centres and bio-corridors. On the one hand, this means that the concept is easily understandable, especially for professionals with technical background. On the other, it can easily omit other features in the landscape that do not follow these rules but have a positive effect on the landscape as well as on people. Examples are extensively used fruit orchards as a part of high nature value farmland (HNV) or domestic gardens. They will never be considered as a bio-centre but will unquestioningly belong to GI (Cameron et al. 2012, Rolf et al.

2018). Therefore, it might be easier to create new GI elements outside of the TSES concept with the help and agreement of landowners, especially if they are aware of the economic benefits of the GI (Vandermeulen et al. 2011, Schmidt and Hauck 2018).

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