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# The role of traditional agricultural landscape structures in changes to green infrastructure connectivity

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ABSTRACT

A reduction and disappearance of traditional agricultural landscape structures (TALSs) has been taking place throughout Europe. TALSs are a mixture of small arable fields with trees, vineyards with and without trees, orchards and field margins, and represent an important component of green infrastructure (GI). This is true especially in intensively used landscapes where GI elements in a true sense (natural or semi-natural elements) are quite rare. Changes of GI and its connectivity in four periods between 1826 and 2017 were studied in the agricultural landscape of South Moravian region, the Czech Republic. Changes of GI were expressed as transitions to different land use categories, with changes of GI connectivity expressed by morphological spatial pattern analysis (MSPA) and equivalent connected area (ECA). Our results showed that the GI was the best connected in the mid-19th century through large core areas of grasslands, forests and water bodies. GI was significantly reduced and its connectivity lowered already in the first half of the 20th century during the first wave of agricultural intensification. During this time, grassland was turned to arable fields and water bodies and wetlands were dried out. The reduction of GI continued during the socialist period (1948–1990), leading to further decreases in connectivity and an overall homogenization of the landscape. During this period and continuing until the present, TALSs and especially small vineyards, started to play a significant role in GI connectivity. Nowadays, GI connectivity has started to again increase also through the introduction of new types of GI. These are bio-centres and bio-corridors (patches of woods that are newly planted in order to create an ecological network) and elements connected with agri-environmental schemes (e.g. erosion control grassed belts).

## 1. Introduction

European rural landscapes have experienced large transformations connected with human activities. These transformations have been the result of different driving forces, namely societal and economic, and have been manifested variously in mountain areas and in lowlands. Mountain areas are often subject to the overgrowth of abandoned agricultural lands, leading to the spread of forest cover (Jepsen et al., 2015). On the other hand, in lowlands, there is a conflict between agricultural intensification (Cvitanovic et al., 2017) and urbanisation, connected with the development of technical infrastructure (Romano and Zullo, 2016; Schulp et al., 2019). This has often led to the reduction and disappearance of traditional agricultural landscapes, with distinct and recognizable landscape structures comprised of narrow strips of arable fields, usually with trees, vineyards or orchards, and small woody, grassed and wetland patches. Especially in Europe, such elements are often considered an integral part of so-called green infrastructure (GI). GI is defined in a European communication on green infrastructure (European Commission, 2013) 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 (Liquete et al., 2015). In an intensively used agricultural landscape, GI elements in the true sense (natural and semi-natural areas) are very rare. Therefore, remnants of traditional agricultural landscape structure (TALS) in the form of arable fields with trees, field margins, small vineyards or orchards can be seen as potentially helping to improve the presence of GI. Such defined TALSs are considered as a part of GI for the purposes of this study.

Other measures to increase GI and enhance its positive influence on surrounding landscapes include applying agri-environmental measures within a Common Agricultural Policy (CAP) programme, especially by introducing new landscape elements (woodlots, groups of trees, grass

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strips/belts) (Dytrtova et al., 2016; Happe et al., 2018). Furthermore, the planning and creating of ecological networks, such as the Czech territorial system of ecological stability (TSES), can significantly help in enhancing GI. TSES is defined as an interconnected system of natural as well as modified but near natural ecosystems keeping a natural balance (Act No. 114/92 Coll., 1992). It consists of three different main groups of elements: bio-centres, bio-corridors, and interactive elements. Bio-centres are areas that due to their size (1–3 ha on local scale, depending on the type of bio-centre) 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. Interactive elements can be seen as stepping stones for migration of organisms. They are usually smaller than the previous two categories and do not have to be directly connected to them (Skokanová and Slach, 2020).

The disappearance of TALSs has been noted across Europe, although caused by slightly different drivers: in Western Europe, the mainly market-oriented intensification of agriculture as well as urbanisation have been the main factors (Antrop, 1997), while in Central and Eastern Europe socialist planning, including collectivisation, has dominated (Spulerova et al., 2017a).

There have been quite a number of studies on TALS. These studies have focused on different aspects ranging from simple changes in TALS (Agnoletti, 2007; Antrop, 1997) and driving forces affecting these changes (Breuer et al., 2010; Parcerisas et al., 2012) or relationships between environmental and socio-economic variables and TALS (Súľovský et al., 2017; Amici et al., 2017). Others have studied the perception of TALS (Assandri et al., 2018; Tempesta, 2010), relationships between TALS and biodiversity (Agnoletti, 2007; Skokanova et al., 2016b) and TALS and ecosystem services (Spulerova et al., 2018). However, not many studies have tried to look at changes in the connectivity of these features (but see Wu et al., 2017; Bianchin and Neubert, 2017). Such an assessment is quite important especially in the current homogenous agricultural landscapes where a lack of GI hinders or even prevents the movement of organisms (Mony et al., 2018). Moreover, research on past GI elements that do not exist anymore can help in planning for their restoration, and thus contribute to a better connectivity of these elements.

To address these issues, we studied long-term (1826–2017) changes of GI in a part of the South Moravian region of the Czech Republic that has experienced similar trends as in other former socialist countries, namely the socialist intensification of agriculture (Skokanova et al., 2016a). In particular, we focused on the disappearance of GI and its transition to other land use categories, changes of GI structural connectivity with respect to different land use categories, and on spatial distribution expressed by the relation of GI to slope. The underlying hypothesis states that GI, and TALS in particular, has declined and changed its spatial distribution over the past 190 years, with the present landscape having the lowest amount and connectivity of GI. This hypothesis is associated with several predictions: a) the largest presence of GI and the highest GI connectivity occurred in the mid-19th century and was associated with low-intensity agriculture; b) the largest decline of GI and its connectivity was associated with socialist agriculture in the mid-20th century; and c) there has been a shift of GI from flatter surfaces to steeper slopes.

## 2. Materials and methods

### *2.1. Study area*

Changes in GI connectivity were studied in an intensively used agricultural landscape in South Moravia, the Czech Republic (Fig. 1). The study area Čejkovice covers 2.500 ha, and is situated in lowlands (average elevation is 208 m a.s.l.) with undulating terrain and a dry warm climate, with annual precipitation of 532 mm and annual temperature of 9 °C (Jan et al., 1998). Due to its chernozem soils and low altitudes, the area is characterized by a prevalence of agricultural land. Large arable fields with cereals, oilseed rape and corn dominate, but vineyards are also distinctive features of the landscape, with a viticulture tradition present for more than 700 years. On the other hand, large GI elements in terms of forests, grasslands or water bodies are quite scarce. Settlements are generally surrounded by remnants of TALSs.

The study area was affected by similar political and socio-economic driving forces/events as in other regions in the Czech Republic over the past two centuries. These include namely land reforms introduced by Maria Theresa, Joseph II and Franz Joseph I in the 18th and 19th centuries, land reform at the beginning of 20th century, socialist agriculture connected with forced collectivisation in the second half of the 20th century, and privatisation and restitution after 1990 (Skokanova et al., 2016a). In local settings, the following events had particular impact on land use:

–the abolishment of statute labour in 1848, which led to changes in land ownership;
–the introduction of the four-fold system and new crops, especially animal fodder and sugar beets at the end of 19th century, leading to the spread of arable land by ploughing grasslands and drying water bodies;
–the establishment of socialist agricultural cooperatives in 1950, with the forced participation of individual farmers from 1957 to 1959;
–the beginning of land consolidation into large plots of mainly arable land in 1955;
–the uniting of cooperatives into one large cooperative in 1974, which resulted not only in further land consolidation but also in the creation of large terraces (Havlicek et al., 2018) and soil degradation (Sarapatka et al., 2018); and
–national subsidies for the planting of vineyards before accession to the EU in 2004.

### *2.2. Derivation of data on traditional agricultural landscape structure and green infrastructure*

TALS and GI were studied in four periods: 1826, 1938, 1963 and 2017. Data for 1826 were derived from so-called stable cadastre maps at a scale of 1:2880. These data are unique because they show landscape characteristics at the transition from a rural to industrial landscape (Skalos et al., 2012). Data for the periods 1938 and 1963 were derived from panchromatic aerial photos with a resolution of $1-2$ m. Data from 1938 show the landscape before the socialist collectivisation that started in 1955. Data from 1963 reflect the first results of socialist collectivisation – land consolidation. Data for 2017 were derived from corresponding coloured orthophotos with a resolution of 25 cm and were verified in the field. Maps and photos from 1963 and 2017 were already in digital format; however, with the exception of 2017 orthophotos (already in a coordinate system), they had to be rectified. This was done in the ArcGIS software, version 10.3, using 2nd Order Polynomial Transformation. Analogue photos from 1938 were digitized and then rectified. Since these photos did not have all the information necessary for automatic orthorectification, the Leica Photogrammetry Suite extension to ERDAS Imagine was used.

Data on TALS and GI were created by manual vectorisation using backward/backdate editing. In this method, TALS and GI were vectorised as polygons on the most recent photograph (2017), and their accuracy was verified in the field. Such adjusted data then served as a baseline for the older photographs and stable cadastre data. A detailed description of this method can be found in Skokanova et al. (2016b). The minimum mapping unit was set to 10 $m^2$ in order to capture woody elements. The backward editing ensured that changes in the borders of polygons were real and not a result of the poorer quality of panchromatic aerial photos. In addition, we asked older members of the

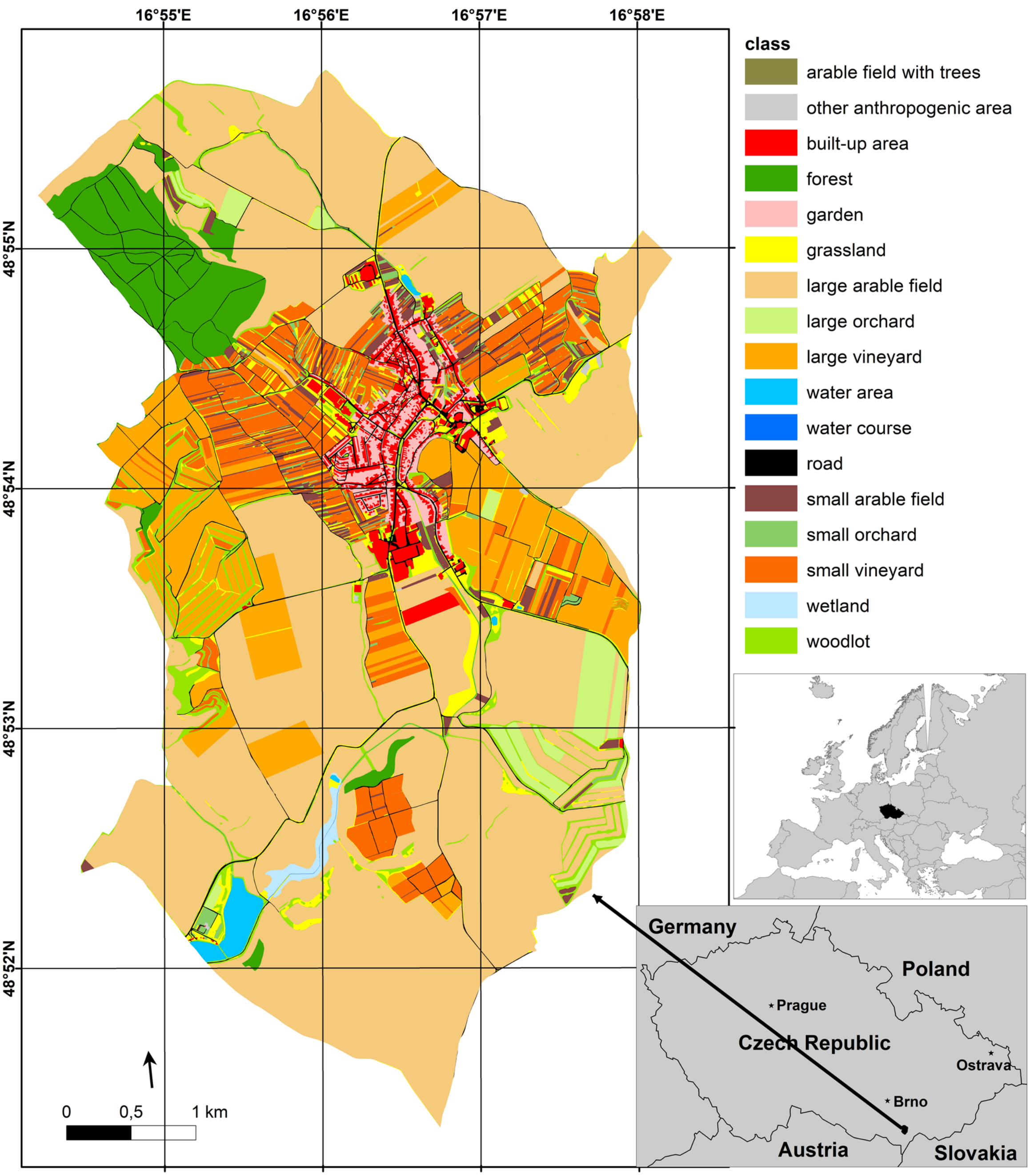



**Fig. 1.** Location of the study area and present land use. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

population with local knowledge and who remembered the landscape in the corresponding periods to check the derived polygons from these photos.

In total, seventeen land use categories were distinguished. These categories were then grouped into three classes focusing on GI:

(1) green infrastructure (GI) – near natural and TALS – forests, grasslands, non-forest woody vegetation, water bodies, water courses (vectorised as polygons with a buffer of 1 m), wetlands, arable fields with trees, small vineyards, small orchards, gardens;
(2) brown infrastructure (BrI) – intensively agriculturally used land – small arable fields, large arable fields, large orchards, large vineyards; and
(3) grey infrastructure (GrI) – man-made structures – built-up areas (both residential and commercial/production), other anthropogenic areas (mining areas, such as quarries, and development areas) and roads.

Based on consultation with professionals from nature conservation, the size for distinguishing small and large features was set to 1 ha. This also reflected the average size of individual plots before land consolidation at the end of 19th century (Skalos et al., 2012).

Changes in the GI spatial distribution focused specifically on relationships between GI and slope. These relationships were studied based on digital model of the relief (DMR) models from two sources: GI data from 1826, 1938 and 1963 were related to DMR from 1963; and GI data from 2017 were related to DMR from 2016. Two different DMRs were used because the terrain of the study area was modified during collectivization in the 1970 s–1980 s. The DMR from 1963 was based on maps from 1963 with the terrain represented by 2 m contour lines or 1

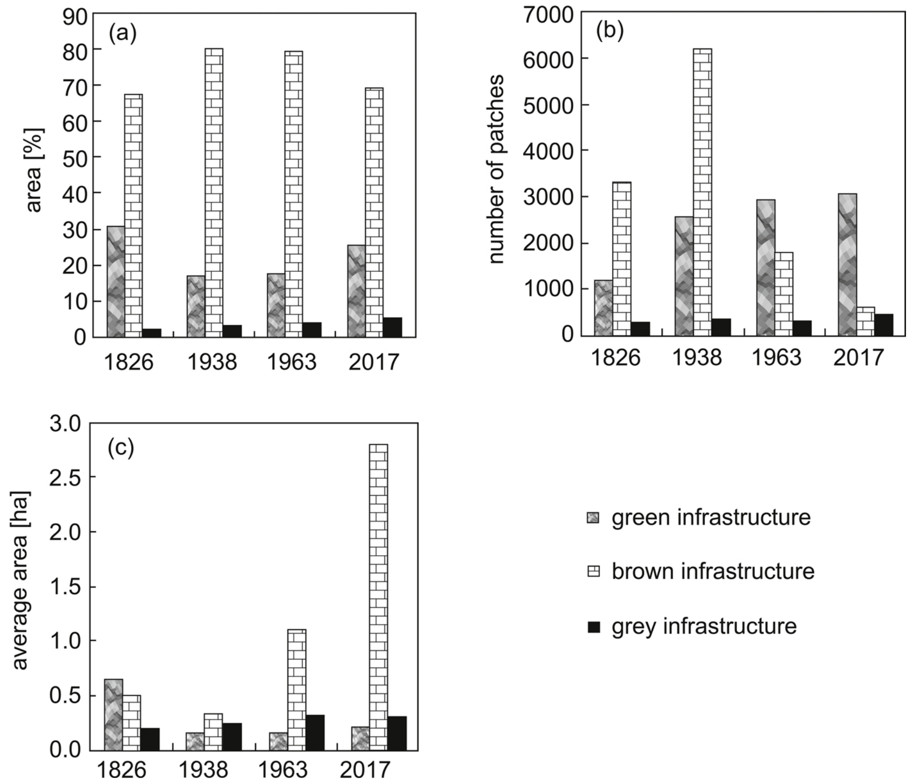



**Fig. 2.** Changes in the landscape structure of green, brown and grey infrastructure expressed by area (a), number of patches (b) and mean patch size (c).

m where necessary. These contour lines were manually vectorised, and then the layer was transformed to DMR using the ArcGIS Spatial Analyst Topo to Raster function with pixel size set to 5 m. From this DMR, slope was derived using the ArcGIS Spatial Analyst Slope function. The DMR from 2017 was based on an already-existing DMR 5 G that was created by the Czech State administration of land surveying and cadastre from aerial laser scanning of the Czech territory. Slope was derived from this DMR the same way as for 1963.

### 2.3. Analyses

The reduction of GI due to transitions to other GI groups and land use categories was derived from the four polygon maps using overlay. This enabled us to create a transition matrix between two adjacent periods that revealed how individual GI categories changed and to which other groups and categories. We used Patch Analyst for ArcGIS, version 5.1 (Rempel et al., 2012) to calculate basic landscape structure indices, namely area, number of patches (NumP) and mean patch size (MPS).

Changes in structural connectivity were based on 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 perforation. In terms of connectivity or the movement of organisms, cores are predefined areas that enable the broad movement of organisms or areas whose distance to the background is greater than a predefined size parameter. Islets are isolated patches that do not contain any core area. Bridges connect two different cores, while loops emanate from the same core and return to it. Both bridges and loops can be considered as connectors. Branches emanate from and facilitate movement outside cores, loops or bridges but do not connect anything. The final two classes represent boundaries: edges (outer boundaries of core areas) and perforation (inner boundaries adjacent to holes in a core area) (Soille and Vogt, 2009; Vogt et al., 2009).

Since MSPA uses only binary raster data, polygon layers from individual periods had to be converted to this format. The pixel size was set to 1 m, and land use categories were converted to GI/not GI. 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 5 m. Maps from MSPA were then overlaid with land use maps to identify which land use categories were present in which MSPA classes and what changes occurred.

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

$$PCnum = \sum_{i=1}^{N} (node\ area\ of\ component)^2$$

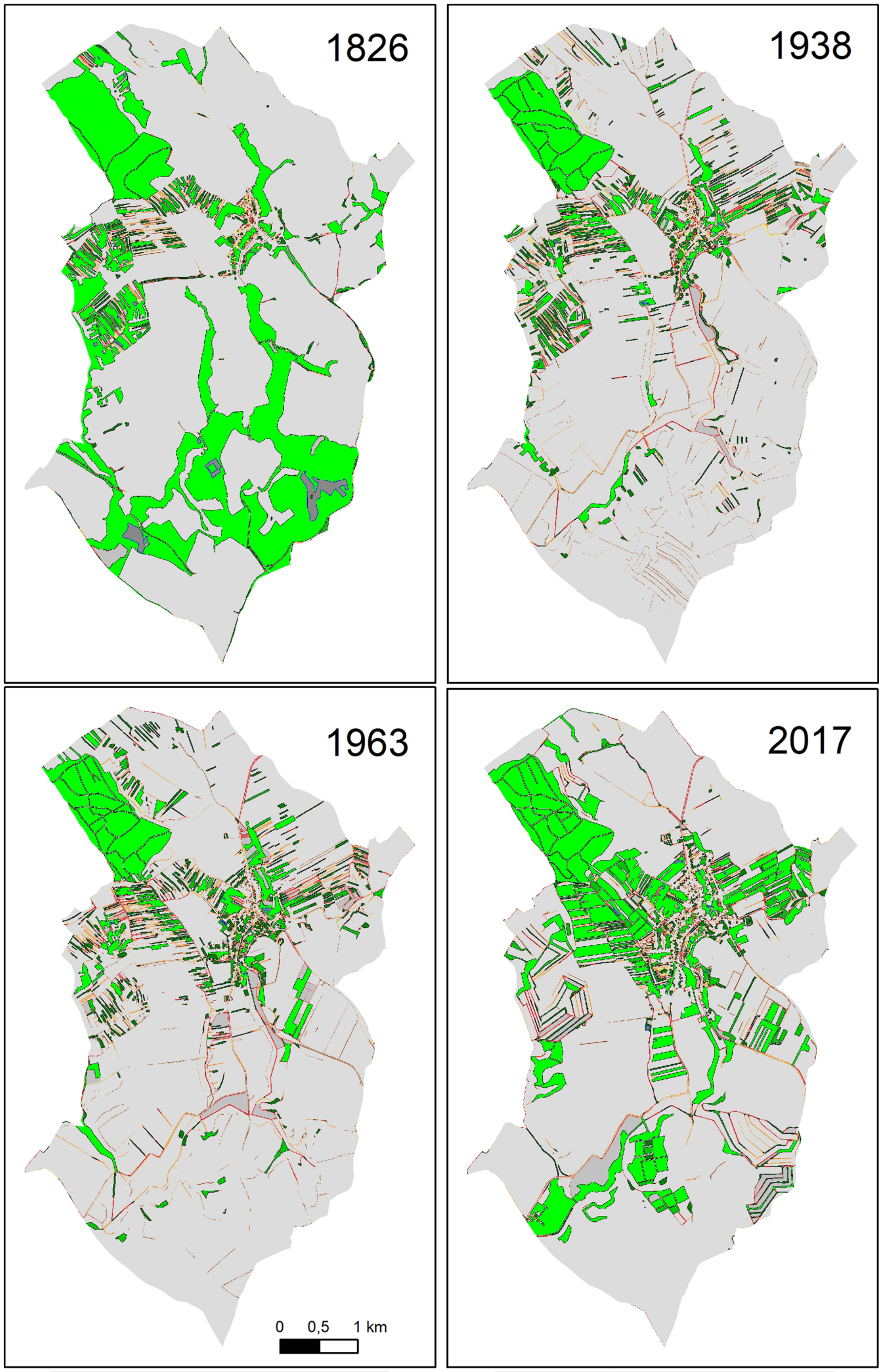
where PCnum is the probability of connectivity.

Finally, to identify relationships of GI to slopes and subsequent shifts, we used the zonal statistic in ArcGIS Spatial Analyst.

## 3. Results

As predicted, GI in the study area was most widespread in 1826 (Fig. 2a) due to large patches – cores (Fig. 2c) of grasslands, forests and water bodies, i.e. more natural GI elements, which also formed large cores (Fig. 3) and bridges, ensuring the largest ECA (221 ha) from all periods. TALSs in this period dominated as branches, loops and islets but also bridges. GI was evenly spread in the whole study area.

The area of GI elements during the first half of the 20th century




| area [ha] | 1826 | 1938 | 1963 | 2017 |
|---|---|---|---|---|
| CORE | 25.44 | 9.51 | 9.85 | 17.7 |
| ISLET | 0.16 | 0.94 | 0.77 | 0.36 |
| PERFORATION | 0.16 | 0.03 | 0.03 | 0.06 |
| EDGE | 4.13 | 4.59 | 4.49 | 5.76 |
| LOOP | 0.04 | 0.07 | 0.06 | 0.03 |
| BRIDGE | 0.18 | 0.54 | 0.84 | 0.72 |
| BRANCH | 0.50 | 1.11 | 1.29 | 0.95 |

| number | 1826 | 1938 | 1963 | 2017 |
|---|---|---|---|---|
| CORE | 615 | 1253 | 1076 | 1388 |
| ISLET | 93 | 986 | 676 | 247 |
| PERFORATION | 14 | 10 | 10 | 23 |
| EDGE | 295 | 567 | 609 | 633 |
| LOOP | 60 | 47 | 47 | 62 |
| BRIDGE | 190 | 410 | 436 | 532 |
| BRANCH | 2328 | 3475 | 4069 | 4936 |

**Fig. 3.** Morphological spatial pattern analysis (MSPA) of green infrastructure in the study area from 1826-2017. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

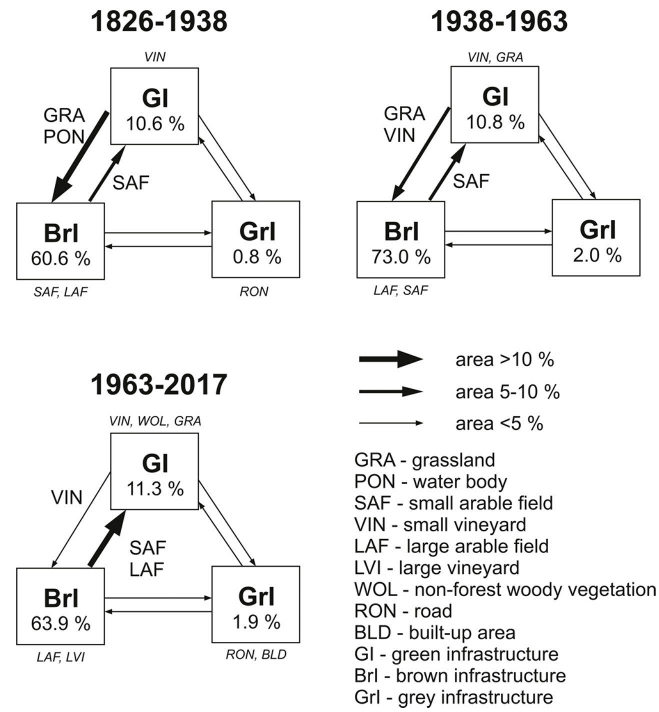



**Fig. 4.** Transition flows (in terms of total area changed) between green (GI), brown (BrI) and grey (GrI) infrastructure between the periods 1826-1938, 1938-1963 and 1963-2017. The thickness of arrows is proportional to the total area change observed. Numbers in the boxes represent the proportion of each group that was unchanged. Elements near arrows are those whose area decreased by more than 1 %. Elements near boxes (in italic) are those that gained the most area (more than 1 %).

significantly dropped (Fig. 2a). This was accompanied by an increase in the number of patches (Fig. 2b), a decrease of MPS (Fig. 2c) and a drop of ECA (to 42 ha). The decrease of connectivity was caused by turning grasslands into arable fields on a massive scale – initially into small fields (in 1938) and later into large ones (in 1963). Another cause for the decrease of GI connectivity was the draining of water bodies, when they were turned mainly into large arable fields (Fig. 4). Existing cores were dominated by TALSs, especially in the form of small vineyards with trees. The grassland remnants served as connectors between the cores, but were mainly isolated patches in an otherwise intensively used landscape. During this period, non-forest woody vegetation started to occur as isolated patches. GI was mostly concentrated in the northern part of the study area (Fig. 3).

The increase of GI area started again in the second half of the 20th century. This was mainly caused by the planting of new small vineyards on arable land, but also by small non-forest woody vegetation that was planted along roads in the form of tree alleys. While small vineyards contributed to the increase of cores' areas, non-forest woody vegetation contributed to the increase of areas of islets, bridges and branches. However, the overall connectivity was the lowest (ECA = 35 ha) due to the smaller number of cores (Fig. 3).

The year 2017 was characterized by an increase in GI in the form of cores, especially new small vineyards without trees, which were planted on arable land (Fig. 4). Other new cores were represented by new and partially restored water bodies as flood control measures, spontaneously developed wetland and non-forest woody vegetation in the form of bio-centres and bio-corridors. Due to this fact, GI again started to be present also in the southern part of the study area. Bio-corridors and other non-forest woody vegetation strips, which spontaneously developed on uncultivated land, and newly-sown grasslands on slopes increased the number as well as area of bridges. All actions resulted in an increase of ECA (to 62 ha).

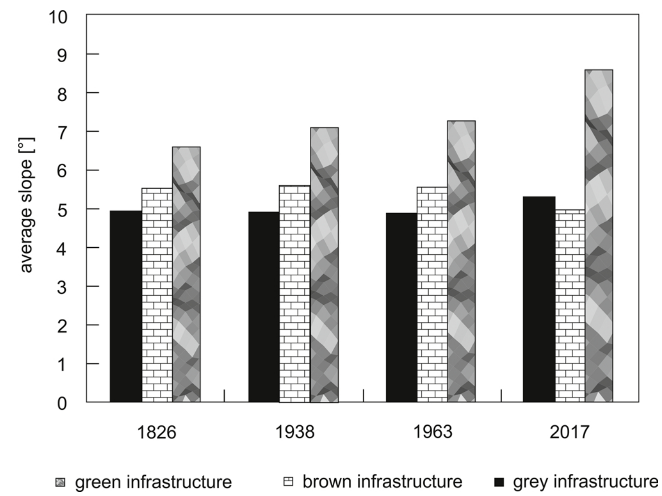



**Fig. 5.** Changes in the relationship between green, brown and grey infrastructure and slope from 1826-2017. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

GI always tended to occur more often on steeper slopes (average inclination around 7°) than BrI and GrI, and this trend increased over time (Fig. 5). This can be attributed mainly to non-forest woody vegetation, grassland and forests, especially in 2017. TALSs also tended to be planted on steeper slopes, especially in 1938 and 1963; however, nowadays their expansion in the form of small vineyards is also occurring on less steep plots.

## 4. Discussion

Our results showed that GI and its connectivity in our study area has indeed declined over the past 200 years (Fig. 2A), but this decline has been reversed in recent years. Therefore, our hypothesis was confirmed only partly. This recent increase in GI area is somewhat different from that found in other Central European (Demkova and Lipsky, 2015; Lieskovský et al., 2013; Skokanova et al., 2016b) as well as Northern European (Agger and Brandt, 1988; Svensson et al., 2019) studies. However, Skalos et al. (2011) noted similar findings.

Contrary to our prediction, the reduction of GI in the study area was largest already at the turn of the 19th and 20th centuries as the result of the first wave of agricultural intensification (Skokanova et al., 2016a). The main land use category that was affected by this process was grasslands, not only in the study area and its wider surroundings (Havlicek et al., 2018) but also in other parts of the Czech Republic (Kilianova et al., 2017; Sarapatka and Sterba, 1998). Water bodies were eliminated as a consequence of the agricultural intensification. However, this process already started to occur during the 18th century and accelerated at the end of 19th century, usually in regions where sugar beets started to be produced (Pavelkova et al., 2016). The continuing removal of GI during the second half of the 20th century due to socialist reforms was similar to that found in other studies from socialist countries (Munteanu et al., 2014). This was caused mainly by socialist agriculture practices, especially land consolidation (Sklenicka et al., 2014) and the creation of large new agricultural terraces in the 1970s and 1980s that not only destroyed the mosaic of TALS but also negatively affected soil conditions (Procházková, 1990). On the other hand, the steep slopes between these terraces incidentally became places where non-forest woody vegetation spontaneously developed, thus creating new GI patches.

The main causes for our increase in the area as well as connectivity of GI elements in recent years are manifold. Newly planted small vineyards belonging to TALS and forming cores contributed the most. One of the main causes was the fact that the majority of landowners were part of a wine cooperative that guaranteed grape collection. However, the character of these vineyards changed: while in earlier periods these vineyards were usually interwoven with solitary trees; by 2017, the trees had quickly disappeared. There are three main factors behind the disappearance of small orchards and arable fields with trees as well as solitary trees in small vineyards during the last 70 years. These are: a) a gradual mechanization in even smallholdings, especially vineyards, where trees represent an obstacle (Skokanova et al., 2016b), b) increasing financial inputs with decreasing market prices leading to a preference for bought products (rather than self-grown), and c) an overall change in lifestyle, with the migration of the younger population to cities, demanding jobs, or less willingness to work on their land. To combat this trend, one incentive to preserve, restore or even intentionally enlarge TALS could be agri-environmental schemes (Dytrtova et al., 2016).

Other new cores were formed by new or restored water related elements, which served as means of flood protection and water retention. This is important especially nowadays, when we face the increasing impact of climate change, which is often expressed by either drought or floods and most pronounced in warm and dry regions, such as our study area.

Connectors in the form of bridges and loops were recruited mainly from non-forest woody vegetation and grassland strips. Grassland strips were intentionally sowed on slopes in the form of soil erosion control, and grassed belts as part of agri-environmental schemes or in river valleys as part of flood control measures. The spread of non-forest woody vegetation can be attributed to unintentional as well as intentional factors. Unintentional factors are connected with the already-mentioned large terracing during the socialist period, where the non-forest woody vegetation developed spontaneously on steep slopes, but also with the abandonment of orchards, which become gradually overgrown. Intentional factors include the planting of tree alleys along roads and planting bio-centres and bio-corridors in order to create an ecological network. The creation of ecological networks is obligatory in territorial plans in the Czech Republic (Decree No. 500/2006 Coll, 2007Decree No. 500/2006 Coll, 2007).

## 5. Conclusions

Our results show that the reduction of GI during the past 170 years indeed negatively affected its connectivity. This was mainly due to the loss of large patches of grasslands and water bodies, which already occurred at the end of 19th and the beginning of the 20th century during the first wave of agricultural intensification in the studied region. The socialist era contributed to further reductions of GI.

Reductions of GI led to an increase of agriculturally managed areas, with the easier use of large machines, more possibilities to implement precise agriculture (Reznik et al., 2016) and the loss of habitats for perceived agricultural pests. This resulted in smaller economic expenses and higher gains. However, reductions of GI also meant a smaller number of pollinators, the loss of habitats for predators and the loss of water retention leading to increased soil erosion. As a result, more fertilizers and pesticides had to be used, which meant higher economic expenses.

Currently, the decline in GI connectivity is being slightly reversed due to the introduction of ecological networks based on territorial planning as well as the restoration of other near natural elements with the help of agri-environmental schemes and other nature conservation measures. However, our study shows that TALSs play an important role in GI connectivity as well and therefore should be supported. Moreover, since TALSs also offer economic gain (in the form of fruit or vegetables), they can be seen as a more appealing measure for boosting GI connectivity.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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