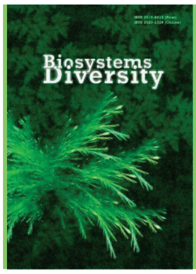

Biosystems Diversity

ISSN 2519-8513 (Print)
ISSN 2520-2529 (Online)
Biosyst. Divers.,
2023, 31(2), 147–157
doi: 10.15421/012315

Development of indicators for assessment of green infrastructure for a territorial network of ecological stability

J. Špulerová*, D. Štefunková*, C. Kulcsár**, H. Kalivoda*, M. Vlachovičová*, D. Kočický***

*Institute of Landscape Ecology, Slovak Academy of Sciences, Bratislava, Slovakia
**Constantine the Philosopher University in Nitra, Nitra, Slovakia
***ESPRIT spol. s r.o., Banská Štiavnica, Slovakia

Article info

Received 05.04.2023
Received in revised form 01.05.2023
Accepted 02.05.2023

Institute of Landscape Ecology, Slovak Academy of Sciences, Štefánikova, 3, Bratislava, 81499, Slovakia. Tel: +4212-232293628. E-mail: jana.spulerova@savba.sk

Constantine the Philosopher University in Nitra, Tr. A. Hlinku, 1, Nitra, 94901, Slovakia. Tel.: +421-37-640-85-95. E-mail: kulcsab@gmail.com

ESPRIT spol. s r.o., Pletiarska, 2, Banská Štiavnica, 96901, Slovakia. E-mail: +421-917-497-748. E-mail: kocicky@esprit-bs.sk

Špulerová, J., Štefunková, D., Kulcsár, C., Kalivoda, H., Vlachovičová, M., & Kočický, D. (2023). Development of indicators for assessment of green infrastructure for a territorial network of ecological stability. Biosystems Diversity, 31(2), 147–157. doi:10.15421/012315

Landscape structure and biotic indicators have a significant role in assessing the green infrastructure of a landscape and design of a territorial ecological network. In this contribution, a methodological approach has been developed for assessing and defining indicators of current land use and biota that can be used for designing a territorial network of ecological stability. We used the assessment of ecological stability of the elements of the current landscape structure, an index of the ecological stability of a representative geo-ecosystem, the cumulative effect of high ecological stability landscape elements, and the Shannon Diversity Index (SHDI) to measure the degree of entropy, or landscape diversity. The assessment of biota was based on qualitative habitat field data and an evaluation of their overall nature conservation importance based on the type of land cover and habitats, the importance of habitats, their current conservation status, how many rare habitats are in a region, and how many vulnerable species are present in habitats. The assessment was applied on a local level, using the example of the Dolný Lopašov study area. The spatial distribution of green infrastructure is not balanced within the study area. The most significant elements of the ecological network consist of natural and semi-natural habitats that have a favourable conservation status. The Malé Karpaty Mountains, situated in the northern region, are forest-covered and have the highest ecological stability. Intensively cultivated fields are dominant in the central and southern parts of the study areas and are characterised by a low proportion of green infrastructure and low ecological stability. The results of the modelling of the cumulative impact of landscape elements on ecological stability by distance show that the cumulative impact of woodland elements positively affects the ecological stability of the area, especially in the area of intensively cultivated fields, an element with a low degree of ecological stability. Using selected indicators of current landscape structure and biota helps to assess the overall ecological stability of the area, identify the most stable areas, as well as areas with the lowest ecological stability, where it is necessary to complete and design new elements of green infrastructure to increase the function of the ecological network.

Keywords: landscape structure; biodiversity; nature conservation value; indicators; ecological networks.

Introduction

The territorial network of ecological stability is the pattern of the ecological network in space. It is made up of ecosystems and their elements that are connected and help support a variety of life conditions in the landscape. An important part of the territorial ecological network is also a proposal of measures for the ecologically optimal structure and management of the landscape. The methodological approach is based on the concept and previous experience with the methodological guidelines for the creation of the territorial network of ecological stability (Kubeš, 1996; Mackovčin, 2000; Miklós et al., 2019; Endel et al., 2020) and on legislative regulations (National Council of the Slovak Republic, 2002). The concept is based on the idea of "spatial ecological stability" of the landscape, which is the ability of the landscape pattern to keep ecological relationships between individual ecosystems even though conditions and life forms change over time. This is true even if the landscape is made up of ecosystems with different (or even low) degrees of ecological stability. This state of the landscape can be maintained by preserving both the "internal" ecological stability of the landscape's key stabilising elements and the spatial network of ecosystems that are not isolated from each other (Miklos, 1996).

The aim of designing the ecological network is (1) to preserve and support the development of the natural capital of the landscape, including natural resources and biodiversity; (2) to preserve and supplement landscape stability and to ensure the favourable effect of eco-stabilising elements on the surrounding, ecologically less stable landscapes; (3) to support the multifunctional use of the landscape with the aim of protecting the individual components of the environment; (4) to preserve significant landscape elements; and (5) to eliminate pressures and threats to natural capital.

The current landscape structure is described and shown on a map as an important part of the analysis for the design of the territorial ecological network. The current landscape structure reflects current land use and the impact of human activity on the biotic and abiotic components of the landscape, as well as the degree of human transformation of the landscape. It indicates the current state of the biota and the economic utilisation of the territory. The interpretations are based on the choice of selective, spatial, and implementation indicators for the creation of ecological networks, with a focus on how the ecological quality of the landscape structure is interpreted. There are a lot of ways to measure landscape diversity, biodiversity, and green infrastructure indices.

Systematically choosing the best landscape elements and indicators is important. Indicators are expected to have a number of useful functions, such as communicating and raising awareness, monitoring and evaluating performance, providing early warning functions, and improving the quality of decisions (Lehtonen et al., 2016). Besides that, the data sources for monitoring and evaluation must be very clear. The amount of different types of land cover, the fragmentation or connectivity of habitat patches, or the proximity of land cover types to certain features are all indicators of ecological quality and stability of landscape structure. Other landscape metrics are quantitative measurements of the structure and configuration of landscape elements, like patch size, shape, and connectivity. They can be used to assess habitat fragmentation, and other aspects of ecological network connectivity.

The ecological connection of fragmented habitats in intensively managed landscapes would be significantly improved by an ecological network plan of ecological corridors (Hong et al., 2013). Plant, animal, or microorganism species can be used as indicators of the biotic value of the landscape, manifested at the level of the habitat, population, or individual (Szili-Kovács et al., 2011). Hemeroby is an integrated indicator for measuring human impacts on environmental systems. Landscape fragmentation is an indicator that, when it reaches and exceeds favourable and sustainable limits, negatively affects biodiversity and the quality of human life. It progresses inconspicuously in time and space, and the consequences become apparent only later. More comprehensive assessments and methodological reports in Europe and worldwide pay considerable attention to fragmentation in relation to ecosystem quality and species diversity conservation (Ružičková, 2007). The Plant Diversity Index is an indicator of great scientific importance and has a high potential to map scale shifts caused by climate change. Given the slow and long-term response of plant species to climate change compared to animal species, they point to long-term trends while short-term fluctuations can be reliably explained (Schliep et al., 2018). Migratory indicators have increased physiological stability. As the environment changes, their range of distribution changes slowly, and they become less able to adapt to the new situation in their original environment (Szigyártó & Fodorpataki, 2009). Although landscape and biota indicators are frequently used to evaluate the ecological condition of the environment, it is not well understood how these indicators capture the spatial distribution of land cover (Fernandez et al., 2019).

This paper is focused on the development of indicators for ecological network design and highlights the role of landscape structure and biotic indicators in assessing the green infrastructure of a landscape. The goal of the study is to come up with a methodological approach and choose biota and landscape structure indicators that will help design the territorial network of ecological stability appropriately. The approach is applied to the local case study of Dolný Lopasov.

Material and methods

The landscape structure and biota are a baseline for the delineation of elements of the territorial ecological network, such as biocenters, biocorridors, and interactive features. The design of the ecological network is the result of the following subsequent steps: I – analysis; II – synthesis; III – interpretation; IV – evaluation; and V – proposals (Miklós et al., 2019). Our assessment is based on analyses, synthesis, and interpretations of the current landscape structure and biota.

Analysis of the current landscape structure involves the spatial mapping of the different categories of landscape elements that show how the earth's surface is covered. The result of the analysis is a map of the current landscape structure. The categories of mapping elements are defined at the resolution level on a scale of 1:10,000. At the most basic level of the hierarchy, the landscape elements are divided into six main groups: (1) woodlands; (2) grasslands; (3) agricultural crops; (4) bedrock, outcrops, and raw soils; (5) surface waters and wetlands; and (6) settlements and built-up areas; which are further subdivided into four hierarchical levels (see example of division of elements of green infrastructure – Table 1). At each level, the criteria for classification are based on ecological and environmental connections and landscape-ecological processes.

We have chosen the following indicators for the evaluation and interpretation of the current landscape structure that will form the basis for the evaluation and design of territorial ecological network elements.

The assessment of current landscape elements in terms of ecological stability expresses the natural-anthropogenic constancy of vegetation, which is their natural ability to maintain a stable species composition even without additional input such as mowing, grazing, removal of tree growth, etc. (Ružičková, 1990). It is assumed that the degree of ecological stability is directly related to the degree of naturalness and inversely related to the intensity of human disturbance of the ecosystem. There are many ways to assess the degree of human disturbance to landscape features, and expert assessment is one of them. For our study, experts rated the ecological stability of landscape features on a scale from 0.1 (no importance, like built-up areas and roads with asphalt or paved surfaces) to 1 (very high importance, like natural and primeval forests, natural grassland, wetlands, peat lands, natural watercourses, and water bodies, including banks, with typical aquatic and riparian communities) (Table 1).

The coefficient of ecological stability (C_{es}) for a given area was calculated using the degree of ecological stability of landscape elements and their area. We calculated C_{es} for the overall case study area and for representative geoecoregions (Miklós et al., 2006) that extend into the study area. The coefficient is calculated as the ratio of the ecologically stable area to the total area of the studied area, which could be a geoecoregion, municipality area, or region (Miklos, 1996). C_{es} values range from 1 (very high C_{es}) to 5 (very low C_{es}).

We also analysed the cumulative impact of landscape elements with high ecological stability. This indicator can be defined as a measure of the total geometric distance from the landscape features with a higher to very high ecological stability value to any point in the study area. The degree to which any point in the study area is ecologically stable depends on how far away it is from eco-stabilizing landscape elements.

We calculated the resulting coefficient of ecological stability of each raster cell as a weighted average of the degree of stability of the cells in the defined circular neighbourhood, with the cell weight decreasing linearly with increasing distance. Thus, the coefficient of ecological stability for each raster cell is calculated according to Eq:

$$C_{es} = \frac{\sum k_{ij}\left(1 - \frac{d_{ij}}{r}\right)}{\sum\left(1 - \frac{d_{ij}}{r}\right)};\ d_{ij} \le r$$

where: C_{esij} – the coefficient of ecological stability of the raster cell, r – the radius of the circular neighbourhood of the cell, k_{ij} – the degree of ecological stability of the *ij*-th cell in the circular neighbourhood; and d_{ij} – the distance of the *ij*-th cell from the centre of the circular neighbourhood.

We experimentally determined the size of the circular neighbourhood, which used to be r = 200 m. The result is a continuous raster of the degree of ecological stability, which for a given point also takes into account the degree of influence of the ecological stability of the surrounding elements, thus comprehensively reflecting the configuration and composition of the current landscape structure in the vicinity of the evaluated point.

The buffer zone was set up along the edge of landscape features with high ecological stability. So, we have identified places where the impact of ecologically stable landscape elements is low and where new green infrastructure needs to be designed.

Entropy is a common and useful indicator of spatial landscape structure. In the context of a spatial landscape structure, entropy will be understood in such a way that the greater the disorder and diversity there are in the way the landscape structure elements are distributed, the higher the entropy level. The Shannon Diversity Index (SHDI), which measures the diversity of each type of landscape element, can be used to show how much entropy or landscape diversity there is. The SHDI value increases with the number of patches in the landscape feature categories. If there is only one patch in a current landscape structure category, then the SHDI is equal to zero. The larger the index value, the greater the heterogeneity of current landscape features. The SHDI was calculated for the whole study area and compared to the highest SHDI values for all of Slovakia's municipalities.

Following the calculation of SHDI, we looked at some simple spatial characteristics of selected types of landscape elements, such as the average size of a landscape feature patch (ha), the overall length of a landscape feature (km), the average length of landscape feature edges (km), the number of landscape features, and the count of landscape feature types.

The current landscape structure categories provide a spatial framework for the qualitative aspects of the biota, in particular habitat distributions and species composition.

The main goal of the biota assessment for the design of the territorial ecological network is to map and evaluate the diversity of native plant and animal species and their communities in the area. The subject of the analyses is the quantitative and qualitative characteristics of the flora and fauna. In the quantitative assessment, the location and size of natural features in the landscape are looked at. The qualitative characteristic focuses on species composition and distribution of habitat types (most common, rare, unique, endangered, and threatened).

Existing maps, a review of the data, studies, and literature, data from the State Nature Conservancy's database (SNC SR, 2020, Complex informative and monitoring system – State Nature Conservancy of the Slovak Republic. www.biomonitoring.sk), and a field survey all played a role in the processing of the distribution of animal and plant habitats. The goal of the field survey was to make detailed maps of habitats, update existing data on current flora, find important flora species, and map the distribution of invasive species, which threaten natural and semi-natural habitats (Medvecka et al., 2012). Plant habitats are assigned to vegetation units according to the Catalogue of Habitats of Slovakia (Ružičková et al., 1996; Stanová & Valachovič, 2002).

Table 1
Detailed 4th level legend of current landscape structure and degree of ecological stability

1st level	Code	2nd level	Code	3rd level	Code	4th level	Degree of ecological stability
1. woodland	11	forests	111	broad-leaved forests	1111	continuous	0.75–1.0
					1112	discontinuous	0.5–0.75
			112	coniferous forests	1121	continuous	0.75–1.0
					1122	discontinuous	0.5–0.75
			113	mixed forests	1131	continuous	0.75–1.0
					1132	discontinuous	0.5–0.75
	12	transitional woodlands	121	forest clearings	1211	managed	0.5
					1212	unmanaged	0.5–0.75
			122	logging sites	1221	young	0.2–0.5
					1222	overgrown	0.75
			123	calamity	1231	young	0.4–0.6
					1232	overgrown	0.6
					1233	managed	0.4–0.6
			124	plantation of energy woods	1240	uncategorized	0.4
			125	forest nurseries	1250	uncategorized	0.5
	13	non-forest woody vegetation	131	small woodlands	1311	broad leaved	0.8
					1312	coniferous	0.8
					1313	mixed	0.8
			132	group of trees	1321	broad leaved	0.7
					1322	coniferous	0.7
					1323	mixed	0.7
			133	linear woody vegetation	1331	alley	0.7
					1332	riparian woodland	0.7
					1333	field edges	0.7
					1334	stabilised potholes	0.7
			134	shrubs	1341	broad leaved	0.8
					1342	coniferous	0.8
					1343	mixed	0.8
2. grasslands	21	permanent grasslands	211	permanent grasslands (meadows and pastures)	2111	without woods	0.6
					2112	with scattered woods	0.7
			212	abandoned grassland and grass-herbaceous vegetation	2120	uncategorized	0.7
			213	semi natural/natural grassland and grass-herbaceous vegetation	2130	uncategorized	1.0

Characteristics of the fauna focused on vertebrates (Vertebrata), such as Amphibia, Reptilia, and Aves, and on invertebrates, such as Crustacea, Isopoda, Orthoptera, Coleoptera, and Lepidoptera.

The result of the synthesis of current land cover and the habitats of plants and animals is the description and map of habitats. These are made up of information about data relevant to current landscape elements and habitats of plant and animal species.

The interpretation and assessment of current landscape structure and biota is one of the key steps in the design of a territorial ecological network. Out of the many possible ways to evaluate habitats for the purpose of designing a territorial ecological network, we chose the following indicators, which are part of the overall assessment of the nature conservation importance (NCI) of habitats:

– *Significance of habitats*: the classification of habitats according to their significance is based on the Habitats Directive (Council Directive 92/43/EEC) and the Decree of the Ministry of Environment of the Slovak Republic No. 24/2003 Coll., which implements Act No. 543/2002 Coll., as amended. Habitats are divided into habitats of European importance (E), habitats of national importance (N), and other unlisted habitats (O).

– *Current conservation status*: a methodology has been developed to assess the current conservation status (favourable, unfavourable inadequate, unfavourable bad, or unknown) for species and habitats of European importance, according to Article 17 of the EU Habitats Directive. Habitat condition assessment is based on monitoring data collected directly in the field. It includes the quality assessment of the habitat (species richness, species composition, structural characteristics, presence of representative species, naturalness degree), and the future perspectives of the habitat (based on the assessment of the current management, the degree of fragmentation or naturalness of habitats, threats by invasive species, and threats from humans).

– *Regional rarity*: the habitat distribution on the local level can be determined in the following categories: A common habitat; B a rare habitat; and C unique and rare habitats. When assessing the distribution of the habitat at the local level, we can take into account the regional and national distribution of certain habitats, their current conservation status, and the level of human degradation within the Natura 2000 network.

– The species vulnerability of habitats is assessed on the basis of the occurrence of protected, critically endangered, vulnerable, rare, and endemic species of plants and animals, or regionally rare species (lists of species according to the Decree of the Ministry of Environment No. 24/2003 Coll., 543/2002 Coll. on Nature and Landscape Protection), and red-listed species (Eliáš et al., 2015). Based on the occurrence of species, we divided habitats into three categories: 1 – habitat with common species; 3 – habitat with sporadic occurrence of rare and endangered taxa (1–10 species in the habitat); and 5 – habitat significant by the occurrence of rare and endangered species (more than 10 individuals, more species).

Based on the sum of all assessed indicators, we classified habitats into five categories of overall nature conservation importance (NCI), from very significant to insignificant. The interpretation of current landscape structure and biotic complex indicators is primarily concerned with determining the intrinsic ecological quality (stability) of current landscape elements in terms of fulfilling the eco-stabilisation function, which is based on the landscape structure's ecological and biological characteristics. The output of the further assessment is the determination of the suitability of individual biotopes to fulfil specific functions in the local territorial ecological network and the visualization of the obtained results on the maps – the assessment of nature conservation importance for habitats.

The methodological assessment was applied to the study area of Dolný Lopašov (with an area 2,292 ha), situated in the Trnava region, Piešťany district (Fig. 1). The total number of inhabitants is 983 (Statistical Office SR (2022). Population and Housing Census. www.scitanie.sk). The settlement consists of a line of housing along the Lopašovský brook, with adjacent other streets that form built-up areas and gardens. The northern part consists of the forests of the Malé Karpaty Mts, and the southern part is part of the Trnavská tabuľa that is intensively used for agriculture without special boundary features (mostly country roads).

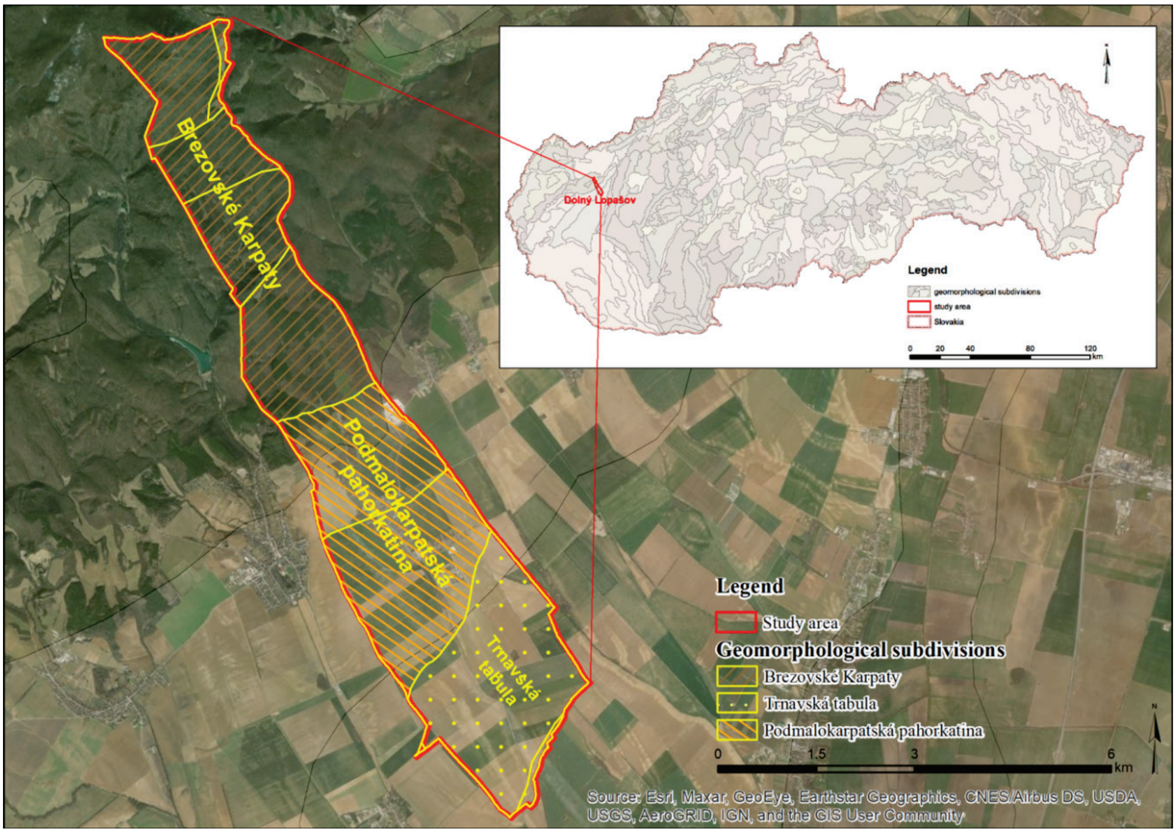

Fig. 1. Dolný Lopašov study area with geomorphological subdivisions indicated

Special Areas of Conservation (SACs) designated under the Habitat Directive (SKUEV0278 Brezovské Karpaty, 51.72 ha of total 2,670.950 ha); Sites of Community Importance (SCIs designated under the Birds Directive – SKCHV014 Malé Karpaty (944 ha of total 52,458.48 ha); and SKCHV054 Špačinsko-nižnianske polia (697 ha of total 12,155.66 ha).

The objects of protection of SKUEV0278 Brezovské Karpaty are vulnerable, protected, and rare habitats and species. SKCHVÚ054 Špačinsko-nižnianske polia were declared in order to protect and ensure the favourable condition of the habitats of bird species of European importance and the habitats of migratory bird species, like the *Falco cherrug*, and to ensure the conditions for their survival and reproduction. SKCHVÚ014 Malé Karpaty is one of the three most important breeding territories in Slovakia for *Falco cherrug*, *Pernis apivorus*, and *Dendrocopos medius*.

Results

Current land cover and green infrastructure. The current land cover is dominated by agricultural crops, covering 1222.58 ha (53.4% of the study area), followed by woodland and scrubland on 924.48 ha (40.3%), built-up areas on 98.03 ha (4.3%), grassland on 33.93 ha (1.5%), and bedrock outcrops and raw soils on 11.24 ha (0.5%). The arrangement of the landscape elements shows that the landscape of the study area is strongly divided. The northern part of the territory consists almost entirely of continuous forest, while in the southern part of the territory, intensively cultivated fields dominate with very little green infrastructure. In the spatial analysis of the current landscape structure, we focused on choosing the landscape elements that, in the southern part of the territory, form the basic matrix of ecologically unstable land use, which is arable land; and also patches and corridors of green infrastructure with high ecological stability and the potential to affect the nearby poorly stable ecosystems, which are made up of non-forest woody vegetation and grassland.

The spatial characteristics of selected landscape elements at the 4th hierarchical level are summarised in Table 2. The average size of the arable land plot is 23 ha, which are relatively large plots used for growing annual crops. The average size of a single plot of grassland, scrubland, and woodland is significantly smaller compared to arable land. At the same time, however, due to the predominantly linear shape of the green infrastructure plots, the length-to-area ratio of the arable land boundary is significantly lower for arable land than for non-forest woody vegetation and grassland. Even considering the significant disproportions in the sizes of the areas of ecologically stable and unstable landscape elements, it can be stated that the elements of the current green infrastructure have, in some places, due to the length of their boundaries, the assumption of better interaction with the prevailing ecologically unstable intensively cultivated land.

The values of the shape and size of the current landscape elements indicate that individual elements cover a fairly large area, but the edges of the elements are rough, which is a prerequisite for good ecosystem interactions in some places. At the same time, the composition of the woodland, scrubland, and grassland is made up of a total of 11 different landscape types, amounting to 75 landscape elements. Arable land and perennial crops (orchards) represent only two landscape types, covering an area of 1224 ha. The green infrastructure is composed of forest, non-forested woody habitats, and grassland.

Forest and non-forest woody habitats. According to the division of forests, deciduous forests prevail on 686 ha, occupying the northern and central parts of the forest massif of the Malé Karpaty Mts. Coniferous forests, which occupy 139.22 ha, are located rather on the southern boundary of the forests, in contact with the agricultural landscape. Mixed forests are scattered throughout 45 ha of the forest area. In the tree species composition of the forest, the most abundant are oak and beech. In terms of naturalness, there are more non-native tree species, with dominant *Pinus nigra*, which covers 9% of the area, and *Robinia pseudoacacia*, which covers almost 3% of the forest area. These species mainly occupy the southern part of the forest massif. The isolated woodland in the southern part of the area is a fragment of the original floodplain forests that were present before the watercourse modifications in the area.

Table 2
Spatial characteristics of selected current landscape elements in the study area of Dolný Lopašov

CLS category (2nd hierarchical level)	Area, ha	%	Average size of landscape elements, ha	Average length of edges, km	Ratio of average length of edges and size of elements	No of landscape categories*
Non-forest woody vegetation	924.48	40.32	1.19	0.82	0.69	7
Grassland	33.93	1.49	0.72	0.47	0.65	4
Arable land	1222.58	53.36	23.07	2.33	0.10	1
Orchards	1.13	0.05	1.13	0.60	0.60	1

Note: number of current landscape categories in the most detailed 4th hierarchical level of the current landscape structure legend.

Small, isolated forests, groups of trees, linear woody habitats, and scrubland are present on 33 ha (1.5% of the area), mostly in the intensively cultivated agricultural landscape or in the vicinity of the settlement and at the transition of the agricultural landscape into the forest zone. The tree lines form a newly established windbreak along the Vrbové-Rakovice bike path, and alleys of fruit trees are often planted around the roads.

Permanent grasslands, which include meadows and pastures, are natural, semi-natural, or human-made habitats that make up about 2% (36 ha) of the study area. They are mostly located in the transition between agricultural and forest landscapes. The most significant are the semi-natural grasslands and natural xerothermic grasslands (Nature Reserve Pod holým vrchom), the former dolomite mining area, and areas of limestone bedrock above the village. Other grasslands are intensively used without trees and shrubs.

Assessment of ecological stability. The coefficient of ecological stability (C_{es}) was assessed for the geomorphological regions of Brezovské Karpaty (0.866), Podmalokarpatská pahorkatina upland (0.227), and Trnavská tabuľa (0.206). The coefficient values indicate the different degree of ecological stability and the need to increase ecological stability in the region of the Podmalokarpatská pahorkatina and Trnavská tabuľa, where the values were influenced by the dominant intensively cultivated fields.

Ecological quality of the spatial landscape structure. Elements of the current landscape structure with a high C_{es} are mainly forests, scrubland, and grassland. The results of the modelling of the cumulative impact of C_{es} elements by distance show that the cumulative impact of woodland elements, such as edges of continuous forest, isolated woodland, lines of trees, watercourses, herbal strips, and grassland, as well as gardens in the village, positively affects the ecological stability of the area, especially in intensively cultivated landscapes (Fig. 2). The positive impact is particularly evident at the transition between forest and agricultural landscapes. However, in locations where the cumulative impact of the existing green infrastructure is low, the priority is to add elements of woody vegetation, grassland, or implement other eco-stabilisation measures.

Assessment of the spatial diversity of the landscape according to the entropy level. The Shannon diversity index (SHDI) value of 1.39 for Dolný Lopašov is lower than the average value of municipalities in Slovakia (1.59, max 2.68). The SHDI value points out that the main problem with the territory's landscape ecosystem structure is its low diversity.

Habitat assessment. The real vegetation is significantly different from the potential vegetation. The real vegetation is the result of natural potential and long-term human intervention in nature. Based on the characteristics of natural, semi-natural, and man-made biotopes in the current land cover, we have distinguished the following groups of real vegetation in the area:

– forest (deciduous, coniferous, and mixed forests);
– non-forest woody vegetation (scrub habitats, succession stands, man-made conditioned habitats of patches, and linear woody vegetation);
– xerothermic grasslands and dryland;
– permanent grassland (intensive and extensive grassland);
– aquatic biotopes (vegetation of flowing and still waters), non-forest riparian biotopes, wetlands (reed communities);
– segetal vegetation of an open agricultural landscape (orchards, plantations, fallow land or segetal vegetation of arable land);
– urban biotopes (parks, decorative gardens, ruderal vegetation).

The assessment includes a list of protected plant species and important functional groups of animals (key, umbrella species) that need priority attention. Several vulnerable, rare, or protected plant species were recorded in these biotopes (Table 3).

Table 3
Protected and rare plant species in Dolný Lopašov study area

Species name	Protection	Vulnerability	Habitat code
Adonis vernalis	N	NT	Tr1
Cephalanthera damasonium	N	NT	Tr1, Kr2b, Kr6
C. longifolia	N	NT	Tr1
Dianthus praecox subsp. *lumnitzeri*	N	NT	Tr1, Kr2b, Kr6
Fumana procumbens	N	NT	Tr1, Kr2b, Kr6
Minuartia glaucina	N	NT	Tr1, Kr2b, Kr6
Orchis militaris	N	NT	Tr1, Kr2b, Kr6
O. morio	N	NT	Tr1
O. purpurea	N	NT	Tr1
Stipa pulcherrima	N	NT	Tr1, Kr2b, Kr6
Scorzonera purpurea	N	NT	Tr1

Notes: category of protection (as defined in the Decree of ME SR, 2003): N – protected species of national importance; E – protected species of European importance; * – priority species of community importance; category of vulnerability according to the Red List (Eliáš et al., 2015) – NT (Near Threatened) in accordance with the IUCN (International Union for Conservation of Nature); Habitat code according to Table 4.

Animals and their zoocenoses. The diverse landscape structure of the study area provides favourable living conditions for a variety of animal groups, many of which are protected or endangered (Table 4).

The fauna of Orthoptera is particularly rich in xerothermic biotopes. The Neuroptera are a distinct group of insects that live primarily on the warm and xerothermic slopes of the Malé Karpaty Mts. Coleoptera is another group of insects with a lot of different species and traits. The rarest species of Coleoptera live in old deciduous forests, riparian forests, tree alleys, grazing forests, and parks with a lot of dead trees. The Western Carpathian endemic *Julus curvicornis* is one of the most notable Diplopoda. The Malé Karpaty Mts. represent the area with the westernmost recorded occurrence (Stasiov, 2005). Lepidoptera is a diverse group of insects that prefer well-lit and flower-rich forest edges, forest roads, clearings, meadows, ecotones, and forest mantle species, which are mostly found near stands of flowering shrubs in the Malé Karpaty Mts' foothills. They create the main sources of food for the imago of these species. These species can only live in well-kept, warm, calcareous, and mostly limestone-based habitats. They occur in the study area in an island-like pattern.

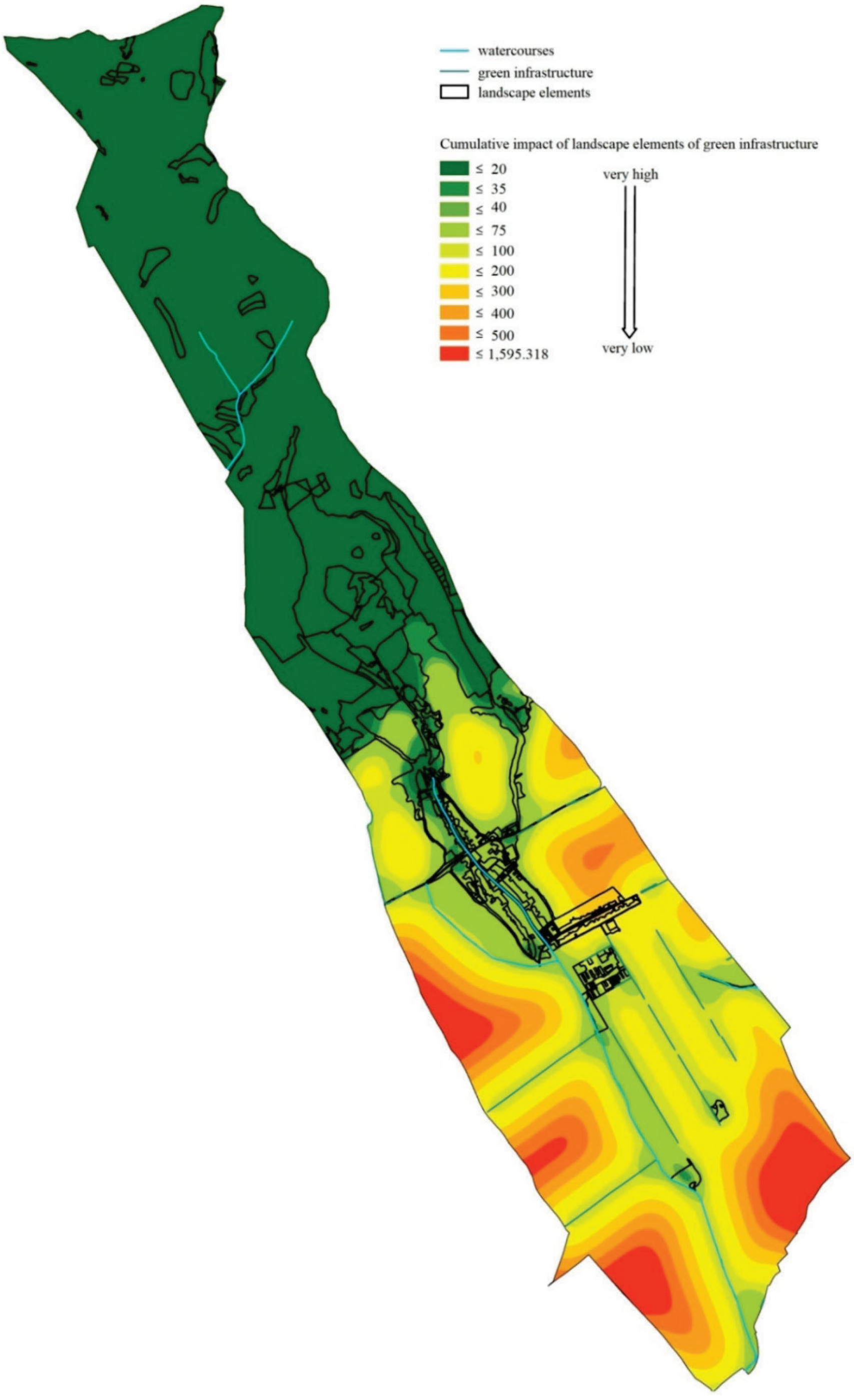

Fig. 2. Cumulative impact of landscape elements with a high coefficient of ecological stability according to distance

Amphibians are associated with aquatic and wetland habitats; they cover only a small percentage of the study area, and the water level in them fluctuates seasonally (Lopašovský or Bukovinsky brook; wetland in the poplar forest in the part of Trstina from Duboviansky). For various developmental stages, many species use temporary water-logging in depressions in the terrain.

Steppe and forest-steppe habitats are suitable habitats for the species *Lacerta viridis*, while *Zamenis longissimus* prefers the southern slopes and, more rarely, the *Coronella austriaca*.

Most of the Dolný Lopašov study area is part of the Special Protection Areas (SPAs): the SPA Malé Karpaty Mts and the SPA Špačinsko-nižnianske polia. The only object of protection in the SPA Špačinsko-nižnianske polia is *Falco cherrug*.

The most abundant terrestrial mammals in the area are concentrated in Carpathian deciduous forests, which are also an important corridor for the migration of animals associated with forest habitats. The Klenová Cave (535 m above sea level) on the north-eastern slope of Klenová is a well-known wintering location for bats in the Dolný Lopašov study area.

Assessment of nature conservation importance of habitats. As a result of the synthesis of current land cover, real vegetation, and animal biotopes, we have identified six important habitats characteristic of the study area of Dolný Lopašov.

I. Forest habitats form continuous habitats with zoocenoses of forest complexes in the north-western part of the study areas, in the Malé Karpaty Mts. These continuous forest complexes form forest habitats of European importance such as 91H0* Pannonian woods with *Quercus pubescens*, 9180* *Tilio-Acerion* forests on slopes, screes and ravines, 9130 *Asperulo-Fagetum* beech forests, 9150 Medio-European limestone beech forests (*Cephalanthero-Fagion*). At lower elevations is the nationally important habitat Ls2.1 Oak-hornbeam forest. Some of the forests have been altered and consist of pine plantations (AP5.2). In the northern part of the area the Chtelnicky brook rises, around which alder floodplain forests have developed (91E0* Mixed ash-alder alluvial forests of temperate and boreal Europe (*Alno-Padion*, *Alnion incanae*, *Salicion albae*)). Carpathian forests create suitable habitats for invertebrates and a rich fauna of Diplopoda. Epigeic communities of Araneae are represented in oak-hornbeam forests, which also migrate here from adjacent agrocenosis habitats. The original forest communities and old trees form suitable habitats for beetles and cavity nesters, many of which are species of European importance. The woodlands form an important habitat in terms of the number and density of breeding and non-breeding bird species. They are home for abundant small terrestrial and medium to large terrestrial mammals. Forests close to settlement are rather modified mixed woodland, consisting of plantations of non-native tree species – *Robinia pseudoaccacia* plantations.

Table 4
Protected animal species in the Dolný Lopašov study area (as defined in the Decree of ME SR, 2003): protected species of national importance; bold font: protected species of European or Community importance

Habitat	Animal group/Species
Forest	Coleoptera: *Lucanus cervus*, ***Cerambyx cerdo***, ***Osmoderma eremita***, ***Rosalia alpina***, ***Cucujus cinnaberinus***, *Limoniscus violaceus*, ***Carabus variolosus*** Lepidoptera: *Callimorpha quadripunctaria;* Amphibia: *Salamandra salamandra*, ***Bombina bombina,*** *Rana temporaria* Reptilia: *Anguis fragilis, Natrix natrix* Aves: ***Dryocopus martius, Dendrocoptes medius, Dendrocopos syriacus, Picus canus, Ficedula albicollis, Ficedula parva;*** Mammalia: ***Barbastella barbastellus***, *Plecotus auritus,*
Grassland (including meadows and pastures)	Lepidoptera: ***Parnassius mnemosyne, Lycaena dispar,*** *Callimorpha quadripunctaria* Aves: ***Lanius collurio,*** *Saxicola torquata*
Steppic habitats	Lepidoptera: ***Eriogaster catax,*** Mantodea: *Mantis religiosa,* Neuroptera: *Libelloides macaronius*
Rock habitats (cliffs, cliff walls and steppic treeless forest)	Mantodea: *Mantis religiosa* Reptilia: *Lacerta viridis, Zamenis longissimus, Coronella austriaca*
Cave	Mammalia: ***Barbastella barbastellus***, *Plecotus auritus*, ***Rhinolophus hipposideros***, *Myotis daubentonii*
Reed communities, wetland	Amphibia: *Pseudepidalea viridis, Pelobates fuscus, Rana dalmatina* Reptilia: *Natrix natrix;* Aves: ***Circus aeruginosus***
Segetal habitats of open agricultural landscape	Aves: ***Falco cherrug, Aquila heliaca, Circus pygargus, Perdix perdix, Lanius minor; Lanius collurio;*** Mammalia: *Cricetus cricetus*
Urban habitats	Lepidoptera: ***Lycaena dispar*** Mantodea: *Mantis religiosa* Amphibia: *Pseudepidalea viridis, Hyla arborea,* Reptilia: *Natrix natrix;* Aves: *Jynx torquilla, Galerida cristata*

II. Grassland habitats are situated next to forest of the Malé Karpaty Mts in the zone of Podmalokarpatská pahorkatina upland. They consist of zoocenozes of grassland and 6510 Lowland hay meadows (*Alopecurus pratensis*, *Sanguisorba officinalis*); 6210 Semi-natural dry grasslands and scrubland on calcareous substrates (*Festuco-Brometalia*) and Tr6 Xerothermophile fringes. With decreasing intensity of management, grassland communities form mosaics with scrub habitats 5130 *Juniperus communis* formations on heaths or calcareous grasslands or 40A0* Continental deciduous thickets. Xerothermic habitats provide suitable habitats for a rich fauna of Orthoptera, including some of the rarer species. They also support a rich and diverse Lepidoptera or Reptilia, many of which are listed as protected and rare endangered species. Several bird species also find suitable conditions for nesting, breeding or food (*Lanius* sp., *Saxicola* sp.) or suitable habitats for rest and collecting food during migration.

III. Habitats of open agricultural landscape are situated in the south-eastern part of the study with intensively cultivated agricultural landscape with zoocenoses linked to open countryside. These habitats generally consist of intensively cultivated fields complemented by mosaics of non-forest woody vegetation – remnants of Kr9 Riparian willow formation, AP1 Plantation of fruit trees, AP3.1 Plantations of introduced deciduous trees – Poplar plantations, AP6 Mixed stands of pioneer succession trees, AP7.2 Mixed stands of non-native tree species, 40A0* Continental deciduous thickets or narrow strips of X3 Nitrophilous ruderal vegetation of open landscape. The area is also part of the SPA Špačinsko-nižnianske polia, the subject of protection is *Falco cherrug* (the species currently nests in birdhouses on very high-tension pylons). The area is also important as a breeding and hunting territory for other common and rare (*Aquila heliaca*, *Circus pygargus*) bird species. Solitary trees, tree plantations and small woodlands in agricultural landscapes are an important resting place and viewpoint for many raptors when hunting. Arable fields are home to small ground mammals, and these provide a food supply for raptors and owls as well as foxes. Birds of prey are a fairly effective biological control against vole over-abundance. Added value for birds is the alfalfa stands, with retention of stubble in autumn and winter, and the higher proportion of grassland strips along field roads.

IV. Habitats of urban settlement – are associated with built-up areas and active quarries, where they provide conditions for zoocenoses of human conditioned habitats. In urban settlement, there are AP10.1 intensively seeded and fertilised grassland, including playing fields and lawns and AP7.1 Mixed stands of native tree species. The quarries form conditions for Sk7 Secondary scree and rock habitats. Synanthropic or common bird species are more likely to be associated with these habitats, and occurrences of vulnerable species are rarer. For several invertebrate species, on the other hand, quarries represent a suitable secondary habitat and can also be inhabited by ecological specialists bound to xerothermic habitats.

V. Wetland habitats of standing or flowing water are only present to a small extent, binding the zoocenoses of the flowing and standing water communities – a small water body with Vo6 Highly artificial man-made waters and associated structures and Lk11 Common reed beds. These form potentially suitable habitats for an Amphibia species and, amongst birds, particularly *Acrocephalus* sp., *Emberiza schoeniclus* and *Circus aeruginosus*.

VI. Rock habitat – A special unique habitat is the cave, as a natural rock habitat that provides hibernation for Chiroptera, including species of European importance. It is associated with 9180* *Tilio-Acerion* forests on slopes, screes and ravines.

The result of the assessment of the significance of habitats, their current conservation status, and the regional rarity and species vulnerability of habitats is the classification of habitats into 5 categories of nature conservation importance for habitats (Table 4; Fig. 3). In terms of biota, plants and animals, forests and steppe xerothermic habitats are among the most important habitat types. They are a hotspot for the occurrence of rare and vulnerable species, including species of community importance. Several rare species of birds of prey use the habitats of open agricultural landscapes to hunt and possibly raise their young.

The habitat assessments mentioned above are a key way to figure out the overall ecological quality of current landscape features. They are also used as important selection criteria in the delineation of territorial ecological network features. In this step of the evaluation process, the ecological quality of landscape elements and their ability to work in the ecological network of local eco-stabilizing elements in the study area are evaluated.

Discussion

The current land cover analysis is an important step in the assessment of green infrastructure as a part of the territorial ecological network because it reflects the impact of human activities on the biotic and abiotic components of the landscape as well as the degree of human transformation of the landscape. This provides a broad framework for understanding the current state of the biota and economic land use and based on that to locate the hotspots of the ecological network and determine the crucial areas of territorial ecological restoration (De Montis et al., 2019, Ran et al., 2022). The aim of landscape-ecological interpretations is to propose a set of indicators for evaluation of current land cover and habitats that characterises the state of the landscape, biodiversity and environmental functions (Labuda & Murtinova, 2014). The main problem in the assessment of landscape quality is not the lack of indicators, but rather their multitude (Sowińska-Świerkosz & Michalik-Śnieżek, 2020). The goal of indicator selection is to find real, specific, measurable, and objectively relevant indicators of landscape units, which are made up of landscape structure and biota characteristics. The results of the indicator assessment are the ecological quality of current land cover in the study landscape, as well as its current state and the threats it faces. These indicators serve the further development of the territorial ecological network as criteria and arguments for the preservation and enhancement of the ecological stability of the landscape, revitalization, or design of new elements of green infrastructure and eco-stabilisation measures (Moyzeova & Kenderessy, 2015; Jiang & Jin, 2020).

Table 4
The list of habitats in study area of Dolný Lopašov

Sk Code	Biotope name (code according Habitat directive 92/43/EEC)	Significance	Conservation status	Regional rarity	Species vulnerability	Habitat group
Lk1	6510 Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*)	E	2	1	2	II
LK3	Mesophile pastures	N	2	2	2	II
Lk11	Common reed beds (*Phragmition*)	O	1	2	1	V
AP10.1	Intensively seeded and fertilised grassland, including playing fields and lawns	O	2	1	1	I
Tr1	6210 Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*)	E	2–3	2–3	3	II
Tr6	Xero-thermophile fringes	N	2–3	2	1	II
Kr2b	5130 *Juniperus communis* formations on heaths or calcareous grasslands	E	3	2	3	II
Kr6	40A0* Continental deciduous thickets	E	2–3	1	3	II
Kr9	Riparian willow formation	N	2	1	1–2	V
Ls1.3	91E0* Mixed ash-alder alluvial forests of temperate and Boreal Europe (*Alno-Padion, Alnion incanae, Salicion albae*)	E	3	2	1	V
Ls2.1	Oak-hornbeam forests	N	3	1	2	I
Ls3.1	91H0* Pannonian woods with *Quercus pubescens*	E	3	2	3	I
Ls4	9180* *Tilio-Acerion* forests on slopes, screes and ravines	E	3	3	2	I
Ls5.1	9130 *Asperulo-Fagetum* beech forests	E	3	2	2	I
Ls5.4	9150 Medio-European limestone beech forests (*Cephalanthero-Fagion*)	E	3	2	2	I
Vo6	Highly artificial man-made waters and associated structures	O	2	3	2	V
Sk7	Secondary scree and rock habitats	O	3	3	3	VI
AP1	Plantation of fruit trees	O	2	1	2	III
AP2	Plantations of native deciduous trees	O	3	1	1	IV
AP3.1	Plantations of introduced deciduous trees – Poplar plantations	O	2	2	1	I
AP5.2	Pine plantations	O	2	1	2	I
AP6	Mixed stands of pioneer succession trees	O	3	1	2	III
AP7.1	Mixed stands of native tree species	O	3	1	2	III
AP7.2	Mixed stands of non-native tree species	O	2	1	2	III
X3	Nitrophilous ruderal vegetation of open landscape	O	2	1	1	III
X7	Intensively cultivated fields	O	2	1	1	III
X9a	Plantations of non-native tree species – Acacia plantations	O	2	1	1	III

Notes: significance of habitats as defined in the Decree of ME SR (2003): N – habitat of national importance; E – habitat of European importance; * – priority habitat of Community importance; conservation status: categories 1 (unfavourable – bad) to 3 (favourable); Regional rarity categories: 1 (common) to 3 (very rare occurrence in region); species vulnerability categories: 1 (common species) – 3 (habits with significant occurrence of rare and vulnerable species); habitat group – based on the results of assessment of nature conservation importance of habitats.

More than 100 indicators were identified in the ecological network analysis, and among these indicators, connectivity was consistently used in most studies (Hashemi & Darabi, 2022). We expressed the spatial diversity of the landscape using the Shannon Diversity Index (SHDI). This indicator reflects, to some extent, both fragmentation and diversity of land use. The more and smaller areas are located in the studied area, the higher the diversity and fragmentation of the landscape. High landscape diversity can be beneficial for some landscape processes and functions, but it can also be a problem or a conflict of interest for others. In terms of the movement of water and material down-slope, any boundary between sites disrupts and alters this movement, so it means that the greater the fragmentation of the area being assessed, the more barriers there are to the movement of water and material, and the better the conditions for water retention in the landscape. From the point of view of biodiversity, having more types of green infrastructure can be beneficial for many different species that find food, shelter, and reproduction opportunities there and support healthy species' competitiveness, but most of them require connectivity of habitats. For the connectivity of ecological networks, high spatial diversity can be a problem as it can present barriers to the movement and reproduction of some organisms. Understanding the link between landscape connectivity, species traits, and how they use various elements in a heterogeneous agro-natural landscape is essential for conservation planning and for the successful management of multifunctional landscapes (Adu-Acheampong & Samways, 2019; Grass et al., 2019).

The ecological stability of current landscape elements is a very common concept that is also the most widely interpreted and, as a result, the least understood (Ivan et al., 2014). The goal of the current landscape structure assessment is to show the overall value of each landscape element in terms of ecological stability. Each landscape element affects its surroundings and the overall ecological stability network in the area being studied. More objective assessments of ecological stability rely on complex, purposeful interpretations of biotic elements. However, simple expert assessments based on experience are also common. Important ways to figure out the overall ecological quality of current landscape features are habitat assessments based on habitat diversity, habitat importance, current conservation status, regional rarity, and species vulnerability. These enter as critical selection criteria in the delineation of territorial ecological network elements. Knowledge of habitats in the study area, their diversity and biodiversity, their spatial extent, the naturalness of their species composition, and other characteristics serve as the foundation for defining the most stable parts of the landscape: representative habitats, ecological network elements (biocentres, biocorridors), gene pool sites, management proposals, and eco-stabilisation measures.

The most important sites are designated as biocenters based on a habitat assessment of their overall nature conservation importance or as gene pool sites based on their size. The area parameters of ecological network elements are based on a minimum dimension – area size, length, and width – below which this dimension cannot fall as the ecological network element would lose its function. The biocenter's core zone should consist of the best-preserved and most valuable natural communities. The most valuable landscape elements are also characterised by long-standing continuity (Sklenicka & Charvatova, 2003). The specific locations of priority or core areas provides scientific spatial guidelines for implementation of territorial ecological conservation and determination of the crucial areas of territorial ecological restoration (Chen et al., 2023). The effective connections of green infrastructure form structurally resilient ecological networks (Hong et al., 2022).

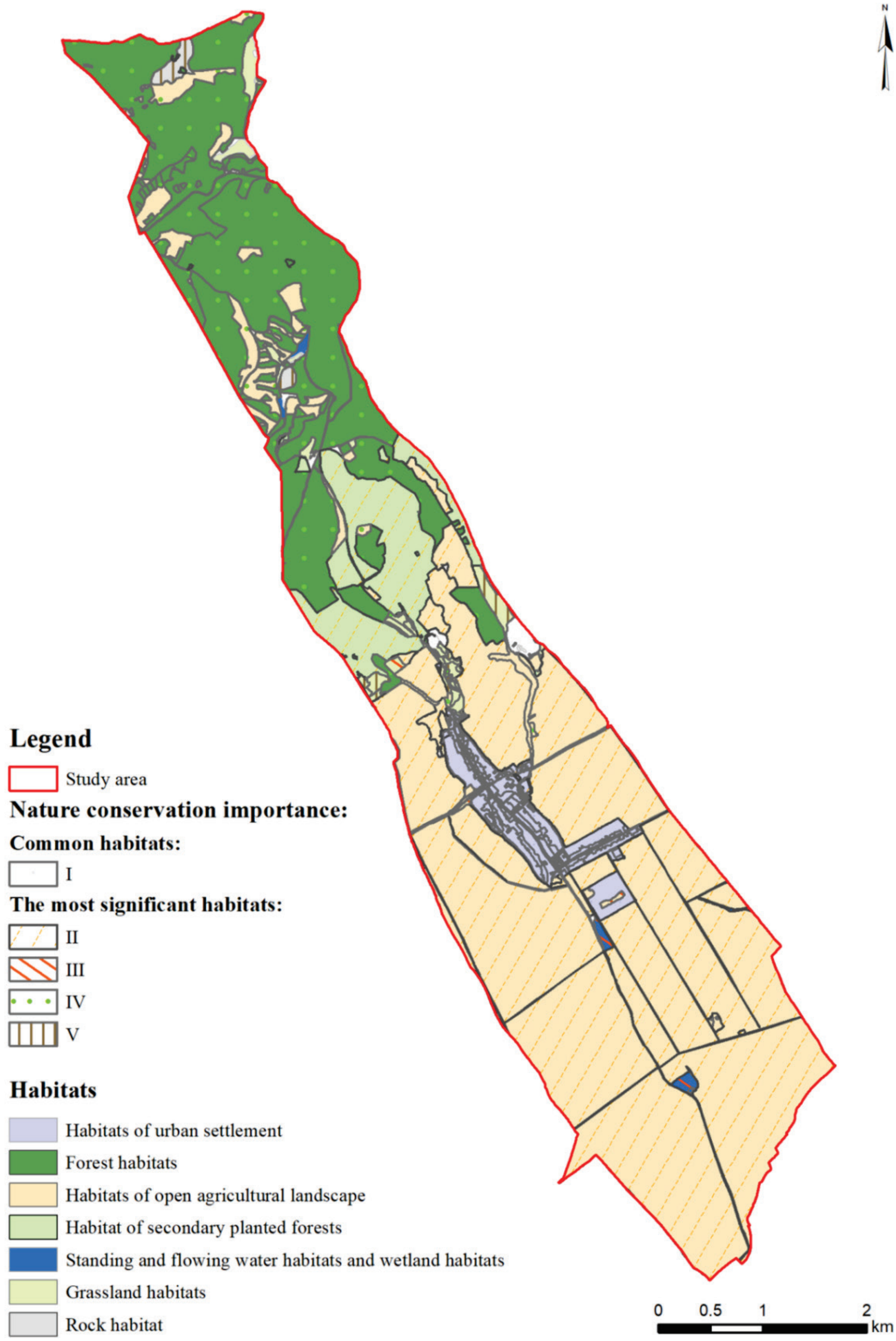

Fig. 3. The assessment of nature conservation importance for habitats

Linear woodlands play an important role as bio-corridors in the migration of animal and plant species and increase the diversity of the landscape. In the intensively managed arable landscape, they are only found as alleys of fruit trees along roads and fluvial forest watercourses, as well as in the vicinity of the settlement. The lowest abundance of woodland, either linear or in patches, is in the southern part of the study area. The result shows their positive impact around barriers and conflict areas, e.g., mining areas, landfills, and roads. Elements of green infrastructure improve their protective, aesthetic, regulatory, hygienic, and aesthetic functions and support greater water retention, erosion control, filtration capacity, etc. (Sandifer et al., 2015, Bezák et al., 2020; Estrada-Carmona et al., 2022). The creation of a regional ecological network in compliance with ecology, landscape and land use requirements will greatly support local and regional environment, ecology, climate and biodiversity (Jiang & Jin, 2020).

As a territorial ecological network is considered as a tool supporting overall nature conservation, ecological connectivity and opportunity of green infrastructure for the multi-sectoral planning of the territory (Abascal & Bilbao, 2022), eco-stabilisation measures play an equally important role as the framework of territorial ecological network. The input criteria for assessing the ability of landscape features to meet the needs of eco-stabilisation measures are also based on other assessments of abiotic and socio-economic phenomena, which we have not addressed in this paper, and therefore a comprehensive design of the territorial network of ecological stability is not part of this contribution. The implementation of ecological networks has to use knowledge and process understanding to design sustainable transformations through stakeholder engagement and the idea of land governance (Verburg et al., 2015).

Conclusion

The list of indicators for assessment of green infrastructure has been developed that can be used to implement the territorial network of ecological stability at a local or regional level, and this methodological approach can be applied in other countries around the world. Based on both quantitative and qualitative data, we chose a set of landscape structure and biota indicators. These helped us to delineate the most important habitats for the proposal of ecological network. The methodological approach was applied on a local level, in the case study area Dolný Lopašov. Using indicators gives feedback on the current state of landscape elements, the biotic value of green infrastructure, their effect on ecological stability, and the sustainability of a landscape. The coefficient of ecological stability showed that the overall ecological stability was low. The value of the Shannon Diversity Index is also lower than the average SHDI value in Slovakia, which points to the low diversity and ecological stability of the area. The low ecological stability is especially evident in the southern part of the studied area of the Trnavská tabuľa georegion. The results of the modelling of the cumulative impact of landscape elements on ecological stability by distance show that the cumulative impact of woodland elements also positively affects the ecological stability of intensively cultivated fields. Based on that assessment, the proposal for new green elements needs to be designed, especially in identified places where the impact of ecologically stable landscape elements is low.

The interpretation of current landscape structure and biotic complex indicators is primarily concerned with determining the intrinsic ecological quality (stability) of landscape elements in terms of fulfilling the eco-stabilisation function. The interpretation and assessment of biota is one of the key steps in the design of territorial ecological network. We selected the following indicators, which were used in the calculation of the nature conservation importance of habitats: the significance of habitats, their current conservation status, regional rarity, and the species vulnerability of habitats. The output of the further assessment is the determination of the suitability of individual biotopes to fulfil specific functions in the local ecological network. The habitats with very significant value are a hotspot for nature conservation and have to be delineated as core zones of biocenters. As a result, a network of existing and newly proposed elements of the ecological network is drafted, along with a map of conflict areas where the elements of the current land cover don't match the landscape-ecological conditions of the area. The implementation of ecological conservation areas as biocenters or bio-corridors and identification of spaces with low ecological stability for territorial ecological restoration can be an effective way of building and supporting ecological networks. Ecological networks are a basis for multi-sectoral planning and crucial to mitigate climate change, mitigate biodiversity loss, and improve the quality of the environment for living organisms.

This publication was supported by the Operational Program Integrated Infrastructure within the project "Support of research and development activities of a unique research team", 313011BVY7, co-financed by the European Regional Development Fund.

References

Abascal, E. H. S., & Bilbao, C. A. (2022). Integrated planning, environment, and management: The French and Brazilian experiences of integration through the Blue-Green Network. Revista de Gestao Ambiental e Sustentabilidade, GeAS 11, e21902.

Adu-Acheampong, S., & Samways, M.J. (2019). Mobility traits influence grasshopper vulnerability to agricultural production in the Cape floristic region biodiversity hotspot. Neotropical Entomology, 48, 992–1000.

Bezák, P., Mederly, P., Izakovičová, Z., Moyzeová, M., & Bezáková, M. (2020). Perception of ecosystem services in constituting multi-functional landscapes in Slovakia. Land, 9, 195.

Chen, X., Kang, B., Li, M., Du, Z., Zhang, L., & Li, H. (2023). Identification of priority areas for territorial ecological conservation and restoration based on ecological networks: A case study of Tianjin City, China. Ecological Indicators, 146, 109809.

Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, Official Journal L 206. 22/07/1992. Pp. 7–50.

De Montis, A., Ganciu, A., Cabras, M., Bardi, A., & Mulas, M. (2019). Comparative ecological network analysis: An application to Italy. Land Use Policy, 81, 714–724.

Eliáš, P., Dítě, D., Kliment, J., Hrivnák, R., & Feráková, V. (2015). Red list of ferns and flowering plants of Slovakia. 5th edition. Biologia, 70, 218–228.

Endel, S., Kuta, D., & Wernerova, E. (2020). Territorial system of ecological stability in selected Czech cities. IOP Conference Series: Earth and Environmental Science, 444, 012015.

Estrada-Carmona, N., Sánchez, A. C., Remans, R., & Jones, S. K. (2022). Complex agricultural landscapes host more biodiversity than simple ones: A global meta-analysis. Proceedings of the National Academy of Sciences, 119, e2203385119.

Fernandez, C., Spayd, J., & Brooks, R. P. (2019). Landscape indicators and ecological condition for mapped wetlands in Pennsylvania, USA. Wetlands, 39, 705–716.

Grass, I., Loos, J., Baensch, S., Batáry, P., Librán-Embid, F., Ficiciyan, A., Klaus, F., Riechers, M., Rosa, J., Tiede, J., Udy, K., Westphal, C., Wurz, A., & Tschamtke, T. (2019). Land-sharing/-sparing connectivity landscapes for ecosystem services and biodiversity conservation. People and Nature, 1, 262–272.

Hashemi, R., & Darabi, H. (2022). The review of ecological network indicators in graph theory context: 2014–2021. International Journal of Environmental Research, 16, 24.

Hong, S.-H., Han, B.-H., Choi, S.-H., Sung, C. Y., & Lee, K.-J. (2013). Planning an ecological network using the predicted movement paths of urban birds. Landscape Ecological Engeneeering, 9, 165–174.

Hong, W., Guo, R., Li, X., & Liao, C. (2022). Measuring urban ecological network resilience: A disturbance scenario simulation method. Cities, 131, 104057.

Ivan, P., Macura, V., & Belčáková, I. (2014). Various approaches to evaluation of ecological stability. In: 14th International Multidisciplinary Scientific Geoconference SGEM 2014, Geoconference on Ecology, Economics, Education and Legislation, Albena, Bulgaria. Vol. 1. Stef92 Technology Ltd., Sofia. Pp. 799–805.

Jiang, C., & Jin, X. (2020). Critical factors in regional construction of ecological networks. Journal of Environmental Protection and Ecology, 21, 359–365.

Kubeš, J. (1996). Biocentres and corridors in a cultural landscape. A critical assessment of the 'territorial system of ecological stability.' Landscape and Urban Planning, 35, 231–240.

Labuda, M., & Murtinova, S. (2014). Environmentálne hodnotenie multifunkčnosti poľnohospodárstva (Komparačná analýza) [Environmental assessment of the multifunctionality of agriculture]. Acta Environmentalica Universitatis Comenianae (Bratislava), 22, 25–36 (in Slovak).

Lehtonen, M., Sébastien, L., & Bauler, T. (2016). The multiple roles of sustainability indicators in informational governance: Between intended use and unanticipated influence. Current Opinion in Environmental Sustainability, 18, 1–9.

Mackovčin, P. (2000). A multi-level ecological network in the Czech Republic: Implementing the territorial system of ecological stability. GeoJournal, 51, 211–220.

Miklos, L. (1996). Landscape-ecological theory and methodology: A goal oriented application of the traditional scientific theory and methodology to a branch of a new quality. Ekológia (Bratislava), 15, 377–385.

Miklós, L., Diviaková, A., & Izakovičová, Z. (2019). Ecological networks and territorial systems of ecological stability. Springer International Publishing, Cham.

Miklós, L., Izakovičová, Z., Boltižiar, M., Diviaková, A., Grotkovská, L., Hrnčiarová, T., Imrichová, Z., Kočická, E., Kočický, D., Kenderessy, P., Mojses, M., Moyzeová, M., Petrovič, F., Špinerová, A., Špulerová, J., Štefunková, D., Válkovcová, Z., & Zvara, I. (2006). Atlas reprezentatívnych geoekosystémov Slovenska [Atlas of representative regions and types of landscape in Slovakia]. Ministry of the Environment of the SR, Institute of Landscape Ecology of the Slovak Academy of Sciences (in Slovak).

Moyzeova, M., & Kenderessy, P. (2015). Territorial systems of ecological stability in land consolidation projects (example of proposal for the Lses of Klasov Village, Slovak Republic). Ekologia (Bratislava), 34, 356–370.

Ran, Y., Lei, D., Li, J., Gao, L., Mo, J., & Liu, X. (2022). Identification of crucial areas of territorial ecological restoration based on ecological security pattern: A case study of the central Yunnan urban agglomeration, China. Ecological Indicators, 143, 109318.

Ružičková, H. (1990). Grasslands and their implication to landscape ecological planning (LANDEP). Ekologia CSFR, 9, 233–240.

Ružičková, H., Halada, L., Jedlička, L., & Kalivodová, E. (1996). Biotopy Slovenska: Príručka k mapovaniu a katalóg biotopov [Biotopes of Slovakia: A handbook for mapping and a catalogue of biotopes]. Ústav Krajinnej Ekológie SAV, Bratislava (in Slovak).

Ružičková, J. (2007). Fragmentácia krajiny, delenie, násobenie [Landscape fragmentation, division, multiplication]. Enviromagazín, 2007, 14–15.
Sandifer, P. A., Sutton-Grier, A. E., & Ward, B. P. (2015). Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. Ecosystem Services, 12, 1–15.
Schliep, R., Walz, U., Sukopp, U., & Heiland, S. (2018). Indicators on the impacts of climate change on biodiversity in Germany – Data driven or meeting political needs? Sustainability, 10(11), 3959.
Sklenicka, P., & Charvatova, E. (2003). Stand continuity – a useful parameter for ecological networks in post-mining landscapes. Ecological Engineering, 20, 287–296.
Stanová, V., & Valachovič, M. (Eds.). (2002). Katalóg biotopov Slovenska. [Catalogue of Slovak habitats]. Daphne – Inštitút Aplikovanej Ekológie, Bratislava (in Slovak).
Stasiov, S. (2005). Millipede communities (Diplopoda) of oak-hornbeam ecosystems (the Malé Karpaty Mts, Trnavská pahorkatina hills, SW Slovakia). Ekológia, 24, 143.
Szili-Kovács, T., Kátai, J., & Takács, T. (2011). Mikrobiológiai indikátorok alkalmazása a talajminőség értékelésében [Use of microbiological indicators in soil quality assessment]. 1. Módszerek. Agrokémia és Talajtan, 60, 273–286 (in Hungarian).
Verburg, P. H., Crossman, N., Ellis, E. C., Heinimann, A., Hostert, P., Mertz, O., Nagendra, H., Sikor, T., Erb, K.-H., Golubiewski, N., Grau, R., Grove, M., Konaté, S., Meyfroidt, P., Parker, D. C., Chowdhury, R. R., Shibata, H., Thomson, A., & Zhen, L. (2015). Land system science and sustainable development of the earth system: A global land project perspective. Anthropocene, 12, 29–41.