FUNCTIONAL CONNECTIVITY OF NATURALLY VALUABLE HABITATS IN THE JESENÍKY PROTECTED LANDSCAPE AREA

HELENA KILIANOVÁ[1*], VILÉM PECHANEC[1], MARCELA PROKOPOVÁ[2], KAREL KIRCHNER[3]

[1]*Department of Geoinformatics, Faculty of Science, Palacký University Olomouc, 17. listopadu 50, 771 46 Olomouc, Czech Republic*
[2]*Global Change Research Institute of the Czech Academy of Sciences, Lipová 9, 37000 České Budějovice, Czech Republic*
[3]*Department of Environmental Geography, Institute of Geonics of the Czech Academy of Sciences, Drobného 28, 602 00 Brno, Czech Republic*
**Corresponding author email: helena.kilianova@upol.cz*

Received: 22nd March 2022, **Accepted:** 19th May 2022

ABSTRACT

This paper focuses on evaluating the functional connectivity of naturally valuable habitats within the territory of the Jeseníky Protected Landscape Area (PLA). Analysis of functional connectivity was carried out for individual zones of classified nature preservation. The methodological approach that is applied is based on determining indicators for expressing the degree of the natural character of individual landscape segments (Nd), the distance to naturally valuable habitats (Dn), and a composite index Distance to Nature (D2N). The results for the individual zones and the PLA as a whole are mutually compared and consequently confronted with values for the territory of the entire Czech Republic. All three research questions, i.e. whether naturally valuable habitats prevail in the most valuable area in the first protected zone of the Jeseníky PLA, whether the distance to naturally valuable habitats in the first zone of the Jeseníky PLA is the shortest, and whether the territory of the Jeseníky PLA is better functionally interlinked when compared with the remaining territory of the Czech Republic (CR), were answered positively. The results highlight the need to assess the connectivity of natural habitats in the least protected zones of other PLAs in the Czech Republic and EU, to decide whether planning measures to support the ecological network are necessary.

Keyword: connectivity; degree of naturalness; habitats

INTRODUCTION

Connectivity, also interconnectedness, allows for the moving and transfer of species (individual, genes) between source territories of the landscape, ecosystems, and habitats. The reduction or even a lack of landscape connectivity and the resulting isolation of habitats may have a negative effect on scattered seed dispersal, gene flow, animal migration, and other ecological processes (Saura *et al.*, 2011). The connectivity of habitats is essential for the protection and preservation of biodiversity through transporting and changing genes, seeds, and individuals among vegetable and animal populations. A lack of connectivity may be the cause of the reduction of species richness and abundance, loss of genetic diversity, and inbreeding, all of which contribute to the reduced functionality of metapopulations and the persistence of species in the fragmented landscape (Levins, 1969; Hanski, 1999; Burel & Baudry, 2005; Baguette *et al*., 2013).

While territorial connectivity derives merely from the structure of the landscape and is determined on the basis of what are called landscape metrics (e.g. isolation, length of borders, the ratio between the area and periphery of the habitat, etc.), evaluated by means of GIS tools (e.g. StraKa - Pechanec *et al*., 2008), functional connectivity follows the real needs of particular organisms, including demonstrations of the behavioural responses of organisms to the physical structure of the landscape (Tischendorf & Fahrig, 2000; Theobald, 2006). The functional connectivity of the landscape stems from the behaviour of organisms and plants within various landscape elements (Tischendorf & Fahrig, 2000) and delimits the availability of various parts of the landscape for a particular organism from the place in the landscape under consideration (Saura *et al*., 2011). A possible loss of connectivity is specific to the species and determines which part of the landscape is available for particular organisms from the place in the landscape under consideration. The impact of ecosystem and habitat fragmentation and the loss of their connectivity are then specific to the species and depend on the ability of the organisms being monitored to change their location, on the areal distribution of suitable habitats, and on the permeability of the landscape matrix through which the organisms need to move (Tischendorf & Fahrig, 2000; Rey Benayas *et al*., 2008; Manning *et al*., 2009). This connectivity is most often evaluated by means of approaches following the graph theory (Pascual-Hortal & Saura, 2006; Urban *et al*., 2009; Galpern *et al*., 2011).

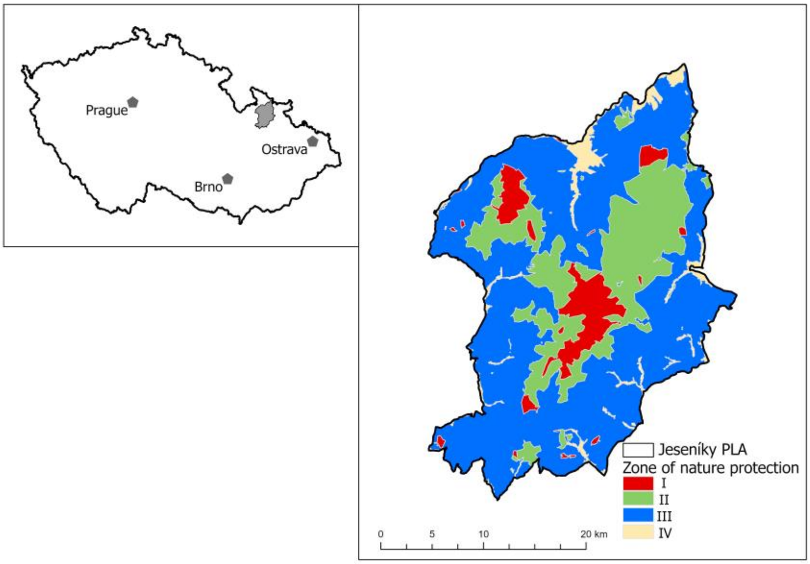
This study focuses on expressing the functional connectivity of the landscape using the following indices: level of natural aspect (Nd), distance to naturally valuable habitats (Dn), and a composite index Distance to Nature (D2N). The fundamental research questions are as follows: 1) whether naturally valuable habitats prevail in the most valuable area in the first zone of the Jeseníky PLA, 2) whether the distance to naturally valuable habitats in the first zone of the Jeseníky PLA is the shortest, and 3) whether the territory of the Jeseníky PLA is better functionally interlinked when compared with the remaining territory of the Czech Republic.

METHODS

Study area

The study area for this analysis is the area of the Jeseníky PLA, over 740 km^2, which is located in the north-eastern part of the Czech Republic and spreads over two regions – the Moravian-Silesian and Olomouc regions. The Jeseníky PLA boasts high forestation, a biologically unique tree line, and the location of rare types of biotas, moorlands, and springs, as well as man-made objects. This area comprises four national natural reserves (Praděd, Šerák-Keprník, Rejvíz, and the Rašeliniště Skřítek peat bog), a national natural monument (the Javorový vrch hill), nineteen natural reserves, and seven natural monuments. This area is divided into four zones of nature protection (Fig. 1). The delineation of the boundaries of the PLA and individual nature protection zones is based on official data layers provided by the Agency of Nature and Conservation of the Czech Republic in an Esri shapefile.

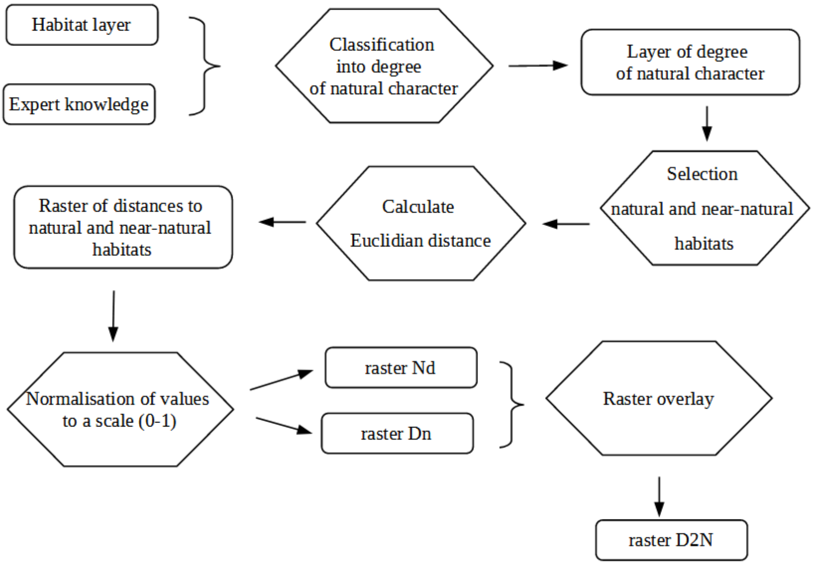
Fig. 1: The nature protection zones of the Jeseníky PLA



Solution process

The methodology for evaluating the functional connectivity of the territory is based on the study by Rüdisser *et al.* (2012). Its basic principle is to set three key indices evaluating the natural character of the landscape, in this case at the level of a habitat, determining the distance from every place in the landscape to the nearest natural or near-natural habitat and their consequent combination (Fig. 2).

Fig. 2: Data processing scheme



The level of natural character of a habitat (Nd) expresses in five grades the natural character of the habitat (Tab. 1). The evaluation was conducted on the strength of a pre-prepared Detailed combined map of habitats (DCL) on a scale of 1: 10,000 for the entire CR and a related knowledge database regarding the level of loss of natural character of individual habitats. A description of the structure and content of this dataset can be found, for example, in Cudlín *et al*. (2020) or Pechanec *et al*. (2021). It is a detailed layer containing 194 (156 natural and 38 non-natural) habitat types, currently composed of 3,397,852 segments. In our study, the categories of natural and near-natural habitats were considered as naturally valuable habitats.

Table 1: Grades of natural character of a habitat

Categories of habitats	Characteristics of habitat	Nd value
Natural habitats	habitat without human influence – e.g. forests, rocks, wetlands	1
Near-natural habitats	habitat creation is influenced by human activities and habitats are permanently maintained by humans – e.g. extensive meadows	2
Distant natural habitats	habitats influenced by active or passive human activities – e.g. forest clearings, alleys, abandoned meadows, abandoned quarries, shrubs on agricultural land, extensive or abandoned orchards	3
Unnatural habitats	habitats created by human activities – e.g. canalised waterways, fields, intensive lawns, utility gardens, intensive orchards, parks	4
Human habitats	habitats created and damaged by human activities – e.g. sewage and sludge tanks, piped streams, built-up areas with minimal vegetation, impervious surfaces, landfills	5

The Distance to naturally valuable habitats (Dn) is defined as the Euclidean distance from the position under evaluation (a place in the landscape) to the nearest naturally valuable habitat within the territory being monitored. The distance calculation was performed over the DCL map that was evaluated.

The Euclidean distance was calculated in a raster environment with a pixel size of 10 m, from which the max, mean, and median statistical indices were also derived. The distance was calculated separately for the Jeseníky PLA and the entire CR. In both instances, the calculations used barriers – locations which cannot be passed through and thus cannot be included in the calculation. Barriers are represented by segments with impermeable surfaces (e.g. asphalt surfaces) with a measurement larger than 0.25 ha.

The Dn values stand for the distances (in metres); there is no limit for them and they may reach infinite values. The greater the distance, the smaller the influence of the natural habitat and that is why a limit value is defined. Above this value, the impact is negligible or equal to zero. The limit value in this study was set at 1000 m, following Rüdisser *et al.* (2012), who themselves followed older works (Gathmann &Tscharntke, 2002; Jauker *et al*., 2009; Knight *et al*., 2009; Kohler *et al*., 2008). Every distance greater than 1000 m was, in the consequent normalisation, evaluated with the same (maximum) value.

The values of the Dn and Nd indices were then normalised on a scale from 0 to 1. The level 0 indicates a natural habitat or zero distance to a natural or near-natural habitat, while a value of 1 indicates entirely artificial devalued habitats or the limit acceptable distance to a natural or near-natural habitat. Normalisation was achieved by dividing the current value by the maximum achieved value.

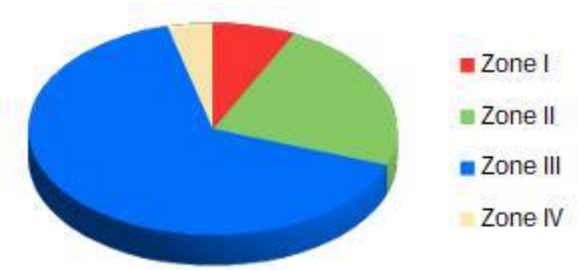
The resulting **Distance to Nature** (D2N) index is calculated by means of map algebra and combines the normalised values of the distance to naturally valuable habitats (Dn) and the level of natural character in every location (Nd) of the territory under analysis. The Nd value thus expresses the level of difficulty involved in crossing the territory, and this is reflected in an increase in the resulting D2N value. The resulting values are in range 0 and 1.

RESULTS

Evaluation of functional connectivity in the Jeseníky PLA

In order to detect the functional connectivity, the Jeseníky PLA was first analysed from the point of view of the natural character grade of the individual landscape segments. More than 50 % of the first protected zone, covering 7.25 % of the area of the Jeseníky PLA (Fig. 3), is evaluated as natural habitats (Fig. 4), 0.7 % as near-natural habitats, and 20 % as distant natural habitats. Other categories, i.e. unnatural habitats and human habitats, represent less than 1 %.

Fig. 3: Review of individual zones in the Jeseníky PLA (in %).

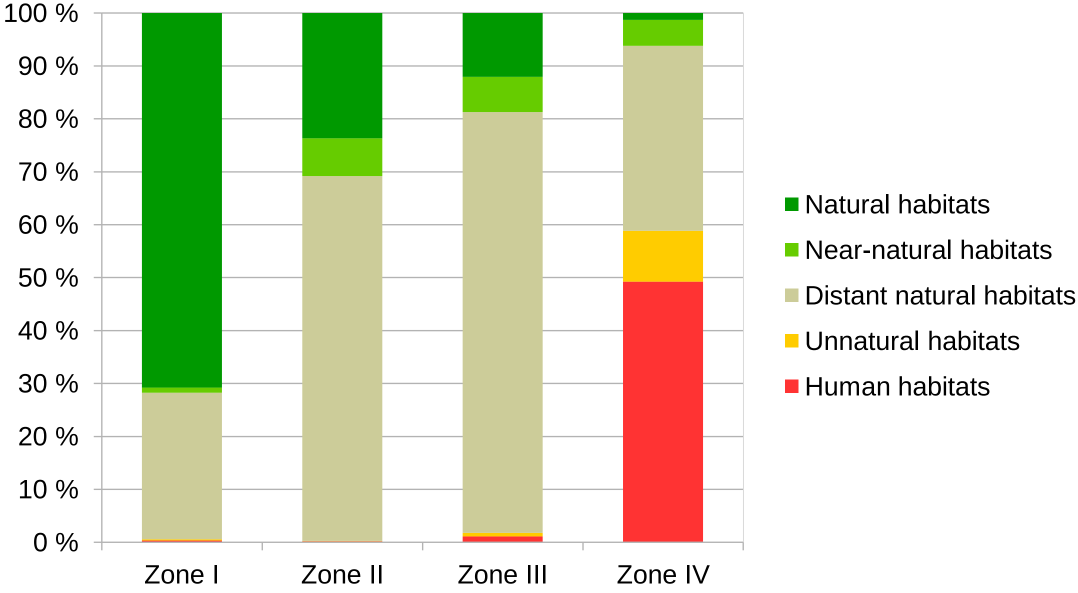


The second protected zone covers an area of 23.23 % of the PLA, of which 22.2 % is classified as natural habitats, 6.6 % as near-natural ones, and 64.5% as distant natural habitats. Unnatural habitats and human habitats represent only 0.2 % of the area of the second protected zone.

The third protected zone covers an area of 65.56 % of the PLA, of which 11.3 % is classified as natural habitats, 6.2 % as near-natural ones, and 74.6 % as distant natural habitats. Unnatural habitats and human habitats represent only 1.6 % of the area of the third protected zone.

The fourth protected zone covers an area of 3.96 % of the PLA, of which 1.3 % is classified as natural habitats, 4.8 % as near-natural ones, 34.4 % as distant natural habitats, 9.5 % as unnatural habitats, and 48.5 % as human habitats.

Fig. 4: Portion of the area classified by the level of natural character in individual zones of the PLA



The value of the distance to naturally valuable habitats (Dn) was set for the individual protected zones, as well as for the entire area. The value of the maximum distance in the first zone is 424 m (Tab. 2), whereas the average value is 20.95 m.

Table 2: Values of the Dn index for individual zones of the Jeseníky PLA

Zone	Max (m)	Mean (m)	Median (m)
I.	424	20.95	0
II.	1643	221.1	107
III.	1319	162.2	108
IV.	1105	203.77	161
PLA	1643	167.29	96

Max = maximum distance, Mean = average distance, Median = the most frequent distance

In the other zones, the maximum values of the Dn index are significantly higher. In the second zone, this distance equals 1643 m, which is, at the same time, the highest value over the entire area. The average value is, however, a mere 221.09 m. The third zone has a value of 1319 m and the fourth zone 1105 m; the average values are 162.19 m and 203.77 m, respectively.

It follows from the above that the distance between the natural habitats in the first zone is significantly shorter than in the other zones of the Jeseníky PLA. The calculation of the median of this index confirms our research question. It is also obvious, on the evidence of the table above, that the most frequent distance between individual habitats in the first protected zone equals zero. In the second zone, the most frequent distance is 107 m, in the third zone

108 m, and in the fourth zone 161 m. The median for the entire area of the Jeseníky PLA is 96 m, which indicates the higher value of the area being monitored.

The values of the composite index (D2N) with a zero value indicate the high natural character in close proximity. On the contrary, values approaching a value of one show degradation of the habitat because of increasing Distance from Nature. The values of the D2N composite index are given in Tab. 3.

Table 3: Values of the D2N index for the individual zones of the Jeseníky PLA

Zone	MAX	MEAN	MEDIAN
I.	0.25	0.01	0.000
II.	1	0.1	0.050
III.	1	0.08	0.053
IV.	0.83	0.16	0.119
Whole	1	0.08	0.047

Max = maximum value, Mean = average value, Median = most frequent value

The index with the value of 0.25 for the maximum distance indicates the highly natural character of the habitats in the first protected zone. The index for the second and third zones equals one, which means that the maximum values of the distances between habitats exceed the limit value, which is also valid for the entire area. In the fourth zone, the value of the index is 0.83, which indicates a higher level of degradation as a result of the distance.

The average of the index values for the individual zones shows the low value of the index, which again confirms the research question. The highest average of the index values is shown in the fourth zone. In the third zone, as well as over the entire area, the average of the values equals half of the average value in the fourth zone.

The median of the values of the D2N composite index shows that the most frequent value of the index in the first zone is zero, which documents the close proximity of natural habitats. The values of the median increase gradually from the first zone, the highest value being 0.119 in the fourth zone. This confirms higher levels of degradation of the habitats as a result of the higher distance from natural resource areas, which corresponds with our research assumption. The entire area shows a median of values of 0.047, which is a lower value than shown in the second, third, and fourth zones.

Comparing the functional connectivity of the Jeseníky PLA and the territory of the Czech Republic

From the comparison of the (Dn) index for the territory of the Jeseníky PLA and the entire Czech Republic (further only the CR) it follows that the value of the maximum distance to a natural environment in the CR is 10 384 m (Tab. 4), whereas within the territory of the Jeseníky PLA it is 1643 m and in the first protected zone only 424 m.

Table 4: Values of the Dn indicator for the area of the Czech Republic

Indicator	MAX (m)	MEAN (m)	MEDIAN (m)
Dn	10 384	275	167

Max = maximum distance, Mean = average distance, Median = most frequent distance

The average of the Dn values is 275 m for the Czech Republic and 167 m for the PLA, while it is less than 21 m in the first protected zone. The median of the values, i.e. the most frequent distance between valuable habitats, is 167 m for the CR. The median value is 96 m within the territory of the PLA and 0 m in the first zone.

The Dn index values and its average and median for the CR unambiguously show that the distances to a natural environment are significantly longer than within the territory of the PLA and its individual protected zones. It confirms our third research question, that the functional connectivity of the Jeseníky PLA is better than that over the territory of the CR.

The calculation of the D2N index values for the territory of the CR (Tab. 5) shows a value of one, which means that the maximum values of the habitat distances exceed the limit value and represent the degradation of habitats as a result of the increasing distance from natural habitats. The limit value of the index is also exceeded within the territory of the PLA and in the third and fourth zones.

Table 5: Values of the D2N index for the area of the Czech Republic

indicator/index	MAX	MEAN	MEDIAN
D2N	1	0.17	0.09

Max = maximum value, Mean = average value, Median = most frequent value

The average of the index values is 0.17 for the CR and 0.08 for the Jeseníky PLA, while the fourth protected zone shows the value of 0.16. It follows from the above that the territory of the fourth zone resembles the value for the CR, while the first zone shows a significantly better result.

The median of the D2N index values shows that the most frequent value within the territory of the CR is 0.09, proving the greater degradation of locations as a result of longer distances from natural source areas. This result is comparable with the value in the fourth zone of the Jeseníky PLA (0.119), whereas the median value is significantly worse for the CR than for the Jeseníky PLA. The result documents the greater degradation of locations within the territory of the CR owing to the longer distances from individual natural source areas.

DISCUSSION

Landscape soil cover undergoes changes partially under the influence of natural development and partially because of urbanisation. This results in the diminution of natural and near-natural habitats and locations and their increasing isolation. In the context of climate change, there is an increasing need for migration corridors and opportunities for species to disperse in order to avoid the local extinction of species. The necessity of preserving the connectivity of the remaining natural and near-natural habitats is essential. For the purpose of evaluating the connectivity of the landscape, a few methods have been proposed for application. Their results may, however, differ and their application may be limited to a certain extent.

The various approaches to the quantification and visualisation of the connectivity of natural habitats in the landscape represent: (a) structural connectivity based on landscape metrics deduced from size, shape, composition, and configuration of habitat areas in the landscape (Forman & Godron, 1981); (b) “Distance to Nature”, which is calculated in a raster map for every pixel of the selected landscape areas and is based on an average distance to the nearest natural or near-natural habitat, in which the resistance of the local matrix is taken into account (Rüdisser *et al*, 2012); (c) the approach *presented* here called functional connectivity on a larger scale, which considers aspects specific to particular habitats or species (i.e. the limits of distances and values of matrix resistance) as it divides natural and near-natural habitats into groups of habitats of similar types. The value for connectivity is derived from the distance to the nearest habitat belonging to the same group of habitats. The distance is calculated as the path with the lowest costs and the values of the matrix resistance are defined separately for each habitat group. Another parameter included in the calculation is the size of the area of the natural habitat which relates to the minimum habitat area necessary for the long-term existence of the habitat; d) functional connectivity based on graph theory and calculated by means of the Conefor software (Saura & Pascual-Hortal, 2007). This method is very complicated and is based on the distances for each pair of habitat patches. In order to define the distances, it also applies the path with the lowest costs and calculates various indices, of which the connectivity probability is most recommended. The differences between these approaches lie in the complexity of their approach, the character of their input data and information, and the processing time.

The presented method provides a quick assessment of connectivity, in the narrower sense, evaluation of functional distance to natural habitats. This method is very dependent on the quality of the input data. There is a direct relationship between the quality of the input layer and the reliability of the results.

In addition to the timeliness of the data, the fundamental parameters influencing the quality of the obtained results (and eliminating the uncertainty in the interpretation of the results) are mainly its spatial resolution, the level of mapper detail and the technical purity of the digital dataset.

The spatial resolution must correspond to the heterogeneity of the analysed area; in the conditions of the Czech Republic, a mapping scale of 1: 5000 - 1: 10,000 is suitable.

The level of detail represents the thematic resolution of the information within the mapped geometry. It is possible to work with different landcover/land-use classifications. They do not distinguish between different types of habitats and thus significantly limit their ability to classify in terms of nature. This can lead to incorrect results being generated. In the conditions of the Czech Republic, we recommend using the level of habitats in the detail of the Habitat Catalogue of the Czech Republic (Chytrý *et al*., 2010) used in the mapping of the Natura 2000 system.

Technical purity represents the quality of individual geometric entities with controlled topology. It is necessary to analyse in point of view of a spatial context correctly. Overlaps, undercuts, and non-topological overlaps degrade the input dataset, over which the performed euclidian distance operation gives unrealistic (incorrect) values.

CONCLUSION

The approach presented here aims at evaluating the complicated issue of the interconnection of habitats and functional connectivity in the landscape of the territory of the Jeseníky PLA that was monitored, using available data on a convenient scale. At the same time, we present a comparison of the status of functional connectivity within the territory of the CR with that of the area that is monitored.

In this study we performed calculations for the Jeseníky PLA and its individual protected zones in a categorisation of habitats based on the degree of their natural character, where the number of areas and the area of individual habitat categories are calculated. Then the Dn indicator of a distance from naturally valuable habitats follows, expressed as the longest distance and its average and median, and the D2N composite index, expressed as a value, and its average and median. For the sake of comparison, corresponding calculations were also performed for the entire territory of the Czech Republic.

From the calculations presented here it follows that the territory of the first protected zone of the PLA reports the best results for all the indices that were calculated. It means that in the first protected zone of the Jeseníky PLA there is a dominant presence of naturally valuable habitats with the shortest distances between them, which confirms the first and second research questions. When the results calculated for the territory of the Jeseníky PLA and that of the CR are compared, it is obvious that the territory of the PLA and its protected zones shows better values, which documents a naturally valuable landscape, specifically more valuable/natural habitats and their greater presence. Thus, the third research question is also confirmed. However, it was found that the D2N index value of the fourth zone is only slightly lower than the average of the whole country, which shows the need for measures to strengthen the ecological network in this area. Across Europe, the zoning system is common in PLAs (Maksin *et al*., 2018) and the least protected zone is often a transition between landscape protection and development. The results highlight the need to focus on connectivity of natural habitats in the least protected zones of other Czech or European PLAs to determine whether planning measures are needed to support the ecological network.

The calculation and evaluation of the functional connectivity of habitats documents the current status of the landscape of the territory being monitored, which is important for the very preservation of the functionality of the landscape, its assessment and evaluation, and for landscape planning.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Baguette et al., (2013). Individual dispersal, landscape connectivity and ecological networks. *Biological Reviews*, 88, 310– 326. DOI: 10.1111/brv.12000

Burel, F., Baudry, J., (2005). Habitat quality and connectivity in agricultural landscapes: The role of land use systems at various scales in time. Ecological Indicators, *Elsevier*, 2005, 5 (4), pp. 305-313. DOI:10.1016/j.ecolind.2005.04.002

Cudlín, O., Pechanec, V., Purkyt, J., Chobot, K., Salvati, L., Cudlín, P. (2020). Are Valuable and Representative Natural Habitats Sufficiently Protected? Application of Marxan model in the Czech Republic. *Sustainability*. 12:(1), 402. https://doi.org/10.3390/su12010402.

Forman, R. T. T., Godron, M., (1981). Patches and Structural Components for a Landscape Ecology. *BioScience*, 31, 733-740.

Galpern, P., Manseau, M., Fall, A., (2011). Patch-Based Graphs of Landscape Connectivity: A Guide to Construction, Analysis and Application for Conservation. *Biological Conservation* 144(1), 44-55. DOI:10.1016/j.biocon.2010.09.002

Gathmann, A., Tscharntke, T., (2002). Foraging ranges of solitary bees. *Journal of Animal Ecology* 71(5), 757-764. DOI:10.1046/j.1365-2656.2002.00641.x

Hanski, I., (1999). *Metapopulation Ecology*. Oxford University Press, New York.

Chytrý M., Kučera T., Kočí M., Grulich V. & Lustyk P. (eds) (2010). *Habitat Catalogue of the Czech Republic*. Second edition. Nature Conservation Agency of the Czech Republic, Prague.

Jauker, F., Diekötter, T., Schwarzbach, F., Wolters, V., (2009). Pollinator dispersal in an agricultural matrix: opposing responses of wild bees and hoverflies to landscape structure and distance from main habitat. *Landscape Ecology* 24(4), 547-555. DOI:10.1007/s10980-009-9331-2

Knight, M. E., Osborne, J. L., Sanderson, R. A., Hale, R. J., Martin, A. P., & Goulson, D., (2009). Bumblebee nest density and the scale of available forage in arable landscapes. *Insect Conservation and Diversity* 2(2), 116-124. DOI:10.1111/j.1752-4598.2009.00049.x

Kohler, F., Verhulst, J., Van Klink, R., & Kleijn, D., (2008). At what spatial scale do high-quality habitats enhance the diversity of forbs and pollinators in intensively farmed landscapes?. *Journal of Applied Ecology* 45(3), 753-762. DOI:10.1111/j.1365-2664. 2007.01394.x

Levins, R., (1969). Some Demographic and Genetic Consequences of Environmental Heterogeneity for Biological Control. *Bulletin of the Entomological Society of America* 15, 237-240.

Maksin, M., Ristić, V., Nenković-Riznić, M., Mićić, S. (2018). The role of zoning in the strategic planning of protected areas: lessons learnt from EU countries and Serbia. *European Planning Studies*, 26 (4), 838-872. DOI: 10.1080/09654313.2018.1426736

Manning, A.D., Gibbons, P., Lindenmayer, D. B., (2009). Scattered trees: a complementary strategy for facilitating adaptive responses to climate change in modified landscapes? *J. Appl. Ecol.* 46, 915–919. DOI:10.1111/j.1365-2664.2009.01657.x

Pascual-Hortal, L., Saura, S., (2006). Comparison and development of new graph-based landscape connectivity indices: towards the priorization of habitat patches and corridors for conservation. *Landscape Ecology*, 21, 959–967. DOI:10.1007/s10980-006-0013-z

Pechanec, V., Pavková, K., Dobešová, Z., (2008). StraKa - GIS tools for the analysis of landscape structure. In: Petrová, A. (ed.) *ÚSES – green backbone of the landscape* (pp. 43-53). (in Czech)

Pechanec, V., Cudlín, O., Zapletal, M., Purkyt, J., Štěrbová, L., Chobot, K., Tangwa, E., Včeláková, R., Prokopová, M., Cudlín, P., (2021). Assessing Habitat Vulnerability and Loss of Naturalness: Applying the GLOBIO3 Model in the Czech Republic. *Sustainability* 2021, 13, 5355. DOI:10.3390/su13105355

Rey Benayas, J.M., Bullock, J.M., Newton, A.C., (2008). Creating woodland islets to reconcile ecological restoration, conservation, and agricultural land use. *Frontiers in Ecology and the Environment* vol. 6 (6), 329-336. DOI:10.1890/070057

Rüdisser, J., Tasser, E., Tappeiner, U., (2012). Distance to nature - a new biodiversity relevant environmental indicator set at the landscape level. *Ecol. Indic.* 15, 208–216. DOI:10.1016/j.ecolind.2011.09.027

Saura, S., Estreguil, Ch. Mouton, C., Rodríguez-Freire, M., (2011). Network Analysis to Assess Landscape Connectivity Trends: Application to European Forests (1990–2000), *Ecological Indicators* 11(2), 407-416 DOI:10.1016/j.ecolind.2010.06.011

Saura, S., Pascual-Hortal, L., (2007). A New Habitat Availability Index to Integrate Connectivity in Landscape Conservation Planning: Comparison with Existing Indices and Application to a Case Study. *Landscape and Urban Planning* 83(2), 91-103. DOI:10.1016/j.landurbplan.2007.03.005

Theobald, D.M., (2006). Exploring the functional connectivity of landscapes using landscape networks. In: Crooks, K.R., Sanjayan, M. (Eds.), *Connectivity Conservation* (pp. 416–443). Cambridge University Press, New York.

Tischendorf, L., Fahrig, L., (2000). On the Usage and Measurement of Landscape Connectivity. *Oikos* 90(1), 7-19 DOI:10.1034/j.1600-0706.2000.900102.x

Urban, D. L., Minor, E. S., Treml, E. A., Schick, R. S., (2009). Graph models of habitat mosaics. *Ecology letters*, 12(3), 260-273 DOI:10.1111/j.1461-0248.2008.01271.x