# Grassland connectivity model

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# Contents

# Introduction

Grasslands in Latvia are threatened by a continuing agricultural intensification and abandonment. Fragmentation of the remaining grasslands further isolates the patches and limits the potential for dispersal of species that depend on grassland habitats. This study was designed to assess the connectivity of Latvian grassland habitats, as well as to identify the most suitable methods for assessing and measuring the importance of grassland patches for their role in supporting the connectivity of grassland habitats. The obtained results will allow to improve the existing system of protected areas if protection is ensured for the will connected habitat networks and steps are taken to improve habiatat connectivity where it is lacking.

This study was prepared as part of the EU-LIFE-funded project, 'GrassLIFE: Restoring EU priority grasslands and promoting their multiple use' (LIFE16 NAT/LV/262). GrassLIFE is led by the Latvian Fund for Nature and focuses on developing, optimising and improving the conservation status of five EU priority grasslands in Latvia. This report contributes to the project objective of supporting the protection of the grasslands and working towards achieving a favourable conservation status for project target grasslands.

# Methodology

## The data sources used

Only countrywide data sources were used to model grassland connectivity in every step of the process to avoid problems caused by likely inconsistencies between regional datasets.

The grasslands belonging to any of the HD Annex I grassland habitats mapped during the Nature Census project carried out by the Nature Protection Agency (2017 – 2021) were used as the habitat patches. The original polygon layer (the version of July 2021) was rasterised at the resolution of 20x20m (pixel size).

The following data sources were used for the creation of the cost landscape map:

- Rural Support Service GIS database of the fields of their customers. This database contains polygons of all crop fields the owner or manager has applied to the Latvian Rural Support service for support payments. A separate polygon is drawn for each field, and the crop grown in the particular year is recorded. The database is maintained incrementally (yearly intervals) and has year-specific versions reflecting the situation for each particular year. The database (reflecting the situation in 2020), and its only layer ("ARCGIS_Lauki") was used for this task.
- Forest stand-level database of the State Forest Service. This database contains polygons of all forest compartments (both private and state-owned), and the information on the forest type, age and other information important for management is recorded. The database contains polygons for forest stands (compartments) and other forest infrastructure such as forest clearings and other openings, peat bogs and other mires, tracks, roads, ditches, forest animal feeding places, etc. The database is maintained continuously, and the database version (reflecting the situation in 2019) and its layer "nogabali" was used for this task.
- Layers of the topographical map (scale 1:10000) of the Latvian Geospatial Agency. This database contains GIS layers needed to display the topographical mao at the scale of 1:10000. The layers "hidro_L", "hidro_A", "road_L", "road_A", "landus_A", "swamp_A" and "build_A" were used for this task.
- Grasslands detected by the Institute of Environmental Solution from Sentinel 2 satellite images and their productivity. All available cloud free Sentinel 2 scenes covering the whole country were collected for the period April 2020 to august 2020. The scenes were classified into land use clases. Pixels belonging to the grassland class were classified into 3 productivity classes based on the seasonal development of their NDVI values.
- The layer of habitats mapped during the Nature Census, filtering our potential biologically valuable grasslands ("potBVZ"). These were grasslands that did not meet the criteria to be recognised as HD Annex I grasslands but contained indicator species of these grasslands and, with proper management, might qualify as HD Annex I grasslands in future.

Forest edges were extracted in a separate layer ("mezmalas") from the State Forest Service database by dissolving ("Dissolve" algorithm of ArcGIS) all forest compartment polygons and then converting to line features ("Feature to Line" algorithm of ArcGIS).

## Preparation of the cost landscape

The first step in the preparation of the cost landscape was assigning the cost values to the polygons and lines of the layers of the topographical map 1:10000, RSS field data (2020), SFS forest compartment database (2019), as well as grass pixels identified by remote sensing, potential biologically valuable grasslands that were used for the creation of the cost landscape (see the previous chapter). For this reason, the possible traversability by grassland species of each polygon and line feature category in the datasets described above were assessed according to two criteria: 1) vegetation height and density and 2) suitability as a habitat for grassland species. The assessment was based on the opinion of botanist expert Dr. biol. Solvita Rūsiņa, and the following categories were used:

- 3 classes of vegetation height and density were used: 3 – low (up to 1 m), 2 - high (up to 2 m) or sparse (e.g., parks), 1 – very high (above 2 m) or dense (e.g., spruce forest)
- 3 classes of habitat suitability for grassland species were used: 1 – unsuitable (no species that can exist), 2 – partly suitable (some species can exist), 3 – suitable (majority of species can exist)

The actual cost values (the cost of crossing the pixel of 20x20m) ranged from 1 (grassland, virtually no cost of crossing) to 60 (dense urban constructions, impossible to cross for species of low mobility). All cost values of feature categories used as input data are given in Appendix 1 (Tables A.1 to A.8).

All polygons and line features described in the previous section were rasterised to grid cells of 20 m spatial resolution and assigned the corresponding cost values as the pixel values. All rasterisation was carried out, ensuring that pixel edges match between the rasters, using the national coordinate reference system LKS-92 (epsg: 3059) and the extent covering the whole national territory of Latvia. All these processing environments were kept constant in further analysis.

The initial cost landscape was created by combining the rasters obtained from the "LRGIS_Lauki" and "nogabali" layers using the conditional ("Con") algorithm of ArcGIS. Similarly, the obtained raster was successively combined with the other rasterised datasets (keeping the lowest pixel value if the values of two overlaying pixels disagreed) in the following order: "landus_A", "build_A", "swamp_A", "hidro_A", "mezmalas", "road_A", "road_L", "hidro_L", "potBVZ", "VRI_raziba".

The resulting cost landscape was a raster (GeoTIFF) file with 20m pixel resolution and values ranging from 1 to 60. The obtained obtained cost landscape overlaid with grassland habitat patches is shown in Figure 1.

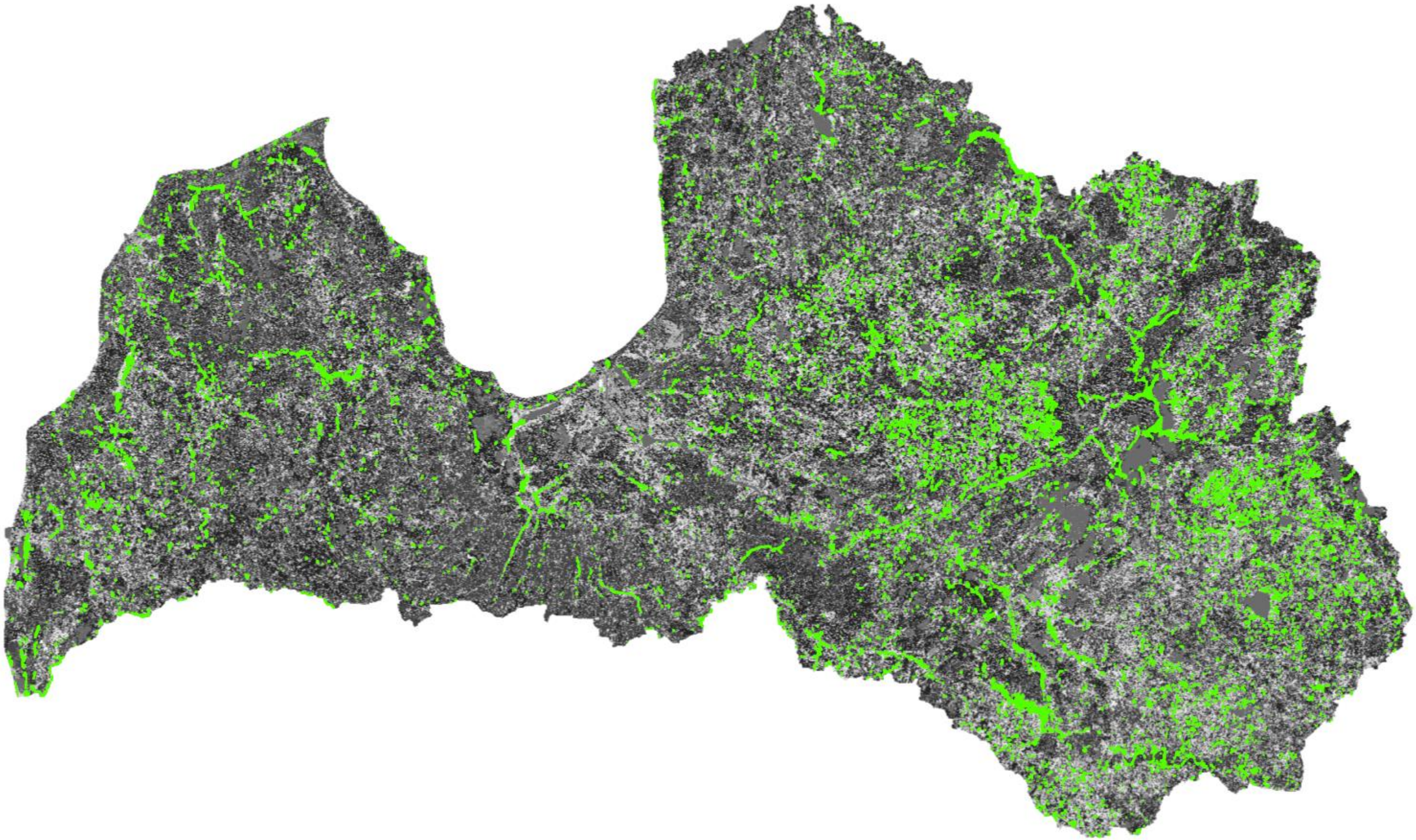

Figure 1. Grasslands (green) on top of the cost landscape map where low costs of traversability by grassland species are white (most of them covered by grasslands) and high costs of traversability are black, and different shades of grey reflect costs between the extremes.

## Maximum cost distances

Species with different mobility inhabit grasslands. Thus a single model would not suit them all. Different maximum cost distances (i.e. the sum of pixel values) that the species can cross were used to create models to increase the applicability of connectivity models. The following maximum cost distances were used:

- 50m
- 100m
- 200m
- 500m
- 1000m
- 2000m

Please, note that these are not physical distances! For example, a species with a maximum dispersal cost distance of 50m can cross 50 grid cells (equivalent to 2km) with a cost value of 1 but cannot cross a single pixel (equivalent to 20m) with a cost value of 60.

Patch connectivity rule of 4 (pixels connected with edges and not pixels connected only with corners that were considered connected) was used in all connectivity calculations, and all the links between patches were potentially taken into account.

## Calculation of metrics

The calculation was done using Graphab 2.6.4. software (Foltête et al., 2021). A Graphab project defining the habitat patches, cost landscape and values, connectivity rule and link restriction settings was created for each maximum cost distance, and link sets were built accordingly. During this process, least-cost paths not exceeding the maximum allowed cost distances for a given project were calculated. Then the actual patches and paths were transformed into graphs consisting of nodes and edges (Foltête and Vuidel, 2017; Urban and Keitt, 2001) for further connectivity calculations.

Table 1 gives an overview of connectivity metrics calculated at each computational level (global, component, local and delta).

Table 1. Overview of connectivity metrics calculated at each computational level and maximum cost distances used

| Metric | Code | Maximum cost distances used for calculations | | | |
|---|---|---|---|---|---|
| | | Global | Component | Local | Delta |
| Betweenness centrality index (Bodin and Saura, 2010) | BC | | | 50 – 1000 | |
| Equivalent Connectivity (Saura et al., 2011) | EC | 50 – 1000 | 50 – 1000 | | 50 – 100 |
| Probability of Connectivity (Saura and Pascual-Hortal, 2007) | PC | 50 – 1000 | 50 – 1000 | | 50 – 100 |

| Metric | Code | Maximum cost distances used for calculations | | | |
|---|---|---|---|---|---|
| | | Global | Component | Local | Delta |
| Flux (sum of) (Saura and Torné, 2009) | F | 50 – 1000 | 50 – 1000 | 50 – 1000 | |
| Interaction Flux (Sahraoui et al., 2017) | IF | | | 50 – 1000 | |
| Integral Index of Connectivity (Pascual-Hortal and Saura, 2006) | IIC | | 50 – 1000 | | |
| Current Flow (Girardet et al., 2015) | CF | | | 50 – 1000 | |
| Node Degree (Freeman, 1979) | Dg | | | 50 – 1000 | |
| Connectivity Correlation (Minor and Urban, 2008) | CCor | | | 50 – 1000 | |
| Clustering coefficient (Ricotta et al., 2000) | CC | | | 50 – 1000 | |
| Closeness Centrality (Freeman, 1979) | CCe | | | 50 – 1000 | |
| Eccentricity (Urban and Keitt, 2001) | Ec | | | 50 – 1000 | |
| Number of Components (Urban and Keitt, 2001) | NC | 50 – 2000 | | | |
| Graph Diameter (Urban and Keitt, 2001) | GD | | 50 – 1000 | | |
| Harary Index (Urban and Keitt, 2001) | H | | 50 – 1000 | | |

## Results

### Link sets

Link sets are sets of paths between habitat patches within the study area that do not exceed the maximum cost distances (Fig. 2). Thus a link set was created for each of the maximum cost distance thresholds. The real least-cost paths are provided as shapefiles (a shapefile for each maximum cost distance threshold) named BVZ-cXX-links.shp, where XX stand for the particular maximum cost distance threshold used.

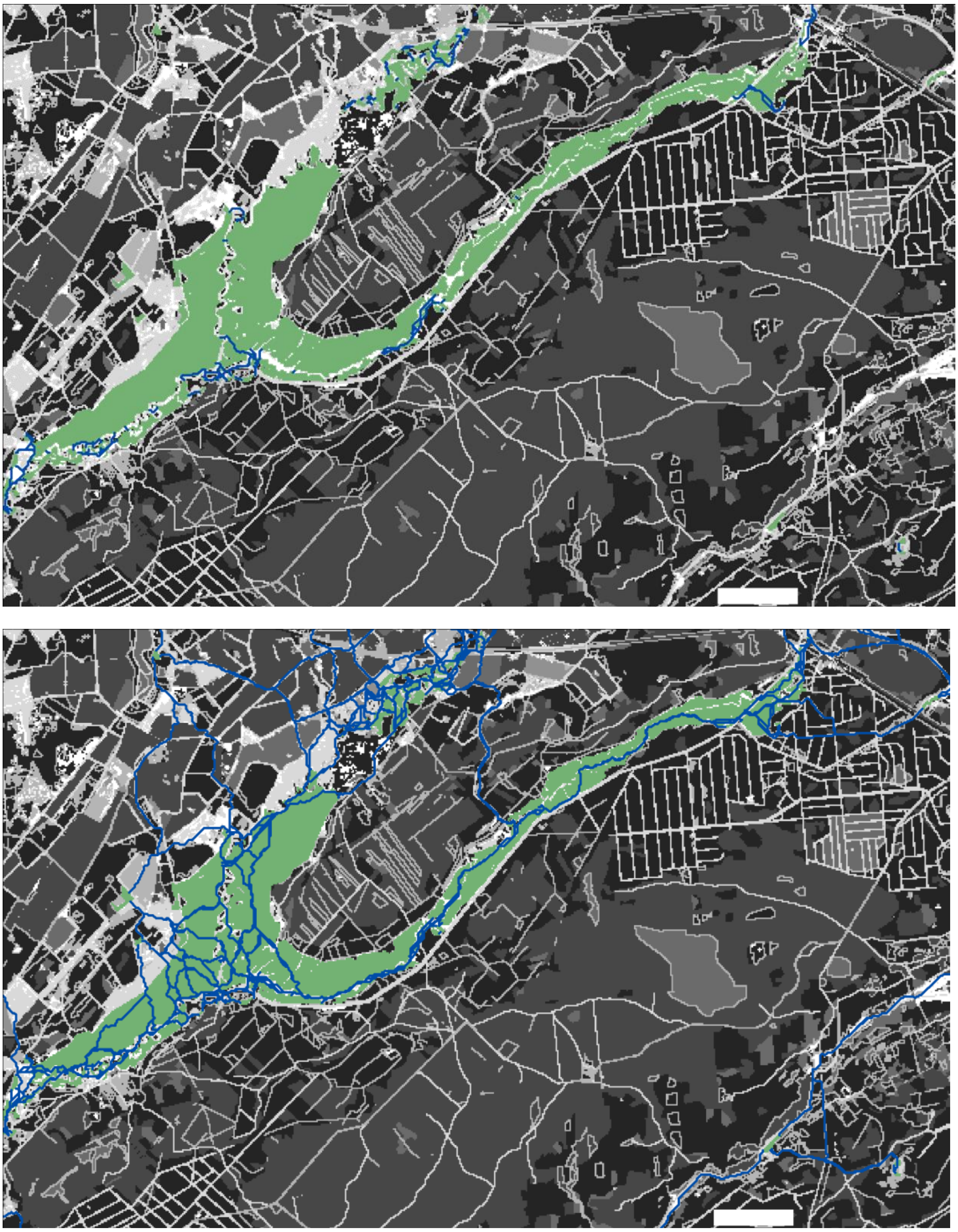

Figure 2. An example of link sets using 50 (above) and 1000 (below) as maximum cost distance thresholds. The green patches are HD Annex I grassland habitats, and the blue lines are the least cost paths between them. The cost landscape is used as a backdrop.

## Graphs

Graphs consist of nodes and links, where the nodes are the set of habitat patches analysed (grasslands in our case), and the links are the potential connections between them, weighted by cost distances (Fig. 3). None of the links exceeds the maximum cost distance used for the particular graph.

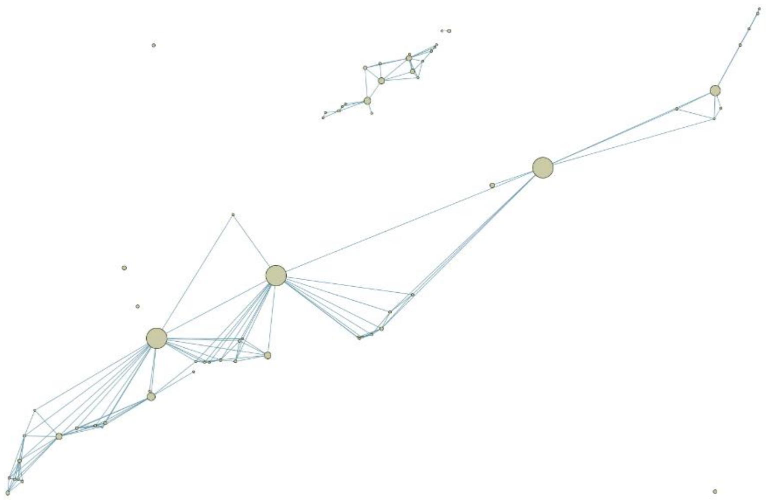

Figure 3. Example graph representations: nodes and links for a graph with a maximum cost distance of 50. The circle size represents the relative grassland patch area. The displayed area is approximately the same as in Fig. 2.

## Global metrics

Global metrics describe the entire graph. Since they provide a single figure for the whole graph (in our case, the whole country), these metrics are not provided in the format of GIS layers. Instead, they are given in Table 2.

Table 2. Global (country level) grassland connectivity metrics.

| Maximum cost distance | EC | PC | sum of F | NC |
|---|---|---|---|---|
| 50m | 23531579.945562795 | 3.887675687201317*10-8 | 2607658023.1680303 | 11305 |
| 100m | 25729734.698621847 | $4.6479181370295974*10^{-8}$ | 4417171637.741165 | 8336 |
| 200m | 29889574.165536143 | $6.27230703601517*10^{-8}$ | 8886407211.408432 | 5138 |
| 500m | 41867956.70192175 | $12.306976934587371*10^{-8}$ | 32545075258.83228 | 1474 |
| 1000m | 62441619.0481779 | $27.37386774304128*10^{-8}$ | 111747153750.57147 | 226 |
| 2000m | 854236764821.33279 | $61.44826474392274*10^{-8}$ | 97566190.286331 | 4 |

## Component metrics

Component metrics describe connectivity within each component (or sub-graph): a set of interconnected patches given the maximum allowed cost distances. The components are usually visualised as Voronoi polygons (partitioning the area into regions nearest to each set of objects) in which the interconnected patches are nested (Fig. 4). Component metrics are component-specific and are available for each component. For each threshold of maximum allowed cost distances, component metrics are provided as 2 dataset: 1) a GIS dataset BVZ-cXX-voronoi.shp (consists of 6 files) and 2) BVZ-cXX-voronoi.csv, where XX stand for the particular maximum cost distance threshold used. The metrics are stored in the second file, and the corresponding metric codes are used in the field names. The second file must be joined to the attribute table of the GIS dataset using the Id fields in both datasets for linking.

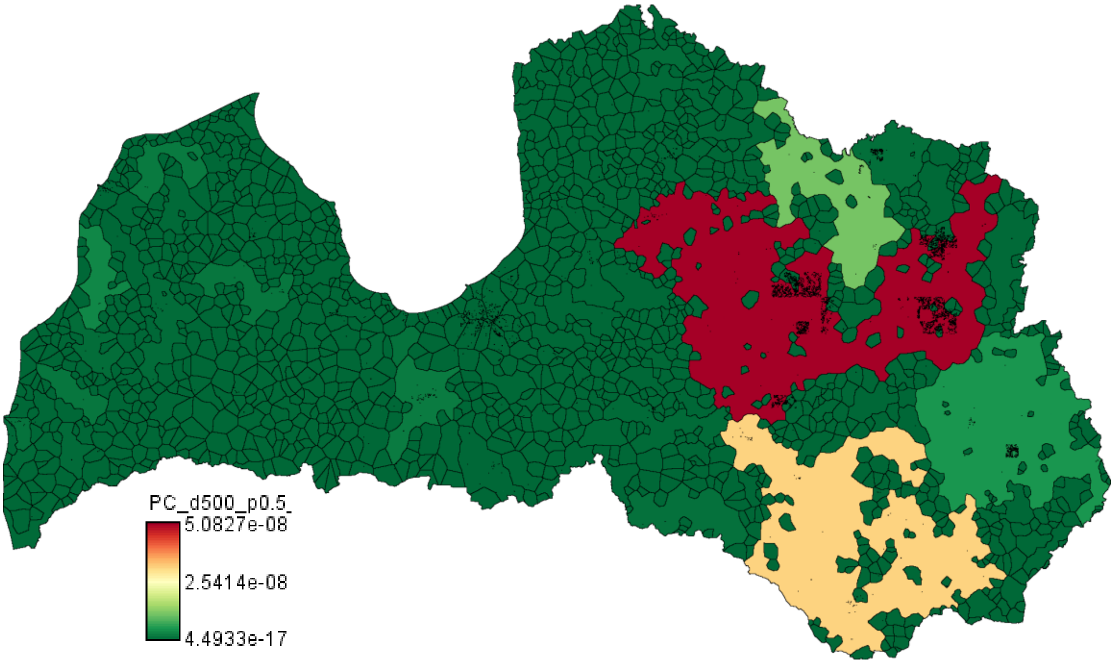


Figure 4. Example of component metrics: the probability of connectivity (PC) calculated for a graph where the maximum allowed cost distance is 50.

## Local metrics

Local metrics describe the connectivity of each graph element (node or link). Thus local metrics are provided for each habitat patch. For each threshold of the maximum allowed cost distances, component metrics are provided as 2 datasets: 1) a GIS dataset Patches.shp (consists of 6 files) and 2) patches_kom.csv. The second file must be joined to the attribute table of the GIS dataset using the Id fields in both datasets for linking. The metrics are stored in the second file, and the corresponding metric codes are used in the field names.

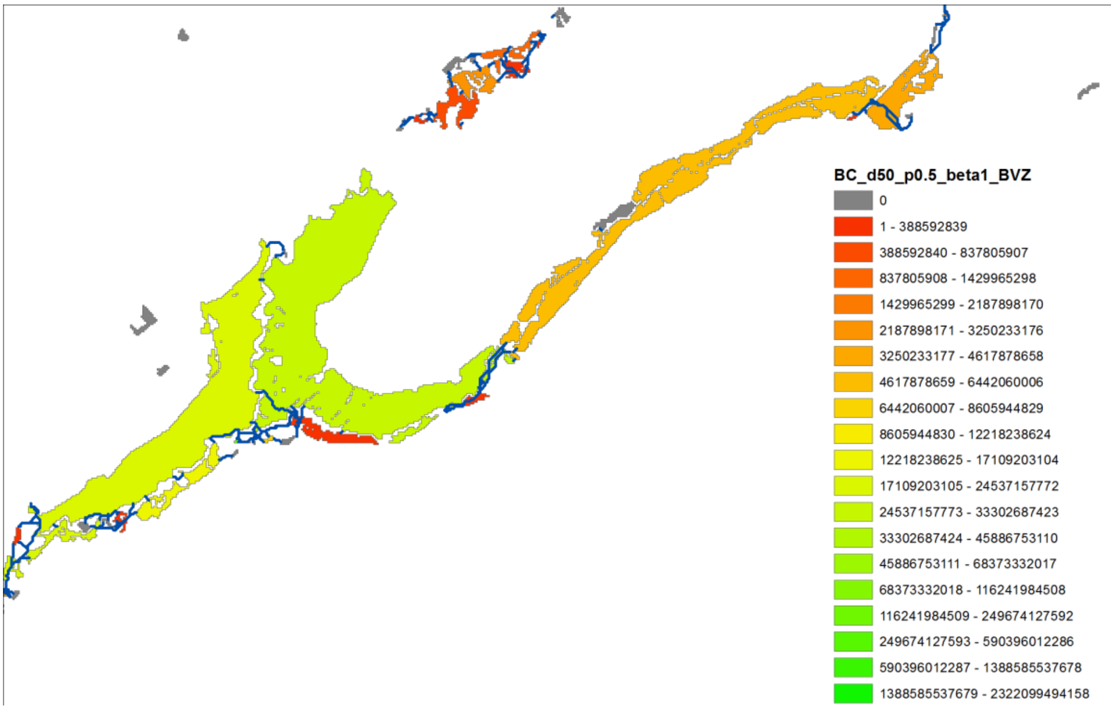


Figure 4. Example of patch metrics: betweenness centrality index (BC) calculated for a graph where the maximum allowed cost distance is 50.

## Delta metrics

Delta metrics also describe each graph element but use a specific computing method. The relative importance of each graph element is assessed by computing the rate of variation in the global metric induced by each removal (Foltête et al., 2021). The result of a delta-metric is at a local level but by reference to the global level. Due to the time constraints of the delta metric calculation, these were calculated only for the graphs with the maximum allowed cost distances of 50 and 100. Delta metrics are provided in the same patches_kom.csv data file, where local metrics are stored and can be recognised by “d_” before the metric code in the field name.

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# Appendices

# Appendix 1. Dataset specific cost values used for the calculation of the cost landscape

Table A.1. Cost values used for line segments of the "hidro_L" (hydrology line features) data layer of the topographic map 1:10000

| Feature category (FNAME field) | Vegetation height/density | Habitat suitability | **Cost value** |
|---|---|---|---|
| Aizsargdambis mērogā | 3 | 1 | **5** |
| Aizsargdambis valnis virs 2m | 3 | 1 | **5** |
| Aizsargdambis valnis zem 2m | 3 | 0 | **10** |
| Dambis ar novadbūvi mērogā | 3 | 1 | **5** |
| Dambis ar novadbūvi virs 2m | 3 | 1 | **5** |
| Dambis ar novadbūvi zem 2 m | 3 | 0 | **10** |
| Krasta līnija nepastāvīga | na | na | **20** |
| Krasta līnija pastāvīga | 3 | 1 | **5** |
| Krasts nostiprināts ar nogāzi | 3 | 1 | **5** |
| Krāce mērogā | na | na | **20** |
| mols | na | na | **20** |
| Nepārbraucama aizspr mērogā mala | na | na | **20** |
| Nepārbraucams aizsprosts mērogā | na | na | **20** |
| Nepārbraucams aizsprosts ārpusm | na | na | **20** |
| Nostiprināta krastmala | 3 | 1 | **5** |
| periodiski izžūstoša ūdtece l'diz3m | 3 | 0 | **10** |
| pārbraucama aizsprosta mala | na | na | **20** |
| Pārbraucams aizsprosts mērogā | na | na | **20** |
| Pārbraucams aizsprosts ārpusm | na | na | **20** |
| Slūžas mērogā | na | na | **20** |
| Viļņlauzis | na | na | **20** |
| Ūdenskritums mērogā | na | na | **20** |
| ūdenskrātuve bas nostādināšana | na | na | **20** |
| ūdenst izžūstošs posms līdz 3m | 3 | 0 | **10** |
| ūdenstece līdz 3m | 3 | 0 | **10** |
| ūdenst izžūstošs posms mērogā | 3 | 0 | **10** |
| ūdenstilpnes nodalošā līnija | na | na | **20** |

Table A.2. Cost values used for line segments of the “road_L” (transportation line features) data layer of the topographic map 1:10000

| Feature category (FNAME field) | Vegetation height/density | Habitat suitability | **Cost value** |
|---|---|---|---|
| autoceļa ar c_s 5līdz7_5m mala | 3 | 3 | **5** |
| autoceļa ar c_seg plat par 7_5m mala | 3 | 3 | **5** |
| autoceļa ar c_seg zem 5m mala | 3 | 2 | **10** |
| autoceļa ar g_s 5līdz7_5m mala | 3 | 3 | **5** |
| autoceļa ar g_seg plat par 7_5m mala | 3 | 3 | **5** |
| autoceļa ar g_seg zem 5m mala | 3 | 2 | **10** |
| autostrādes ar cieto segumu mala | 3 | 3 | **5** |
| brauktuve apbūvētā teritorijā | na | na | **20** |
| gājēju celiņš līdz 3 m | 3 | 3 | **5** |
| gājēju celiņš mērogā | 3 | 3 | **5** |
| lauku un meža ceļš | 3 | 3 | **5** |
| stāvlaukums mērogā | na | na | **20** |
| taka | 3 | 3 | **5** |
| zemesceļš | 3 | 3 | **5** |

Table A.3. Cost values used for line segments of the “road_A” (transportation polygon features) data layer of the topographic map 1:10000

| Feature category (FNAME field) | Vegetation height/density | Habitat suitability | **Cost value** |
|---|---|---|---|
| poligons_Brauktuve | na | na | **20** |
| poligons_Ceļš_ciets_segums | na | na | **20** |
| poligons_Ceļš_grants_segums | na | na | **20** |

Table A.4. Cost values used for line segments of the "landus_A" (land use polygon features) data layer of the topographic map 1:10000

| Feature category (FNAME field) | Vegetation height/density | Habitat suitability | **Cost value** |
|---|---|---|---|
| meldrājs ūdenī | 1 | 1 | **50** |
| sēklis | na | na | **20** |
| augļudārzs | 2 | 2 | **30** |
| grants | na | na | **20** |
| grīslājs | 2 | 2 | **30** |
| izcirtums | 2 | 2 | **30** |
| izdegums | 2 | 2 | **30** |
| jaunaudze | 1 | 1 | **50** |
| kapi | 2 | 2 | **30** |
| krūmaugu_plant | 2 | 2 | **50** |
| krūmājs | 1 | 1 | **50** |
| kūdra | na | na | **20** |
| meldrājs ūdenī | 1 | 1 | **50** |
| meža kapi | 2 | 2 | **30** |
| mežs | 1 | 1 | **50** |
| nec_purvs_grīslājs | 2 | 2 | **30** |
| nec_purvs_meldrājs | 2 | 1 | **40** |
| nec_purvs_sūnājs | 3 | 1 | **30** |
| ogulājs | 2 | 2 | **30** |
| parks | 2 | 2 | **30** |
| pārējā zeme | 3 | 2 | **10** |
| pļava | 3 | 3 | **0** |
| sakņudārzs | 3 | 1 | **30** |
| skrajmežs | 2 | 2 | **30** |
| smiltājs | na | na | **20** |
| sūnājs | 3 | 1 | **30** |
| zāliens | 3 | 2 | **10** |
| zālaugu plant | 2 | 2 | **30** |
| blīva apbūve | na | 1 | **60** |
| vasarnīcu apbūve | 2 | 2 | **30** |
| viensētu apbūve | 2 | 2 | **30** |
| caurejams_purvs | 3 | 1 | **30** |
| atklāts ūdens | 3 | 1 | **30** |

Table A.5. Cost values used for polygons of the “LRGIS_Lauki” (crop type polygon features) data layer of the Rural Support Service GIS database for the customer fields

| Feature category (RSS codes) | Vegetation height/density | Habitat suitability | **Cost value** |
|---|---|---|---|
| 1** (graudaugi) | 2 | 1 | **40** |
| 2** (graudaugi rapsis, ripsis) | 2 | 1 | **40** |
| 3** (lini, aņepes) | 1 | 1 | **50** |
| 4** (graudaugi+zirņi, tauriņzieži utml.) | 2 | 1 | **40** |
| 610 (papuve) | na | na | **20** |
| 6** (īscirtmeta atvasāji) | 1 | 1 | **50** |
| 710 (ilggadīgie zālāji) | 2 | 3 | **5** |
| 71* (izņemot 710, stiebrzāles vai tauriņzieži sēklām)) | 2 | 2 | **30** |
| 72* (stiebrzāles aramzemē, zālāji aramzemē) | 2 | 2 | **30** |
| 73* (stiebrzāles sēklām) | 2 | 2 | **30** |
| 74* (kukurūza) | 1 | 1 | **50** |
| 76* | | | **30** |
| 79* (kukurūza biogāzei) | 1 | 1 | **50** |
| 8** (dārzeņi) | 3 | 1 | **30** |
| 926 (zemenes) | 3 | 1 | **30** |
| 9** (ilggadīgie stādījumi) | 2 | 2 | **30** |
| 620 nevar attiec. gadā saņemt atbalstu | na | na | **20** |
| 792 platība, kur dabiski iesējušos augu īpatsvars pārsniedz 25% | 2 | 2 | **30** |

Table A.6. Cost values used for forest types in the "nogabali" (forest stand polygon features) data layer of the State Forest Service

| Feature category (MT field) | Vegetation height/density | Habitat suitability | **Cost value** |
|---|---|---|---|
| Sils | 2 | 2 | **40** |
| mētrājs | 2 | 2 | **40** |
| lāns | 2 | 2 | **40** |
| damaksnis | 1 | 1 | **50** |
| vēris | 1 | 1 | **50** |
| gārša | 1 | 1 | **50** |
| grīnis | 2 | 2 | **40** |
| slapjai smētrājs | 2 | 2 | **40** |
| slapjais vēris | 1 | 1 | **50** |
| slapjā gārša | 1 | 1 | **50** |
| purvājs | 2 | 2 | **40** |
| niedrājs | 2 | 2 | **40** |
| dumbrājs | 1 | 1 | **50** |
| liekņa | 1 | 1 | **50** |
| viršu ārenis | 1 | 1 | **50** |
| mētru ārenis | 1 | 1 | **50** |
| šaurlapju ārenis | 1 | 1 | **50** |
| platlapju ārenis | 1 | 1 | **50** |
| viršu kūdrenis | 1 | 1 | **50** |
| mētru kūdrenis | 1 | 1 | **50** |
| šaurlapju kūdrenis | 1 | 1 | **50** |
| platlapju kūdrenis | 1 | 1 | **50** |
| slapjais damaksnis | 2 | 2 | **30** |

Table A.7. Cost values used for non-forest land category polygons of the "nogabali" (land category polygon features) data layer of the State Forest Service

| Feature category (ZKAT field) | Vegetation height/density | Habitat suitability | **Cost value** |
|---|---|---|---|
| zāļu purvs | 2 | 2 | **30** |
| virsājs | 3 | 2 | **10** |
| sūnu purbs | 3 | 1 | **30** |
| smiltājs | 3 | 2 | **10** |
| sēklu ieguves plantācija | 2 | 2 | **30** |
| pārejas purvs | 3 | 1 | **30** |
| rekreācijas platība | 3 | 2 | **10** |
| meža lauce | 3 | 2 | **10** |
| rekultivēta zeme | 3 | 1 | **30** |
| pārplūstošs klajums | 3 | 2 | **10** |
| kokmateriālu krautuves vieta | 2 | 1 | **40** |
| bebru appludinājums | 2 | 1 | **40** |
| meža dzīvnieku barošanas vieta | 2 | 1 | **40** |

Table A.8. Cost values used for grasslands detected by the Institute of Environmental Solution from Sentinel 2 satellite images

| Productivity category | Vegetation height/density | Habitat suitability | **Cost value** |
|---|---|---|---|
| IES grasslands productivity 1 (low) | 3 | 3 | **0** |
| IES grasslands productivity 2 (medium) | 2 | 3 | **5** |
| IES grasslands productivity 3 (high) | 2 | 2 | **10** |

## Appendix 2. Data files for connectivity if the maximum allowed cost distance is 50.

Provided as an archived dataset Connectivity_50.zip

## Appendix 3. Data files for connectivity if the maximum allowed cost distance is 100.

Provided as an archived dataset Connectivity_100.zip

## Appendix 4. Data files for connectivity if the maximum allowed cost distance is 200.

Provided as an archived dataset Connectivity_200.zip

## Appendix 5. Data files for connectivity if the maximum allowed cost distance is 500.

Provided as an archived dataset Connectivity_500.zip

## Appendix 6. Data files for connectivity if the maximum allowed cost distance is 1000.

Provided as an archived dataset Connectivity_1000.zip