Green Infrastructure Decision Support Mapping Approach for Ecosystem Services

Technical development of a green infrastructure decision support mapping approach for ecosystem services in Dún Laoghaire-Rathdown (DLR) using the SITxell territorial mapping approach

Final report

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1. Introduction

Developing systems for mapping and assessing ecosystem services at all levels was one of the targets of the 2020 EU Biodiversity Strategy to 2030. In response, municipalities and regions across Europe are increasingly attempting to map and assess their ecosystem services and use such information in the decision-making process. While methodologies for strategic ecosystem services mapping have been developed and are assisting in national, regional and local level decision-making, there are still key challenges. More specifically, the roll-out of green infrastructure is a policy priority, but there is a limited understanding by decision-makers regarding potential conflicts between the protection, development and maintenance of ecological networks and corridors on the one hand, and of recreational and commuting greenway services on the other (Basnou et al. 2020).

The proposed Pilot Action involves the transfer of the SITxell Territorial Information System (https://www.sitxell.eu/en/default.asp), which was identified as a Good Practice during the first thematic semester of the Interreg Europe PROGRESS project, to develop and test a mapping approach to enhance decision-making around Green Infrastructure in the Eastern and Midland Region, Ireland. SITxell is a cartographic and alphanumeric database on a 1:50 000 scale that helps with the study, analysis, evaluation and planning of the open areas in the province of Barcelona. The conceptual basis of this tool lies in the conviction that the open spaces as a whole are the basic territorial system, upon which settlement and infrastructure systems must properly be placed, so that open areas maintain their key ecological and socio-economic functions. It is therefore essential to understand the main features of these areas - both their intrinsic characteristics and the attributes associated with overall network processes.

On the technical side, SITxell is a project concerning territorial analysis, which is structured through different layers of geographical information and intended to study and evaluate the open areas of the province. On a political level, SITxell is a tool intended to influence land planning processes, on both local and regional scales, by providing accurate and reliable socio-economic and ecological information and criteria for plans and projects developed by the competent authorities. The success and influence of SITxell since its launch have been based, firstly, on the strength and usefulness of the information, applicable in land use planning at different scales and in other specific types of planning (water, agriculture, conservation of habitats and species, strategic environmental assessment, etc.). Secondly, strong partnerships with various levels of government, universities, research centres and private sector (specialized consultants, farmers associations and NGOs) have been established, that have ensured the quality of information and the objectivity of analysis.

Following the example of SITxell, the main objective of the Pilot Action was to score and map ecosystem services across the county of Dún Laoghaire-Rathdown (DLR) and thereby provide information and criteria for supporting forward planning and development management tasks by the local authority. Thus, a first information system for the county of DLR summarizing a set of spatially coherent GIS layers on selected indicators has been produced. A second objective was to perform a first analysis of the synergies and trade-offs between the most relevant indicators to identify the areas maximizing the sum and the diversity of values.

2. Study area

Dún Laoghaire-Rathdown County, is located between the outer suburbs of Dublin City and the Dublin mountains in the east of Ireland; with its 17km of coastline, harbour, towns and villages alongside communities where residents and visitors enjoy some of the best natural amenities in Ireland. It also has the benefit of unparalleled access to public transport, employment opportunities, leisure facilities, education, shopping and an attractive public realm. The County covers the electoral areas of Blackrock, Dundrum, Dún Laoghaire, Glencullen-Sandyford, Killiney-Shankill and Stillorgan. The County's vibrant community is focused across a necklace of villages, each with its own strong identity, such as Dalkey, Foxrock, Monkstown, Rathfarnham, Shankill, Sandyford and Stepaside. A new town, the biggest urban infrastructure in the country is being built at Cherrywood, which will have a population of 25,000 people.

Dún Laoghaire-Rathdown is home to 18.6% of the population of Dublin, with a population of 218,018, according to the most recent Central Statistics Office (CSO) census in 2016.

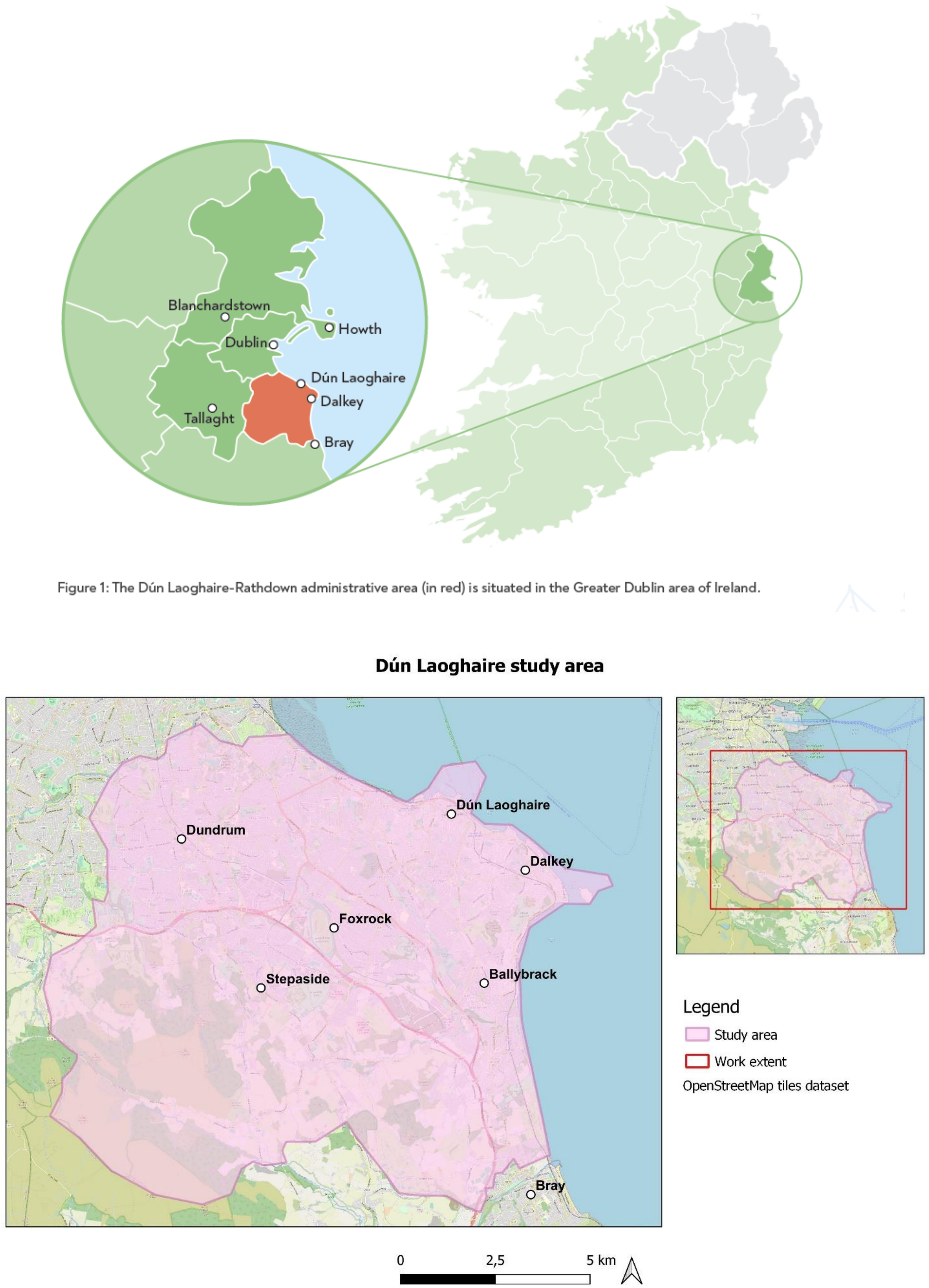

Fig. 1. Situation of Dún Laoghaire-Rathdown (DLR) County

3. Data setup

Basic information for the development of the Pilot Action was identified in collaboration with the DLR County Council. First, a Land Cover map of the study area was produced by combining two maps as follows:

- The Habitat Map of Dún Laoghaire Rathdown, which provides the most recent general view of terrestrial habitats of the county , following the Fossitt Classification (2000) that has been adopted as the official classification of habitat types in Ireland. This map was reviewed in 2020 and its information was updated using more recent surveys and also using high resolution photography.
- The zoning map of the Cherrywood Strategic Development Zone (SDZ), which is the single largest undeveloped land-bank in Dún Laoghaire-Rathdown (ca.360 hectares), nestled at the foot of the Dublin Mountains. DLR County Council, in recognising the area's strategic importance, applied to the Government for Strategic Development Zone (SDZ) status and the Government designated it as an SDZ in May 2010. This area is currently under development as a new town centre with residential, education, business, amenity and parks areas. Cherrywood cartography was also updated to include the most recent information on its development status.

The combination of both maps has produced a new land cover map, called **Basic DLR land-cover map** hereafter (Fig. 2). Also, a layer with the official population density data was provided by DLR County Council.

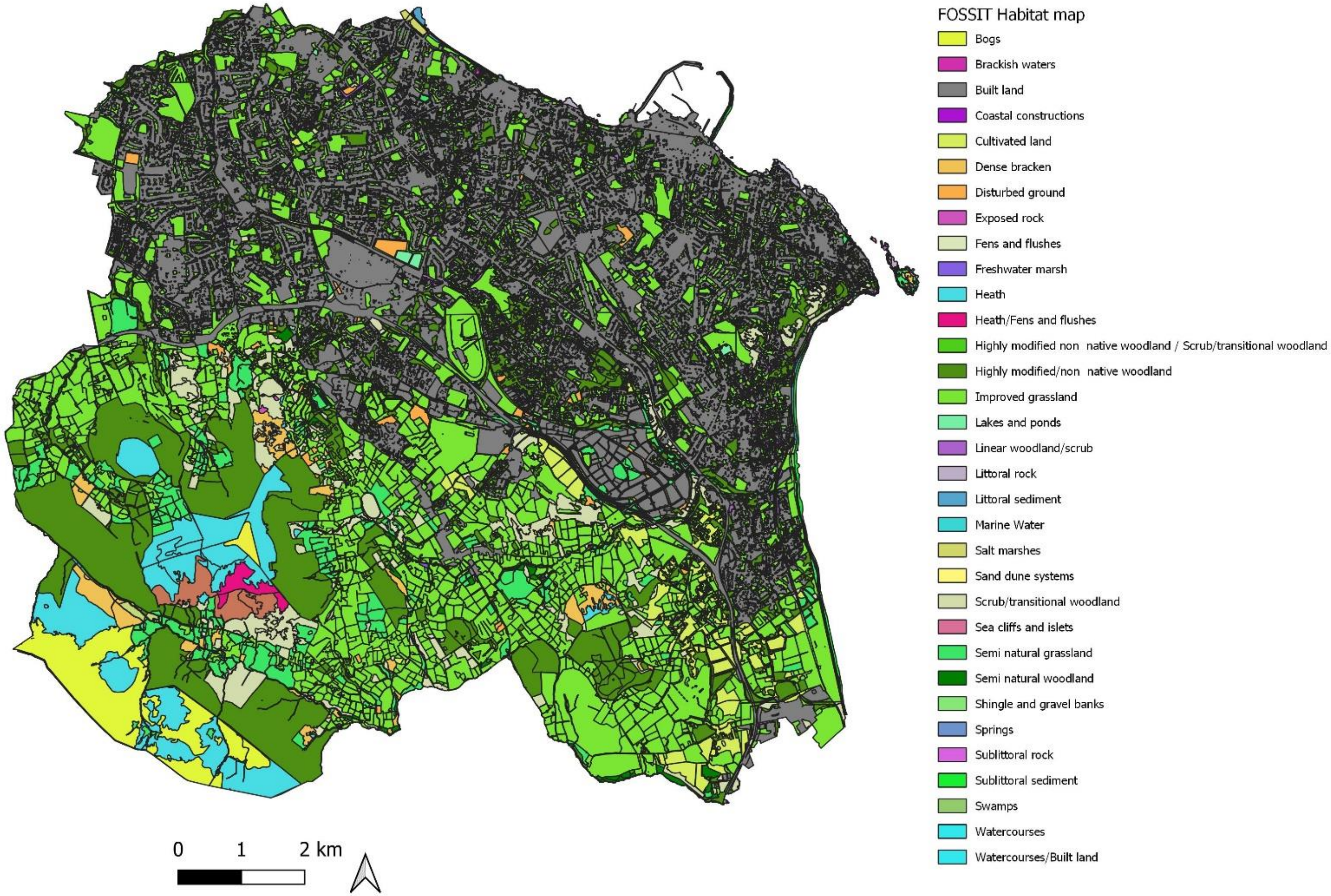

Fig. 2. Basic DLR land-cover using Fossitt Classification of habitats in Ireland (2020)

4. Indicators

Following the SITxell model for mapping ecosystem services, a set of land value indicators have been prepared on the basis of 1) Biodiversity conservation value, and 2) Functional value. Ecosystem services are the goods and services that biodiversity provides to people (Fig. 3). Biodiversity underlies all ecosystem services which may be provided by ecosystems - Without biodiversity and functioning ecosystems, no services can be derived. In the urban context, population proximity to functioning ecosystems with associated demand for recreation and commuting greenway services places substantial pressure on these ecosystems. With this in mind, we also map the population density and distance to the main elements of GI in DLR, using an isotropic (as the crow flies) spatial approach. The development of a comprehensive range of land value indicators for recreation goes beyond the scope of this Pilot project.

Source: Natural Capital Coalition (2016)

4.1. Biodiversity conservation value

This approach will be based on the proposal developed using information provided by Dún Laoghaire-Rathdown County Council (DLRCC) (Fig. 3) that includes in separate GIS (shape format) the following areas

- **International EU and national areas of most conservation concern**: these designations include European sites such as SACs (Special Areas of Conservation) and Special Protection Areas (SPAs), which are important on a European level. They have been designated specifically to protect core areas for a subset of species or habitat types and species listed in the EU Habitats and Birds Directives. It also includes NHA (Natural Heritage Areas) and proposed NHAs of Ireland, which correspond to the basic designation for wildlife in the country. These areas are considered important for the habitats present or which holds species of plants and animals whose habitat needs protection.

- **Important local areas for biodiversity**, otherwise known as LIBS (Local Important Biodiversity Sites) which have been designated by DLR. LIBs are outside protected areas but considered to form an integral part of the ecological network across a county, are important at a local level and provide a range of ecosystem services to communities. They have no formal designation but are sites which, based on expert analysis, are worthy of protection and enhancement, providing additional benefits to and supporting protected areas.
- **EU Annex Habitats of conservation / potential conservation concern.** EU Annex I habitats are habitats listed in Annex I of the Habitat Directive that are of EU Community Interest. The directive defines habitats of EU Community Interest as those that (i) are in danger of disappearance in their natural range; or (ii) have a small natural range following their regression or by reason of their intrinsically restricted area; or (iii) present outstanding examples of typical characteristics of one or more of the seven biogeographical regions. These occur outside a Natura 2000 site, as individual areas of Annex I habitat.
- **Wildlife Corridors –** These include watercourses, riparian (riverside) habitats, hedgerows and other associated habitats and some of these wildlife corridors may overlap with LIBS, Annex habitats, European and national designations.

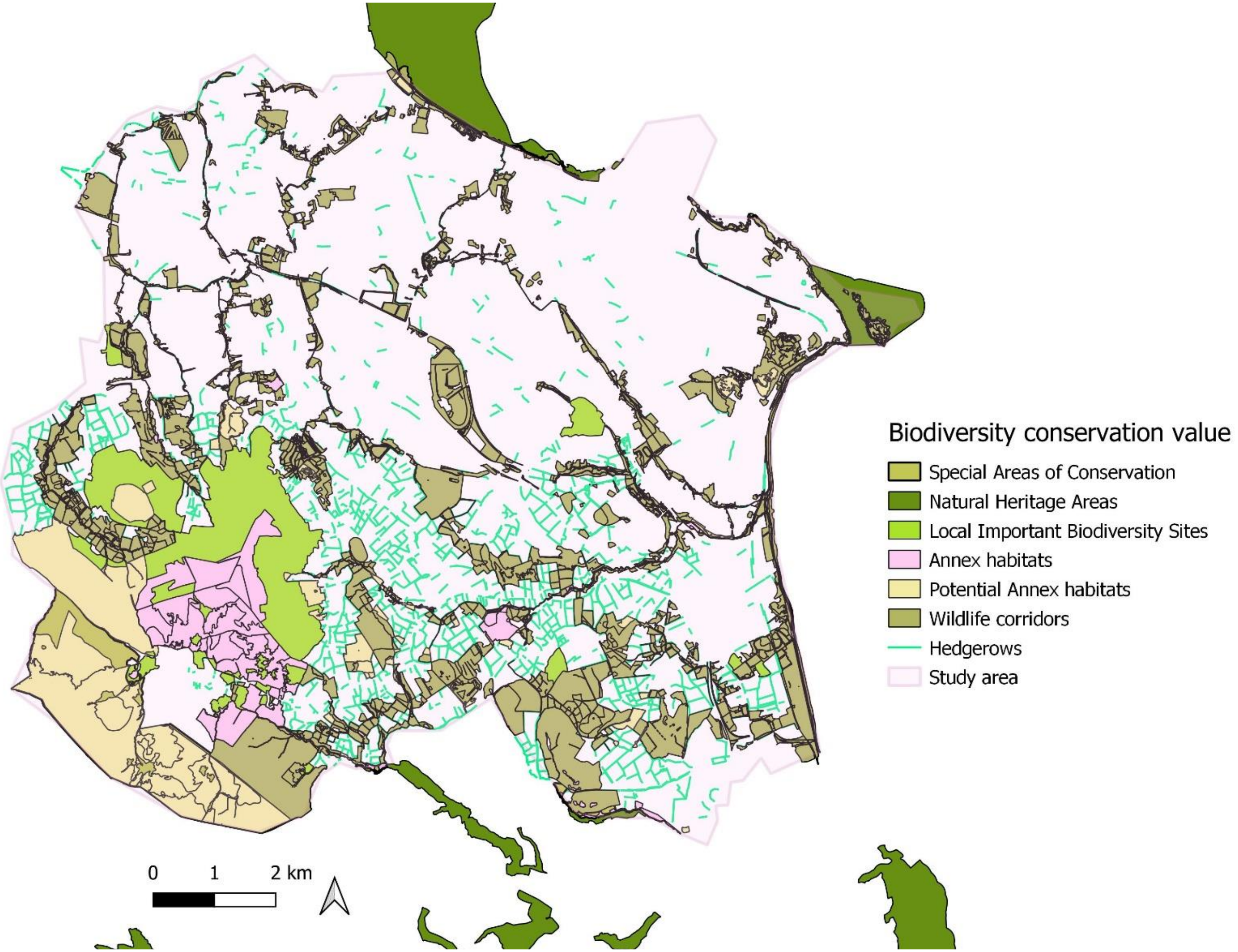

Fig. 3. Biodiversity conservation value areas

4.2. Functional value

This dimension has been mostly developed by the CREAF team with the advice of DLRCC Biodiversity Officer and Ecologist. Using the SITxell methodology, a set of indicators of contrasting functional attributes were developed as follows using the Fossitt Classification map (see table in the Annex I for more details):

Habitat naturalness

Habitat naturalness was originally defined as the degree of preservation of the pristine state of habitats (Pino et al. 2006). The concept of habitat naturalness used here is inspired by the classical theory of succession, yet it combines (i) the closeness of a given habitat to a potential status in equilibrium with the environment (i.e., climax or plagioclimax) and (ii) its conservation degree (i.e., the inverse of human alteration; Pino et al. 2009). Based on these criteria, a habitat naturalness map has been obtained (Fig. 4) by reclassifying the basic DLR land cover map into the following categories:

- *0. Artificial:* totally transformed and strongly altered areas, in which there is little space for nature: built areas, artificial all-weather pitches and paved roads.
- *1. Very disturbed/ Altered*: artificially denuded or highly altered areas.
- *2.Cultivated/Improved/Invaded:* habitats with a strong degree of human intervention, including croplands, improved grasslands frequently reseeded and fertilized and being dominated by few species (e.g. *Trifolium repens* and *Lolium perenne*), commercial forestry, amenity areas (parks with landscaped flower beds etc), golf courses and plant communities that are dominated by alien species.
- *3. Seminatural,* including unimproved or semi-improved dry grasslands and meadows that may be either calcareous or neutral, and associated with low intensity agriculture or in open green spaces. It also includes native transition woodland, sometimes quite altered, and non-native plantations that might offer some forest services, as well as linear woodland and parks and scattered trees. Finally, non-vegetated habitats (i.e. sediments, cliffs, rocks) whose status is uncertain have also been included here.
- *4. Close to natural.* Including transitional woodland, heath and scrub and potentially well-preserved wetland, marshland and aquatic habitats.

Landscape diversity

Landscape diversity is a key landscape property that has been traditionally associated with the capacity of landscapes to house species and habitats (Nagendra 2002; Corrado et al. 2011). One of most frequently used numerical indices for assessing landscape diversity is the Shannon index (Shannon & Weaver 1949; McGarigal et al. 2012). This index provides information on the number of habitats in the landscape, their equifrequency and is particularly sensitive to rare habitats (Nagendra 2002).

The Shannon index has been calculated for the DLR County using a simplified version of the Basic DLR Land Cover map, in which categories corresponding to habitat mixtures have been assigned to their dominant habitat. Correspondences between original and simplified categories are summarized in the Annex I).

Landscape diversity has been then calculated using this simplified map for areas of diverse size (100, 250 and 500 m; Fig. 5, 6 and 7), using a 2-m raster grid of the simplified habitats. We used the classical formula of the Shannon diversity index $SI = -\sum p_i * Log(p_i)$, where *pi* corresponds to the proportion of pixels of each habitat category. The index has been calculated for (i) all habitats and (ii) only for those included in the green infrastructure (i.e., all but excluding built-up areas). The resulting maps identify the areas potentially housing the highest levels of biodiversity in terms of habitats, which is in turn considered a proxy for species biodiversity, regardless of their conservation value.

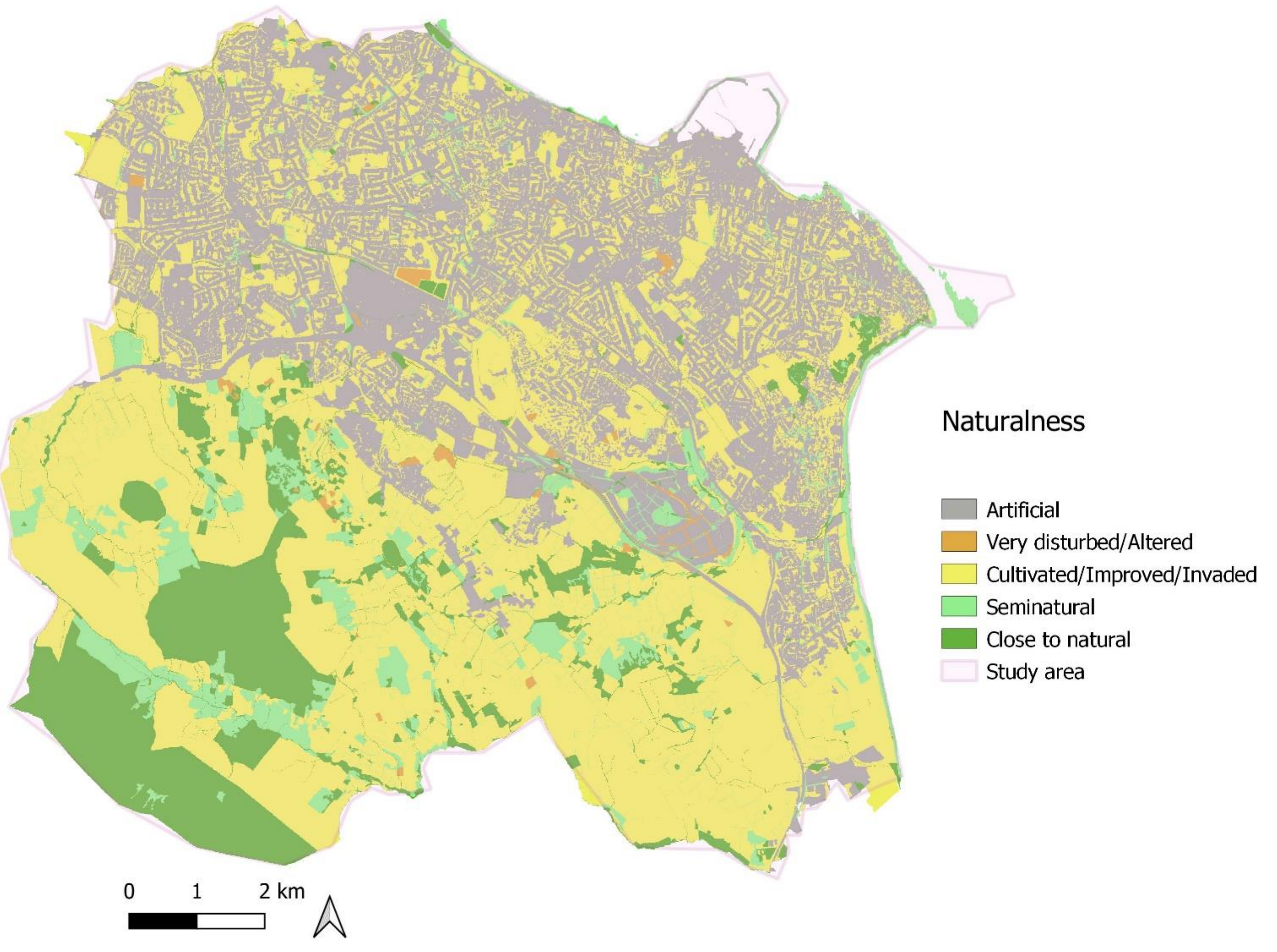

Fig. 4. Naturalness map of DLR County

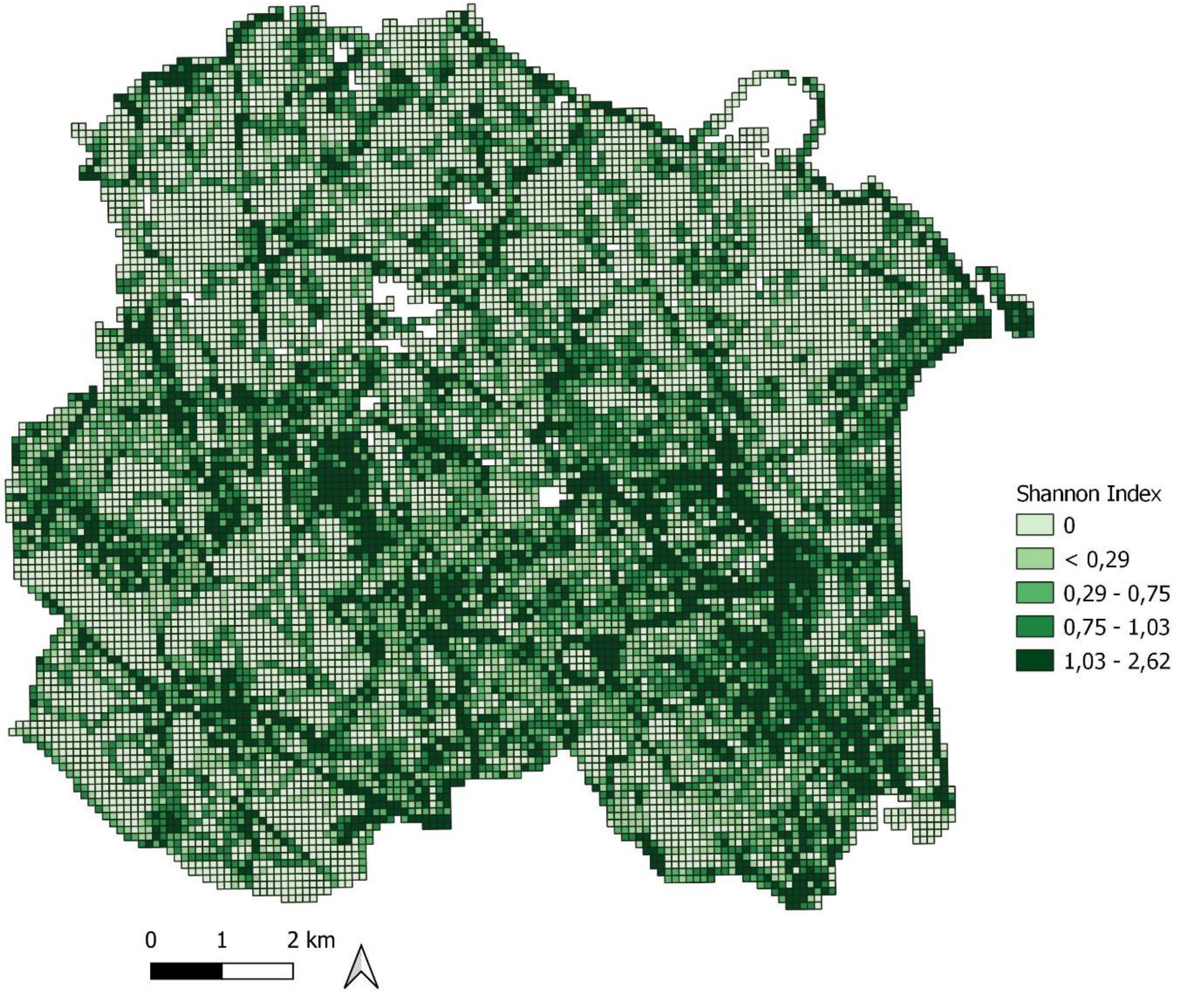

Fig. 5. Landscape diversity indicators (Shannon index on non-built habitats) of Dún Laoghaire Rathdown at contrasting spatial scales (100, m of cell size)

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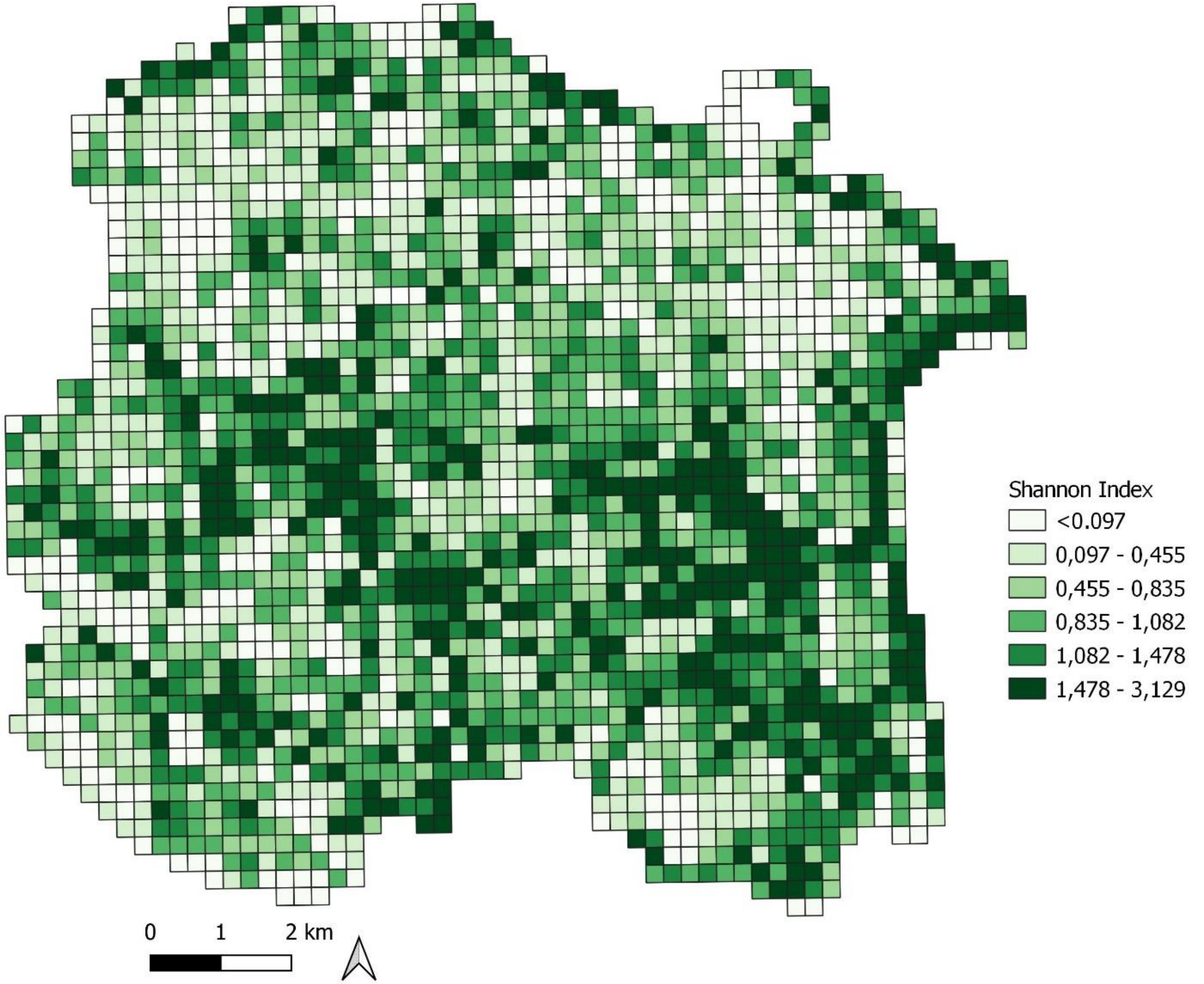

Fig. 6. Landscape diversity indicators (Shannon index on non-built habitats) of Dún Laoghaire Rathdown at contrasting spatial scales (250, m of cell size)

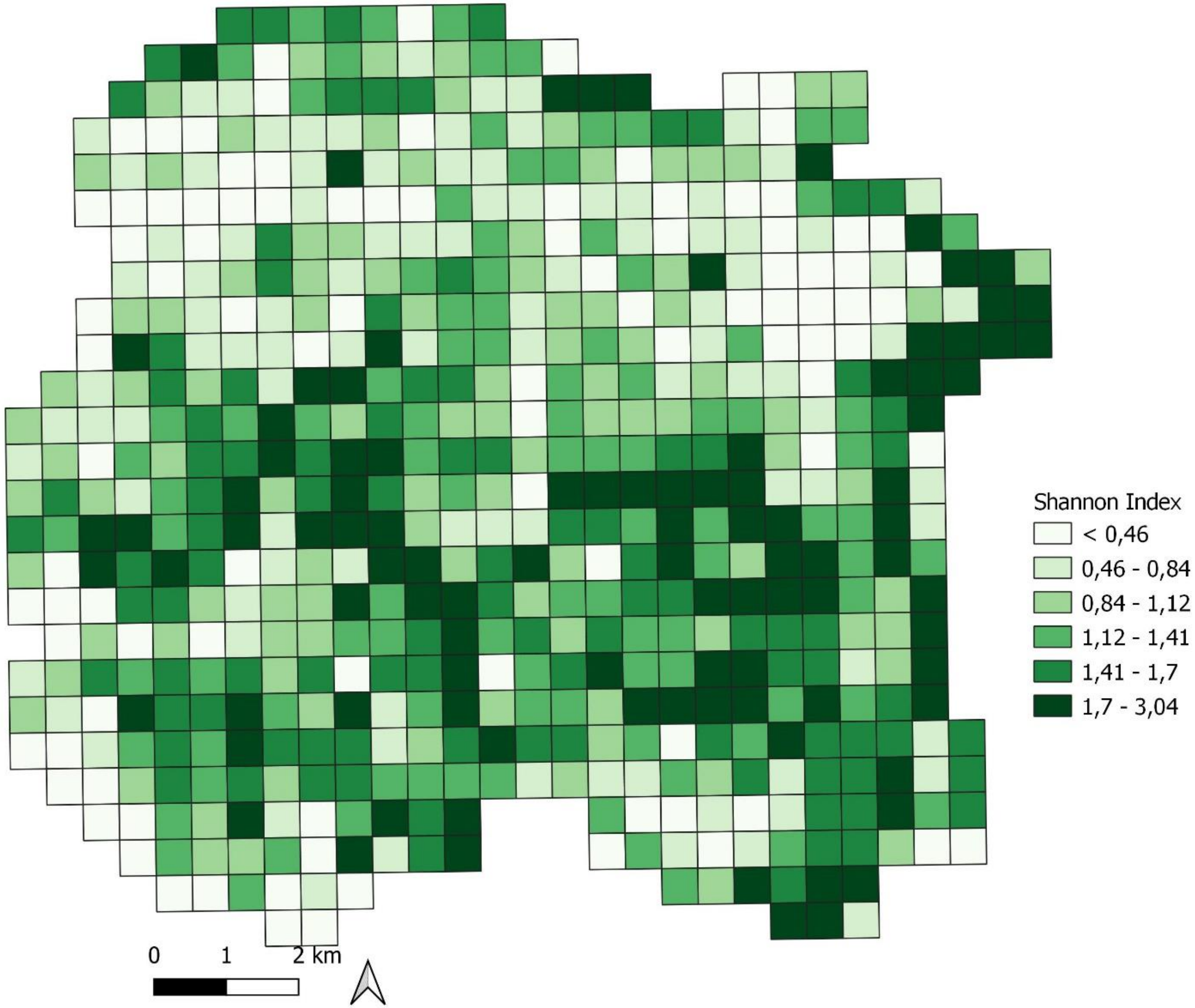

Fig. 7. Landscape diversity indicators (Shannon index on non-built habitats) of Dún Laoghaire Rathdown at contrasting spatial scales (500, m of cell size)

Landscape connectivity

Connectivity is a key property for the conservation of biodiversity and of biological and environmental processes in metropolitan territories where anthropic pressure is especially important. This necessarily happens through the development of quantitative and sufficiently detailed cartographic models, which is not trivial given the complex definition - with different structural and functional meanings- of the concept of connectivity (Calabrese & Fagan 2004).

One of the models developed by CREAF – as part of the SITxell ecosystem services module – with most application at regional level is the Terrestrial Connectivity Index (TCI), has been applied in the Master Plan for the Ecological Connectivity of Andalusia, the draft Master Plan for Ecological Connectivity of Catalonia and the Urban Master Plan of the Metropolitan Area of Barcelona. The TCI is an index specifically designed to make a quantitative mapping of ecological connectivity for large groups of organisms with certain mobility characteristics and landscape requirements. It is a modification of the index proposed by Hanski (1999) and it is calculated on a set of major land cover types. Conceptually, it indicates the connectivity from a given focal point in terms of potential habitat (in area units), which depends on the amount of the habitat itself and of related habitats and the functional distance (cost distance) to this focal point (Fig. 8).

We obtained the TCI for a set of main habitat types making up the blue-green infrastructure of the DLR County, which were obtained by reclassification of the basic DLR land-cover map (Table 1 in the Annex). The TCI was calculated for 10 habitats with relevance for biodiversity conservation (Table 1):

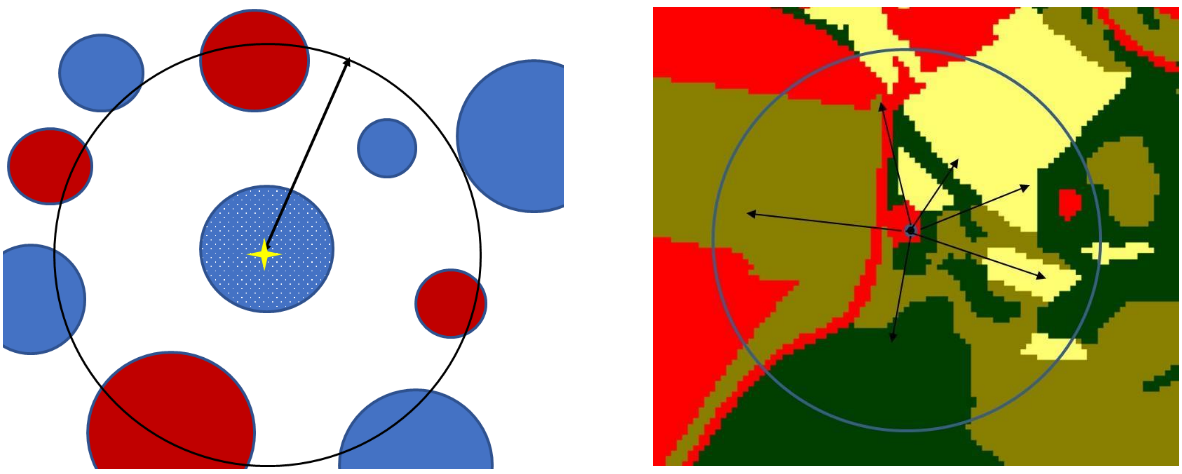

Fig. 8. Conceptual definition of the Terrestrial Connectivity Index (TCI) developed for DLR County. The ICT is conceived (*left*) as the potential available habitat (in area units) for a given organism type

around a given point (yellow star) and considering a circular buffer (black circle) defined by the maximum dispersal distance of the modelled organism. Then, the TCI calculates the amount of a specific habitat (in blue) and of similar habitats (in red) within this dispersal distance, weighing (i) the amount of similar habitat area by a habitat affinity factor (ranging 0, non-affinity to 1, total affinity), and (ii) all habitats by an exponential inverse of their cost distance (see main text for more details on this) to the focal point. In practice (*right*), it is calculated pixel by pixel, thus adding the area of each pixel weighed by the factors mentioned above. The TCI is calculated separately for each habitat of a selected set, and also for all habitats as a whole, obtaining the average of TCI of all these habitats.

Table 1. Main habitats defining the Blue-Green infrastructure of DLR County (see Fig. 9 for its geographical distribution). TCI were calculated for habitats in black. Those in *red italics* were only used for including affinities and impedances in the TCI calculation. Correspondences between these habitats and those of the basic DLR land-cover map are summarized in Table 1 of the Annex.

Aquatic	Improved grassland
Bogs and Fens	*Littoral and sublittoral sediments*
Built	Modified woodland
Crop	*Rocks*
Disturbed	Salt marshes
Dunes	Scrub
Freshwater marshes and peatlands	Semi natural grassland
Heath and bracken	Semi natural woodland

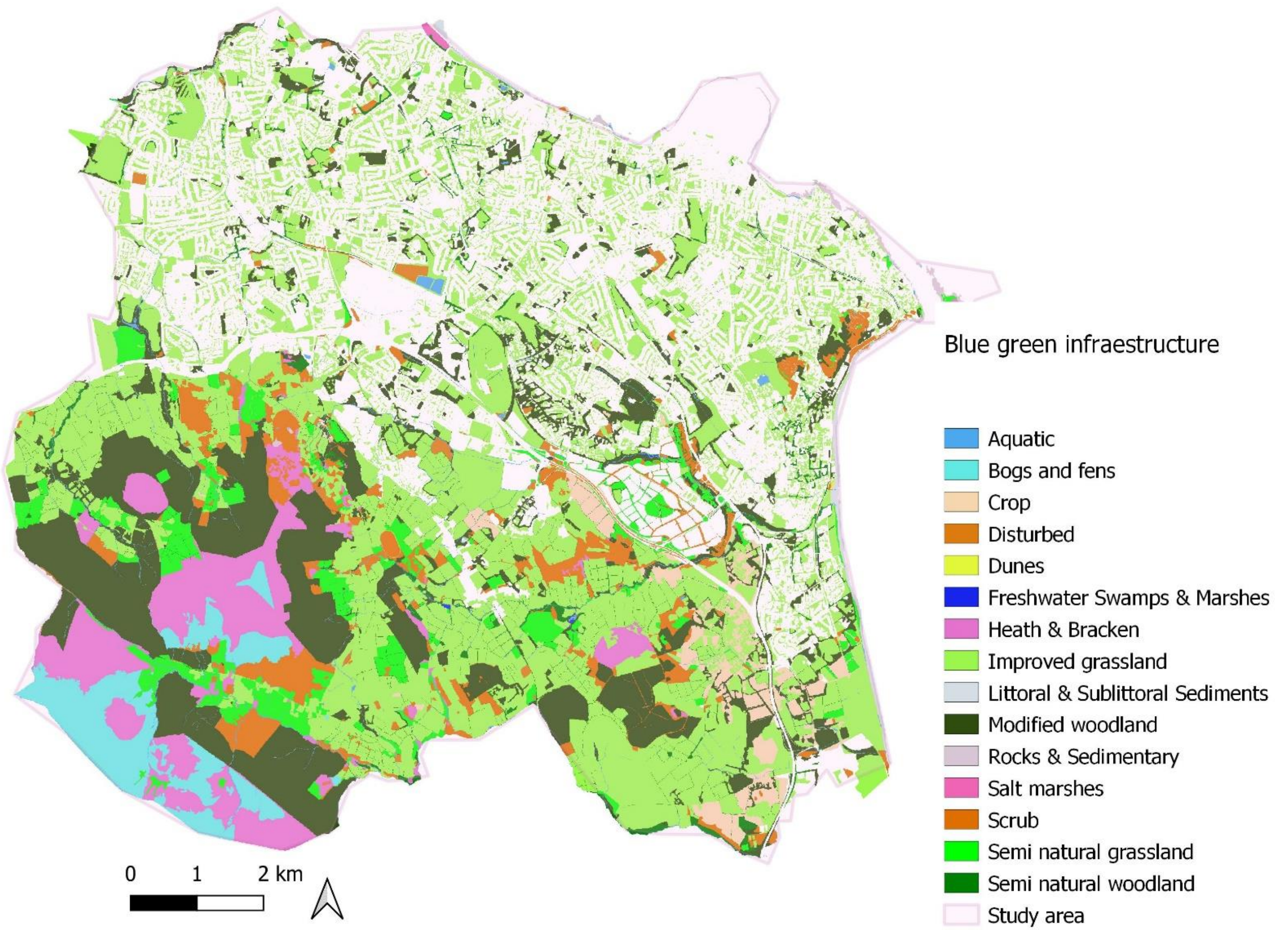

Fig. 9. Blue-green infrastructure of DLR County

The TCI of each selected habitat has been calculated taking a generalist, medium-sized terrestrial organism (e.g. a badger) as target organism, and using the following formula:

$$ICT_i = \sum a_i A_p e^{-\alpha \delta i}$$

with the following parameters:

***A_p*: pixel area**

***α*: average dispersion coefficient.** It adjusts the species dispersion curve, that is, the probability that a species will disperse at a certain distance. It is obtained considering the distance at which the dispersion probability is 0.05. Then

$$\alpha = -Ln\ (0.05) / d.$$

In order to model the case at hand (terrestrial organisms with medium dispersion capacity) and by expert knowledge, d has been set at 1000 m (α = 0.002996)

***Ai*: affinity of each habitat type with the focal habitat.** It adjusts the equivalent area with which each habitat collaborates in the connectivity of a focal habitat. In practice it can be understood as the proportion of species of a certain habitat that can live in the focal habitat. In agreement with the DLR Biodiversity managers, affinity between habitats has been adjusted using the following semi-quantitative scale: total 1; very high 0.75; high 0.67; medium 0.5; low 0.33; very low 0.1; no affinity 0.01 (Table 2).

Table 2 Affinities between habitat types used in TCI calculation. TCI were only calculated for habitats in black. Those in **red** were only used for including affinities in the TCI calculation.

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	Crop	1	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2	Improved grassland	0.5	1	0.75	0.5	0.5	0.1	0.1	0.33	0.33	0.1
3	Semi natural grassland	0.5	0.75	1	0.67	0.5	0.1	0.1	0.33	0.33	0.25
4	Heath and bracken	0.1	0.5	0.67	1	0.5	0.1	0.33	0.33	0.33	0.1
5	Scrub	0.1	0.5	0.5	0.5	1	0.5	0.67	0.33	0.33	0.1
6	Modified woodland	0.1	0.1	0.1	0.1	0.5	1	0.5	0.1	0.1	0.1
7	Semi natural woodland	0.1	0.1	0.1	0.33	0.67	0.5	1	0.1	0.25	0.1
8	Freshwater marshes and peatlands	0.1	0.33	0.33	0.33	0.33	0.1	0.1	1	0.5	0.1
9	Bogs and Fens	0.1	0.33	0.33	0.33	0.33	0.1	0.25	0.5	1	0.25
10	Salt marshes	0.1	0.1	0.25	0.1	0.1	0.1	0.1	0.1	0.25	1
	Aquatic	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.5	0.5	0.5
	Rocks	0.1	0.33	0.33	0.33	0.33	0.1	0.1	0.1	0.1	0.1

Littoral and sublittoral sediments	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.33	0.33	0.5
Dunes	0.1	0.33	0.33	0.33	0.33	0.1	0.1	0.1	0.1	0.33
Disturbed	0.5	0.33	0.33	0.1	0.33	0.1	0.1	0.1	0.1	0.1
Built	0.1	0.1	0.01	0.01	0.01	0.1	0.01	0.01	0.01	0.01

δ_i: cost distance from each focal point to each habitat. Calculated using the Euclidean distance weighted by the resistance or impedance of the different habitats. One of the key features of the TCI is that it considers two major sources of impedance for each modelled habitat (Fig. 8):

- I1: Intrinsic impedance of habitats (I1): the inverse of affinity (see affinity values in Table 2).
- I2: Edge effect of infrastructure and urbanized areas, which decreases with distance to infrastructures or urban areas according to the formula $I2 = I1.e^{-\alpha.d}$, where d is the distance to the urban area or infrastructure and α is obtained after defining the distance (d) at which the edge effect is almost null (P=0.05) as in the dispersal coefficient.

Thus, δi is calculated as the maximum value of I1 and I2 for each habitat type.

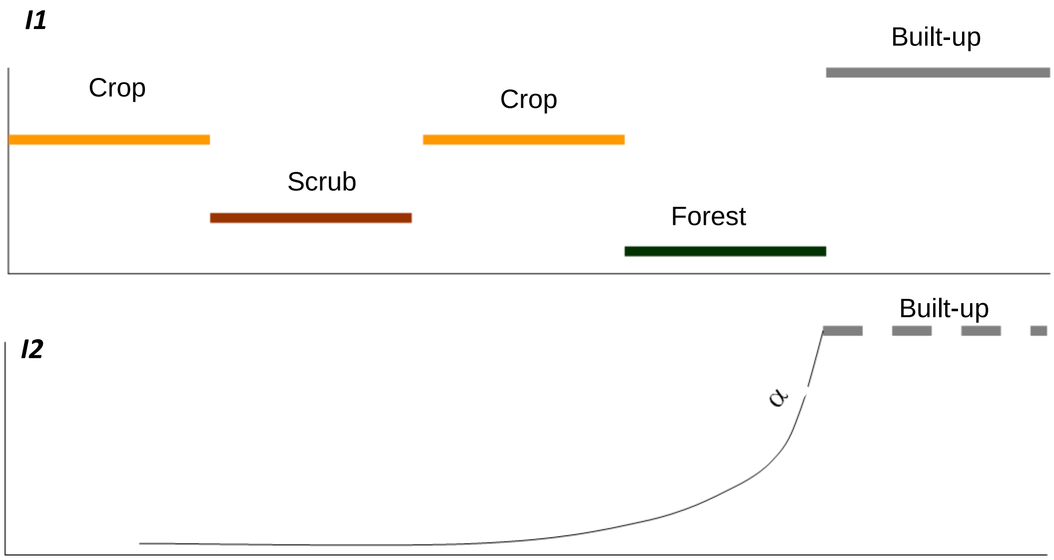

Fig. 10. Representation of the two impedance sources considered in the calculation of TCI

Thus, TCI was calculated for each selected habitat and in each of a set of points distributed every 100 m throughout the DLR County (21,720 points in total). This was performed using a specific GIS batch procedure developed *ad hoc*. Subsequently, the first versions of the TCI per habitat type (100- m of pixel size) were obtained by direct rasterization of the point layer. These initial versions were then densified by bilinear interpolation up to a resolution of 10 m. Finally, a Log (x + 1) transformation of the values was carried out to reduce the large differences between values. The general TCI was then obtained by averaging these partial models obtained for each habitat (Fig. 11). Specific models were finally obtained for each habitat, by clipping them by the areas corresponding to these habitats (see examples of improved grasslands and all seminatural habitats in Fig. 12 and 13 respectively).

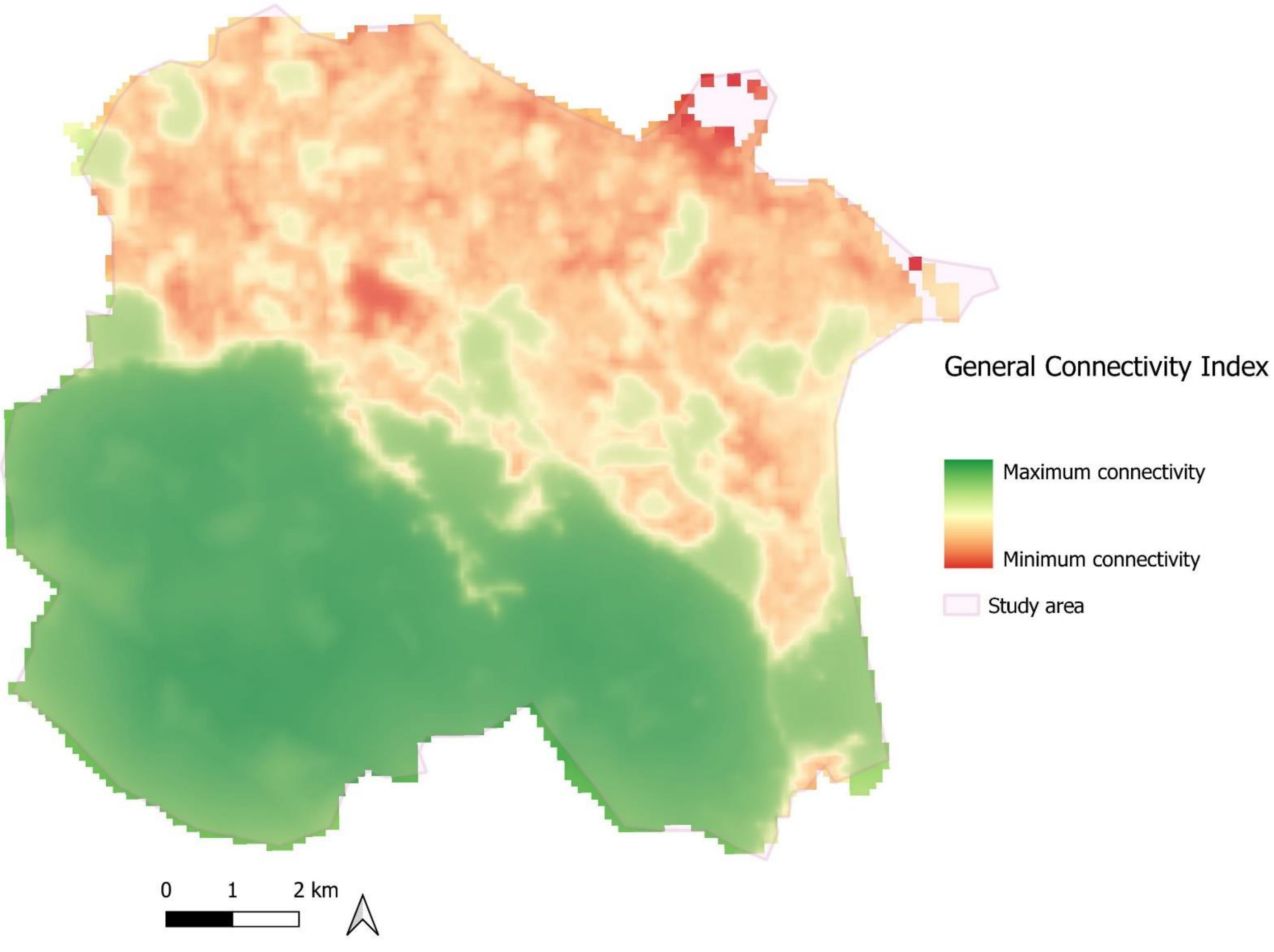

Fig. 11. General Terrestrial Connectivity Index

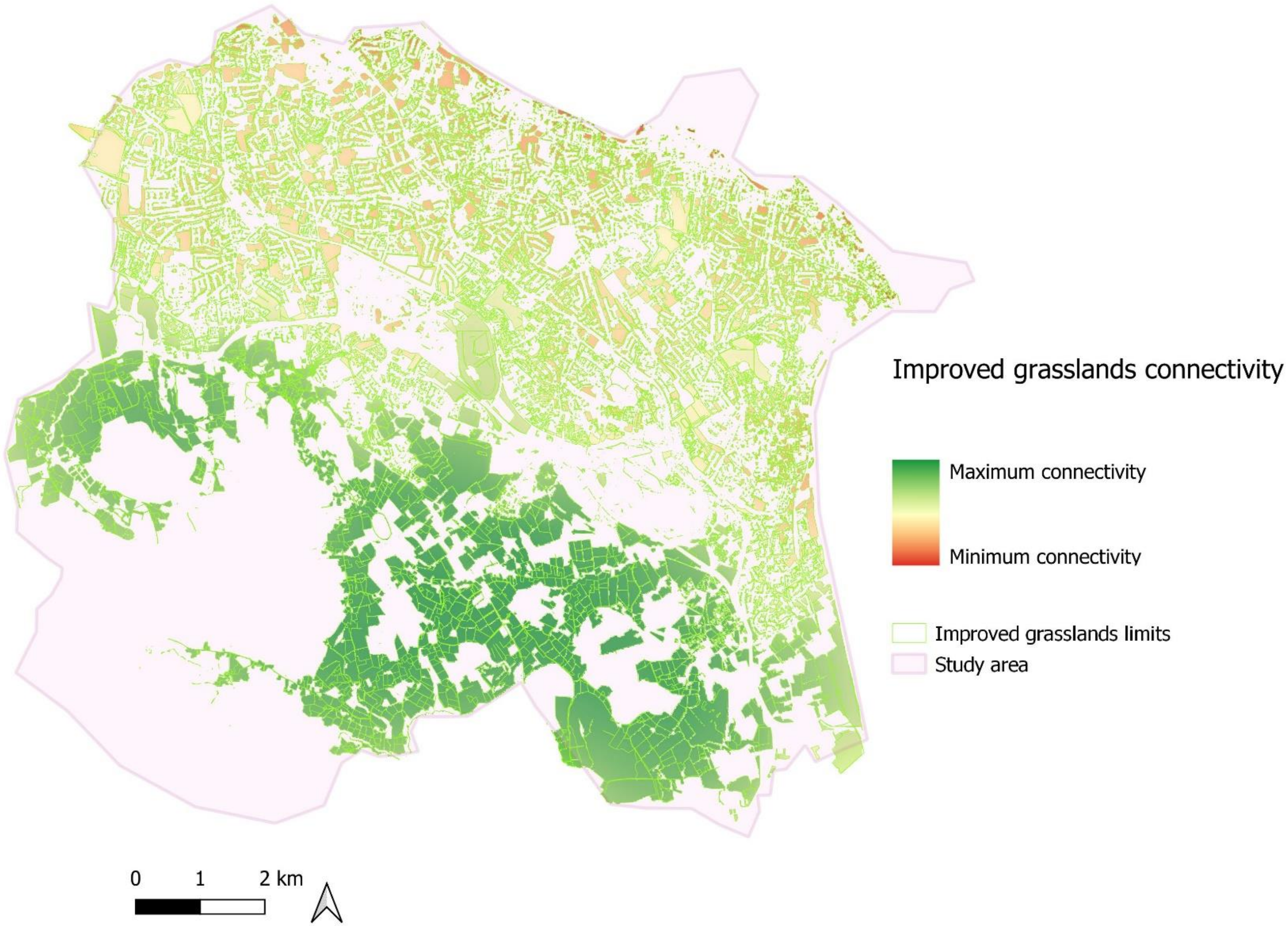

Fig. 12. Terrestrial Connectivity Index for improved grasslands

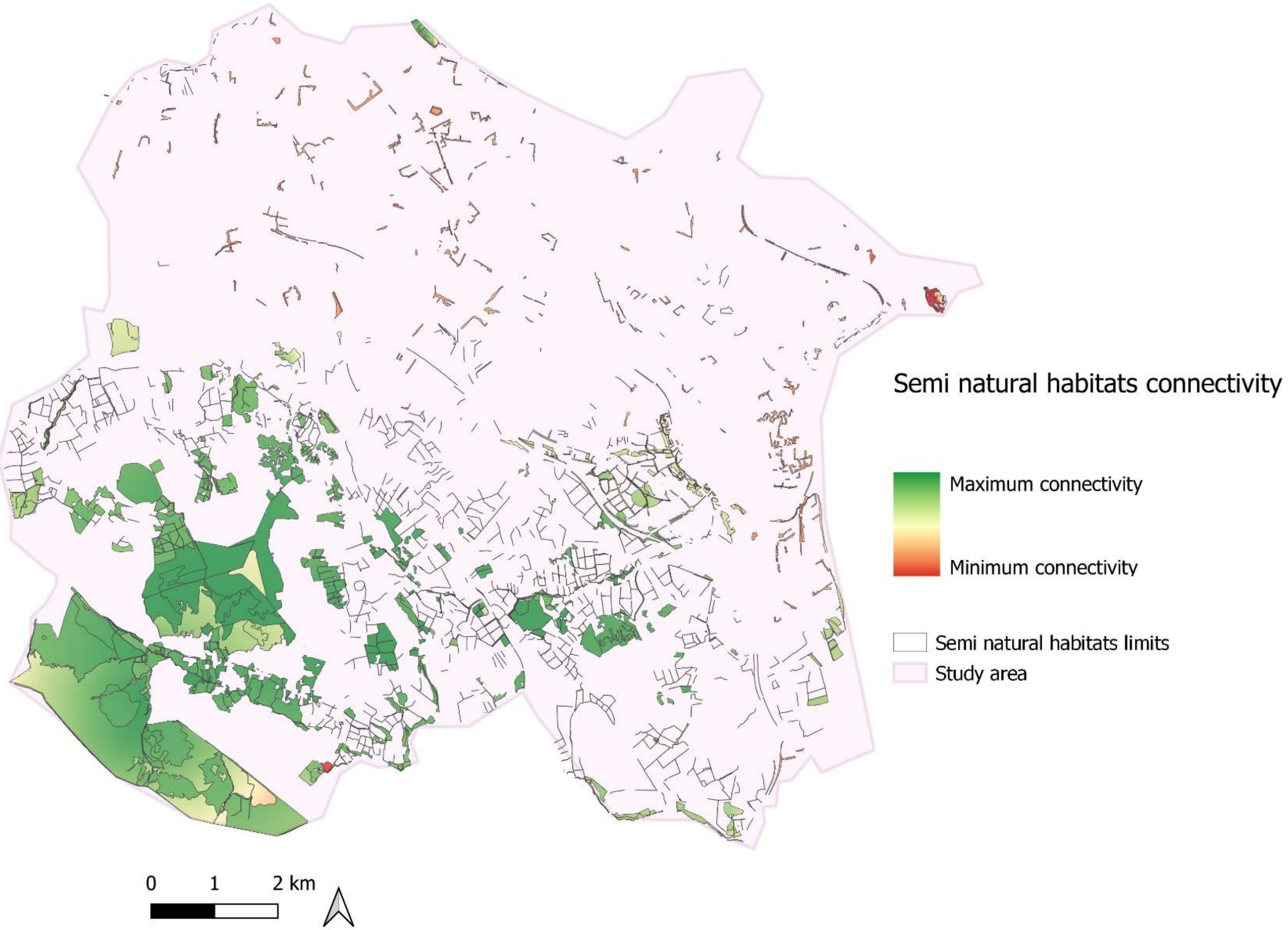

Fig. 13. Terrestrial Connectivity Index for all seminatural habitats pooled together (Semi natural grassland, Heath and bracken, Semi natural woodland, Bogs and Fens and Salt marshes)

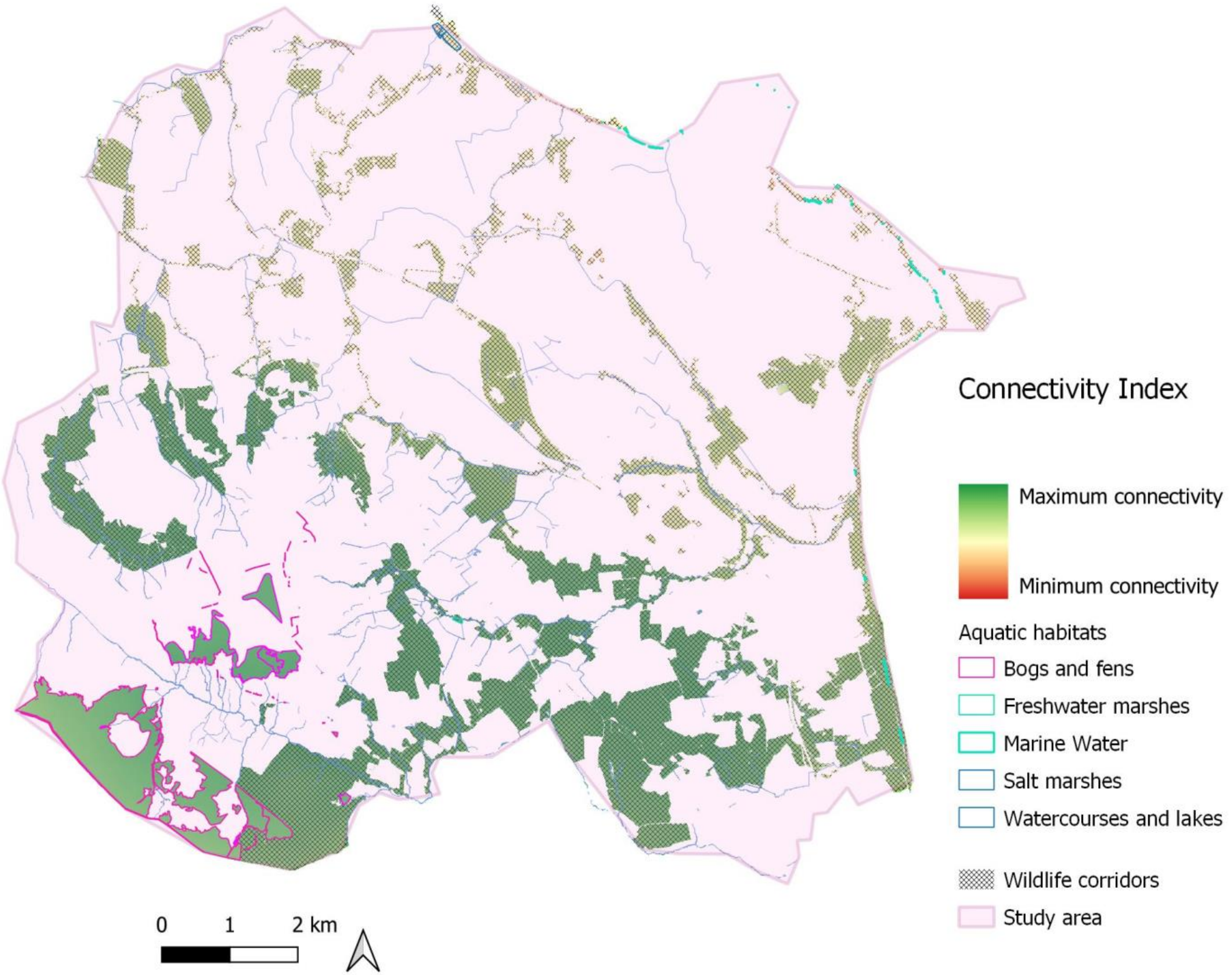

Fig. 14. Terrestrial Connectivity Index for aquatic habitats pooled together (Bogs and Fens and Salt marshes, Freshwater marshes, salt marshes, watercourses and lakes) and Wildlife Corridors

4.3. Population proximity

Recreation is an important cultural ecosystem service and is one way in which communities experience the direct and indirect benefits arising from the experiential use of their environment. However, there are inherent conflicts between biodiversity protection and ecosystem functioning on the one hand and the provision of public access, recreation and greenway infrastructure on the other. Cultural ecosystem services are defined as all the non-material and normally non-consumptive, ecosystem outputs that affect physical and mental states of people (Haines-Young and Potschin 2013). Examples of cultural ecosystem services include the appreciation of landscape aesthetics, tourism and recreation, symbolic values of species and ecosystems and the educational, scientific, spiritual and religious value (Haines-Young and Potschin 2013, M.A. 2005). Outdoor recreation is considered especially important in urban and peri-urban areas but its feasibility from an ecosystem services perspective depends heavily on the availability, distribution and type of ecosystems and careful consideration of the potential negative impacts of recreation use on biodiversity conservation and functional values which are the cornerstone of healthy ecosystems.

Furthermore, modelling the spatial distribution of cultural and recreational ecosystem services is difficult because of the lack of both conceptual models and reliable data (Maes et al. 2016, Paracchini et al. 2014). Recent research has identified the potential use of emerging datasets like geotagged photos and site visit records in social networks like Flickr, Instagram, and Twitter (Balzan & Debeno 2018). Despite this, these data are scarcely available and this results in the development of indicators of potential recreational use, based on general proxies (Basnou et al. 2020).

Given the limitations of this demonstrative action, mapping of indicators for recreational values was not possible. Instead, in order to demonstrate the potential pressures of urban populations on ecosystem functioning, we have mapped population density and distance to the main elements of GI, using an isotropic (as the crow flies) spatial approach. This is not a measure of recreational value, any approximation of which would require (i) relevant datasets for multiple dimensions of recreational value, and (ii) the application of modelling approaches to human movement including the road and path network and existing barriers (e.g. fences, motorways, private property etc.).

Using a GIS procedure, we calculated a set of population proximity maps to the main Biodiversity Conservation elements following this general formula:

$$P=D*e^{-k.d}$$

with the following parameters:

D= population density (a rasterized map from the official layer provided by DLR administration managers)

d= an isotropic (as the crow flies) distance map to each element type of biodiversity conservation, including

- EU areas of conservation concern
- National Heritage areas of conservation concern (NHA and proposed NHA)
- Local Importance Biodiversity Sites (LIBS)
- Actual and Potential Annex I habitats
- Wildlife corridors

k= a parameter adjusting maximum distance to 1000, 2000 and 5000 m corresponding to different mobility distances (walking, running, biking)

Thus, a total of 15 partial population proximity maps (raster format, 5-m of pixel size) were obtained, considering 3 distances and 5 element types. Maps of each distance were finally summarized in a Global proximity map, using the maximum value of these maps. Both partial and global maps are provided (Fig.15, 16 and 17). This approach can help to identify the locations under the greatest pressure for nearby recreation, an important consideration in balancing recreation needs of the population – and its demonstrated health and well-being benefits – with the protection of sensitive ecosystems in the context of the global biodiversity emergency.

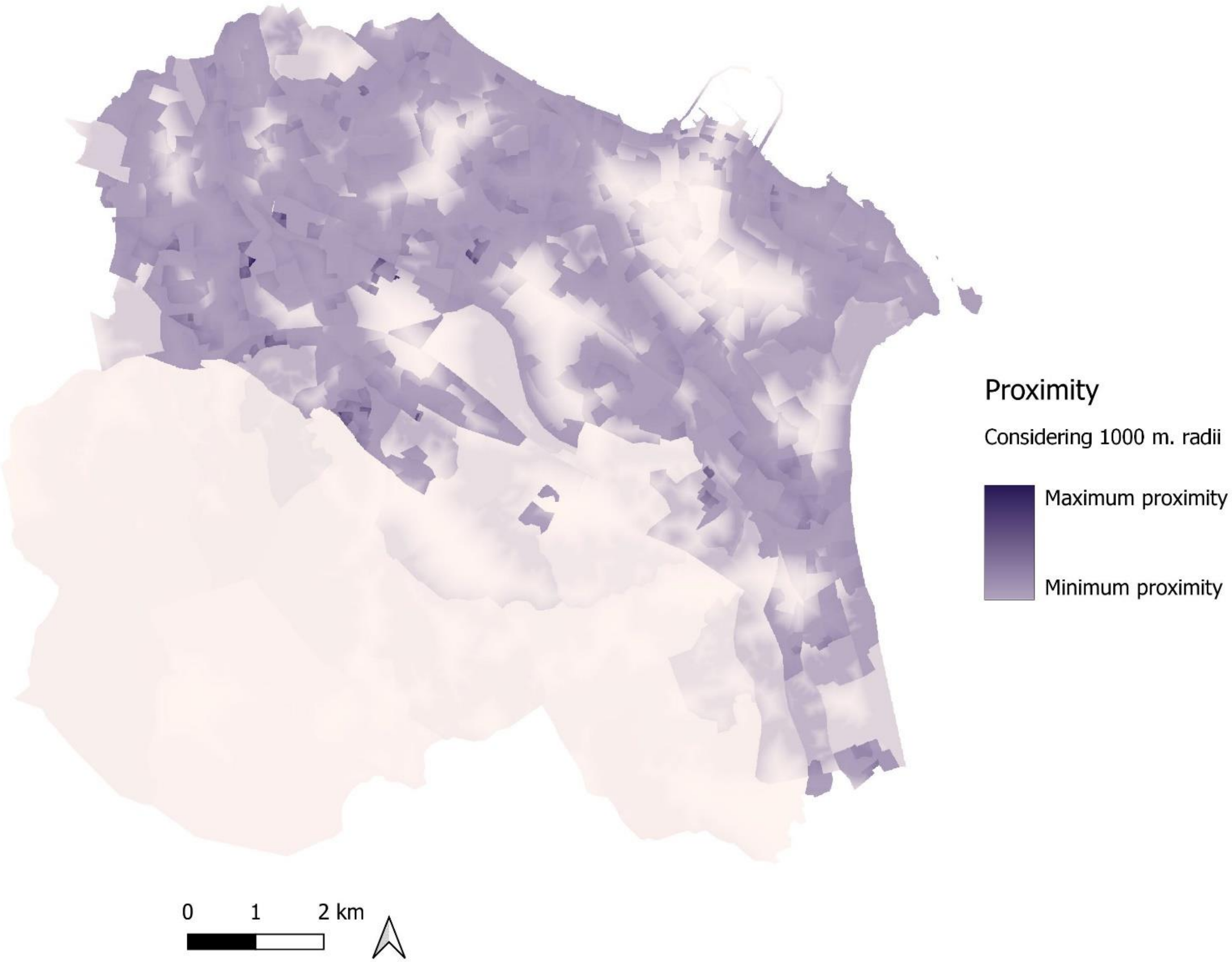

Fig. 15. Global proximity maps to all elements of biodiversity conservation considered in the DLR County, for three radii (1000 m)

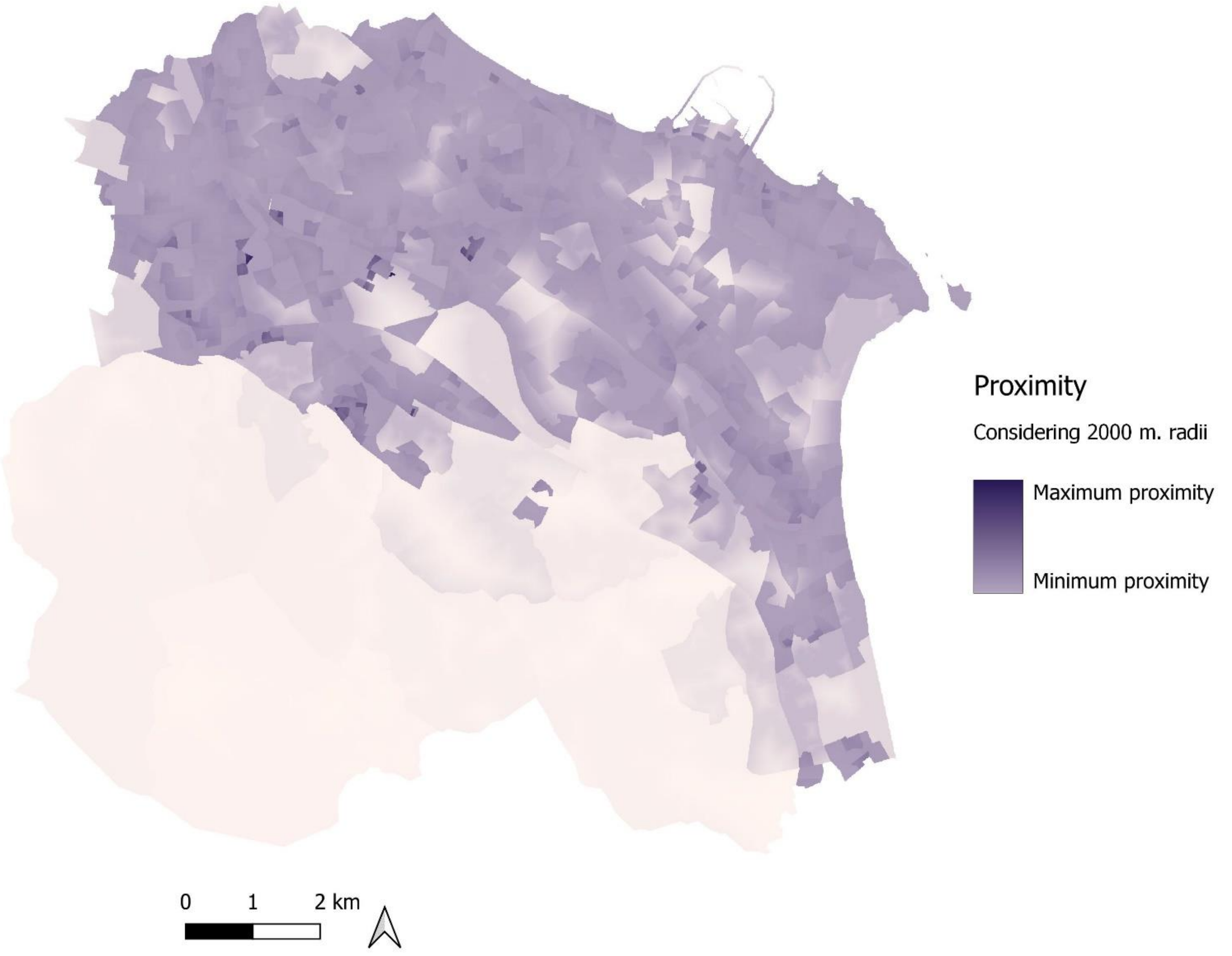

Fig. 16. Global proximity maps to all elements of biodiversity conservation considered in the DLR County, for three radii (2000 m)

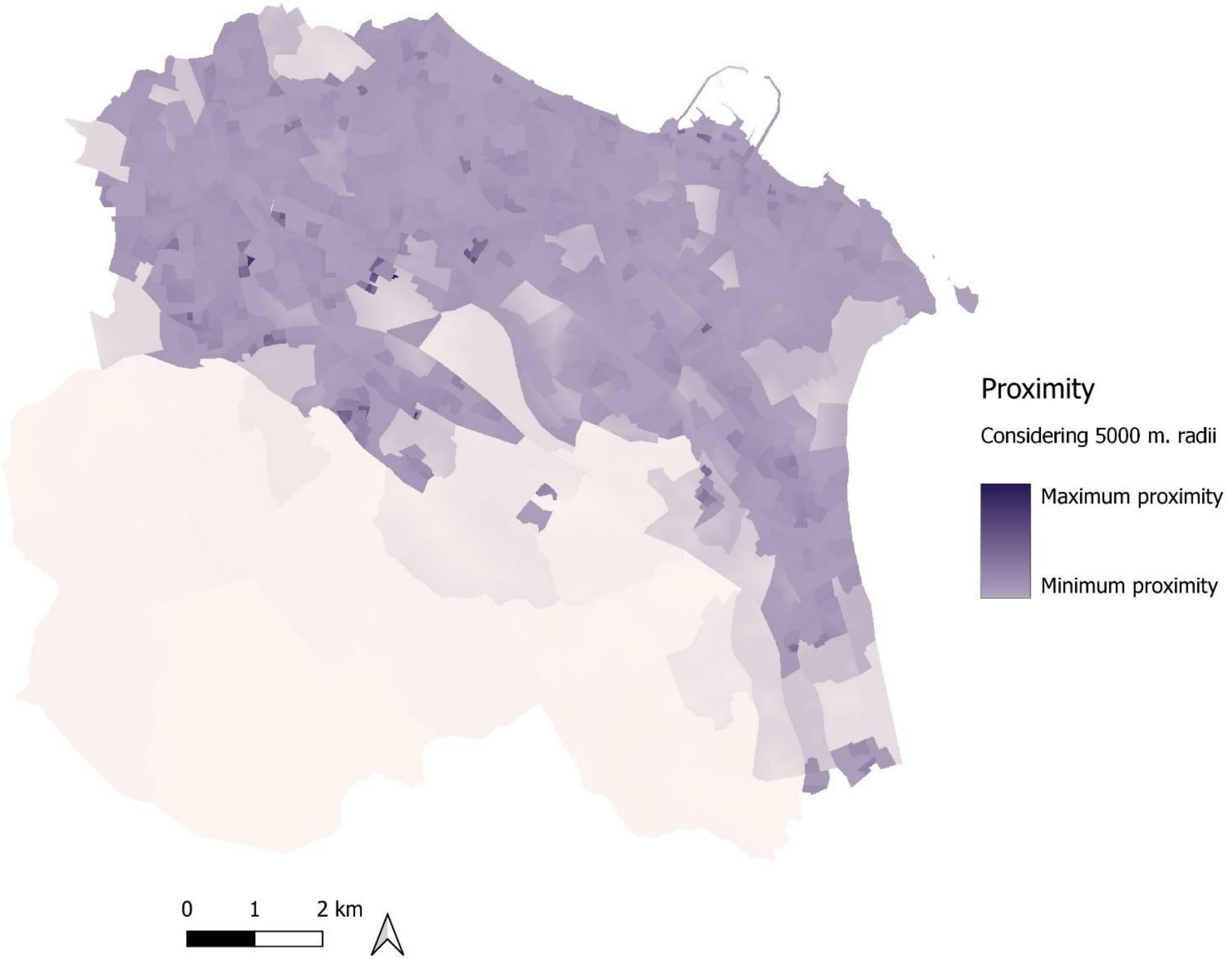

Fig. 17. Global proximity maps to all elements of biodiversity conservation considered in the DLR County, for three radii (5000 m)

5. Analyses of synergies and trade offs

The need to make the ecosystem services (ES) approach operational for GI planning through reliable, spatially explicit indicators is estimated by assessing the spatial relationship between ES supply and demand (Burkhard et al., 2014; Basnou et al. 2020). In metropolitan areas where citizens are increasingly dependent on the ecosystems beyond their frontiers (Bolund and Hunhammar, 1999; Cadenasso et al., 2007), there is a great need for studies that enhance the understanding of rural-urban flows of ES (Andersson et al., 2014; Baró et al. 2016). Such understanding is critical to allow for integrative and realistic GI planning, it helps to assess multifunctionality, synergies and trade-offs between socio-ecological systems (Hansen and Pauleit, 2014; Tzoulas et al., 2007). It thus helps to identify which functions or ES are to be prioritised by planners and decision makers, and which is the scale where strategic actions of GI management and planning are to be applied.

In order to do a first assessment of the synergies and trade-offs between the intrinsic, functional and leisure value of the DLR County, we selected a set of indicators representative for these dimensions:

- **Biodiversity conservation value,** obtained by merging the following layers mentioned above and assigning to them the following values: 3, EU and Nation-wide areas of most conservation concern; 2, Important local areas for biodiversity including LIBS and wildlife corridors; 1, EU Annex Habitats of conservation / potential conservation concern; and 0, the rest of land.
- **Naturalness**, using the layer mentioned above with its original values (4, Close to natural; 3, Seminatural; 2, Cultivated/Improved/Invaded; 1, Very disturbed/ altered; 0 Artificial)
- **Connectivity,** using the average connectivity index (TCI)
- **Landscape diversity indices (Shannon index)** calculated for non-built habitats and for 100, 250 and 500 m of cell size.
- **Population proximity.** Global proximity indices calculated for radii of 1000, 2000 and 5000 m

Using GIS tools, we set up a point dataset with 2000 points randomly distributed across the DLR County, and we combined it with the indicators mentioned above to collect their values in the point database. These values were then used to assess the degree and the sign of the association between indicators, through a Pearson correlation matrix and a Principal Component Analysis (PCA). Almost all Pearson correlations between indicators are significant (Table 3) due to the high sample size (n=2000). Moreover, trivially high correlations are observed within the Diversity and Population proximity sets of indicators, thus indicating that these indicators are very redundant. In any case, it should be noted (i) the high positive correlation between biodiversity conservation, naturalness, and connectivity; (ii) the negative correlations of these indicators with those of population proximity, and (iii) the comparatively low or even non-significant correlations of landscape diversity with the rest of indicators.

The two main components of the PCA explain up to 69% of total variance of the studied indicators (Table 4). The representation of these components (Fig. 13) corroborates that biodiversity conservation, naturalness and connectivity in the DLR County are positively associated each other, and that all of them are negatively associated to population proximity indicators. In contrast, landscape diversity is weakly associated to these attributes as shown by almost perpendicular arrows to the previous ones.

Table 3. Pearson correlations for a set of selected indicators of biodiversity conservation, functional and population proximity in the DLR County (see section 5 for more details). Black and red values correspond to positive and negative associations, respectively. Values in italics are not significant for p=0.01. (*Conserv*., Biodiversity conservation; *Natur*., Naturalness; *TCI*, Terrestrial Connectivity Index; *Div100, Div250, Div500*, Shannon diversity indices for 100, 250 and 500 m of cell size; *Pop1000, Pop2000, Pop5000*, Global population proximity indices for 1000, 2000 and 5000 m)

	Conserv.	Natur.	TCI	Div100	Div250	Div500	Acc1000	Acc2000
Conserv.								
Natur.	0.61							
TCI	0.5	0.67						
Div_100	*0.05*	0.19	0.19					
Div_250	*0.04*	0.16	0.22	0.61				
Div_500	0.08	0.21	0.32	0.49	0.72			
Prox1000	-0.24	-0.38	-0.5	*-0.05*	*-0.04*	-0.11		
Prox 2000	-0.31	-0.45	-0.58	-0.11	-0.11	-0.18	0.97	
Prox5000	-0.36	-0.49	-0.64	-0.16	-0.16	-0.24	0.89	0.97

Table 4. Standard variation, and raw and cumulative variance proportion of the the PCA obtained for a set of selected indicators of biodiversity conservation, functional and population proximity in the DLR County (see section 5 for more details).

	Standard deviation	Variance proportion	Cumulative proportion
PC1	**2.0344**	**0.4599**	**0.4599**
PC2	**1.4351**	**0.2288**	**0.6887**
PC3	1.1049	0.1356	0.8244
PC4	0.7311	0.0594	0.8838
PC5	0.6459	0.0464	0.9301
PC6	0.5433	0.0328	0.9629

PC7	0.5024	0.0280	0.9909
PC8	0.2833	0.0089	0.9999
PC9	0.0371	0.0002	1.0000

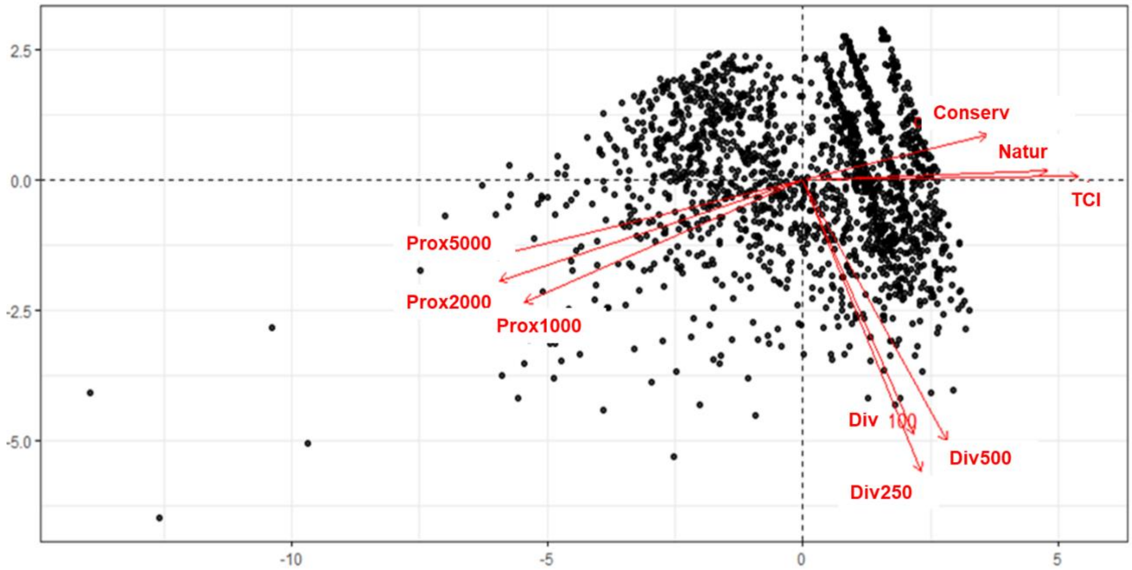

Fig. 13. Representation of the axes 1 (X) and 2 (Y) of the obtained for a set of selected indicators of biodiversity conservation value, functional value and population proximity in the DLR County (see section 5 for more details).

6. Conclusions and future development

The reported results are part of a demonstrative Pilot Action within the Interreg Europe PROGRESS project based on the SITXell example (www.sitxell.eu/en/default.asp) in Barcelona. The report was based on analysis undertaken independently by CREAF on behalf of the Eastern and Midland Regional Assembly and does not necessarily represent the views of either the Eastern and Midland Regional Assembly or DLR County Council.

While the action was conditioned by the available information and by limited time and resources, the results obtained are promising. The biodiversity conservation and functional value of the blue-green infrastructure in the DLR County have been assessed and mapped through a set of indicators made up from the basic information available. The action has also provided a first assessment of the synergies and trade-offs based on these indicators, which shows the opposite (trade-off) patterns of biodiversity conservation, naturalness and population proximity to blue-green infrastructure, and the fact that landscape diversity provides an additional, non-redundant dimension to blue-green Infrastructure in the County, probably because the habitats involved in this diversity belong to very diverse conservation and naturalness status.

While the results from this demonstrative action are promising in terms of the applicability of the SITxell approach for ecosystem service and green infrastructure mapping in DLR, it should be noted that this analysis was a Pilot Action and was subject to a number of key limitations. Firstly, only readily available datasets relating to habitats and biodiversity in DLR were employed in the analysis. Workshops held with key stakeholders as part of this Pilot Action revealed the need to include much wider ranging datasets and data types for a more comprehensive and holistic analysis of ecosystem services. Suggestions from stakeholders included incorporation of datasets for the following:

Ways, barriers and access points	Catchment data
Road network and noise	Species data
Climate risk and vulnerability	Elevation data
Zoning/planning/strategic datasets	Carbon sequestration capacity
Recreational features	Thematic census data

Second, in testing the transfer of the SITxell approach, some of the indicators employed were calculated through simplified approaches. For example, the terrestrial connectivity index did not incorporate the barrier effect of fences and highway barriers, and the population proximity indices were calculated using an isotropic approach (as the crow flies) to human movement instead of using path and road networks. Such improvements are feasible if the data are available (in some cases they were obtained during the action), but implementation was not possible within the demonstrative action.

Finally, given the limitations of the demonstrative action (time and dataset availability), it was not possible to include robust measures for cultural ecosystem services. However, the use of the population proximity tool can help to identify the locations under the greatest pressure for nearby recreation, an important consideration in balancing the recreation needs of the population – and its demonstrated health and well-being benefits – with the protection of sensitive ecosystems in the context of the global biodiversity emergency.

7. References

Balzan MV, Debono I (2018) Assessing urban recreation ecosystem services through the use of geocache visitation and preference data: a case-study from an urbanised island environment. OneEcosystem 3: e24490.

Baró F, Palomo I, Zulian G, Vizcaino P, Haase D, Gómez-Baggethun E (2016) Mapping ecosystem service capacity, flow and demand for landscape and urban planning: A case study in the Barcelona metropolitan region. Land use policy 57: 405-417.

Basnou C, Baró F, Langemeyer J, Castell C, Dalmases C, Pino, J. (2020) Advancing the green infrastructure approach in the Province of Barcelona: integrating biodiversity, ecosystem functions and services into landscape planning. Urban Forestry and Urban Greening, 55, [126797].

Bolund P, Hunhammar S (1999). Ecosystem services in urban areas. Ecol. Econ. 29, 293–301.

Burkhard, B., Kandziora, M., Hou, Y., Müller, F., 2014. Ecosystem service potentials, flows and demands – concepts for spatial localisation, indication and quantification. Landsc Online 32, 1–32.

Cadenasso ML, Pickett STA, Schwarz K. (2007) Spatial heterogeneity in urban ecosystems: reconceptualizing land cover and a framework for classification. Frontiers in Ecology and Environment, 5: 80– 88.

Calabrese J.M., Fagan W.F. (2004). A comparison shoppers' guide to connectivity metrics: trading off between data requirements and information content. Frontiers in Ecology and the Environment, 2: 529-536.

Corrado, Battisti & Longino Contoli (2011) Diversity Indices as 'Magic' Tools in Landscape Planning: A Cautionary Note on their Uncritical Use, Landscape Research, 36:1, 111-117.

Fossit J.A. (2000) A guide of habitats in Ireland. The Heritage Council of Ireland Series

Haines-Young R, Potschin M (2013). Common International Classification of Ecosystem Services (CICES): Version 4. www.cices.eu.

Hansen R, Pauleit S (2014) From Multifunctionality to Multiple Ecosystem Services? A Conceptual Framework for Multifunctionality in Green Infrastructure Planning for Urban Areas. AMBIO 43, 516–529

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

M.A. (2005) Ecosystems and Human Well-Being: A Framework for Assessment. Island Press, London.

Maes J, Zulian G, Thijssen M, Castell C, Baró F, Ferreira A, Melo J, Garrett C, David N, Alzetta C, Geneletti D, Cortinovis C, Zwierzchowska I, Louro Alves F, Souto Cruz C, Blasi C, Alós Ortí M, Attorre F, Azzella M, Capotorti G, Copiz R, L F, Manes F, Marando F, Marchetti M, Mollo B, Salvatori E, Zavattero L, Zingari P, Giarratano M, Bianchi E, Dupre E, Barton D, Stange E, Perez-Soba M, Eupen M, Verweij P, Vries A, Kruse H, Polce C, Cugny-Seguin M, Erhard M, Nicolau R, Fonseca A, Fritz M, Teller A (2016) Mapping and Assessment of Ecosystems and their Services. Urban Ecosystems. Publications Office of the European Union.

McGarigal, K., Cushman SA, Ene E. (2012). FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. http://www.umass.edu/landeco/research/fragstats/fragstats.html

Nagendra H (2002) Opposite trends in response for the Shannon and Simpson indices of landscape diversity. Applied Geography, 22: 175-186.

Paracchini ML, Zulian G, Kopperoinen L, Maes J, Schägner JP, Termansen M, Zandersen M, Perez-Soba M, Scholefield P, Bidoglio G (2014) Mapping cultural ecosystem services: A framework to assess the potential for outdoor recreation across the EU. Ecological Indicators 45: 371-385.

Pino J., Seguí J.M., Alvarez N. (2006) Invasibility of four plant communities in the Llobregat delta (Catalonia, NE of Spain) in relation to their historical stability. Hydrobiologia. 570: 257-263.

Pino J., Vilá M., Alvárez N., Seguí J.M., Guerrero C. (2009) Niche breadth rather than reproductive traits explains the response of wetland monocotyledons to land cover change. Applied Vegetation Science, 12:9-21.

Shannon C, Weaver W (1949) The mathematical theory of communication. Univ. Illinois Press, Urbana.

Tzoulas K, Korpela K, Venn S, Yli-Pelkonen V, Kaźmierczak A, Niemela J, James P (2007) Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. Landscape and Urban Planning, 81: 167-178.

8. Annex

Table with the correspondences between original habitats in the Basic DLR land cover m<p and the proposed values of naturalness and categories of the green-blue infrastructure

Basic DLR LC Map	Naturalness	Blue-Green Infrastructure
Bogs	4	Bogs and Fens
Bogs/Heath	4	Bogs and Fens
Brackish waters	4	Aquatic
Built land	0	Built
Coastal constructions	0	Built
Cultivated land	2	Crop
Dense bracken	3	Heath and Bracken
Disturbed ground	1	Disturbed
Exposed rock	3	Rocks and Sedimentary
Fens and flushes	4	Bogs and Fens
Fens and flushes/Heath	4	Bogs and Fens
Freshwater marsh	4	Freshwater Swamps and Marshes
Heath	4	Heath and Bracken
Heath/Fens and flushes	4	Heath and Bracken
Highly modified non native woodland / Scrub/transitional woodland	2	Woodland
Highly modified/ non native woodland	2	Modified Woodland
Improved grassland	2	Improved grassland
Improved grassland/Built land/Semi natural grassland	2	Improved grassland
Improved grassland/Semi natural grassland	2	Improved grassland
Lakes and ponds	4	Aquatic
Linear woodland/scrub	3	Semi natural woodland
Littoral rock	3	Rocks and Sedimentary
Littoral sediment	3	Littoral and Sublittoral Sediments
Marine Water	4	Aquatic
Salt marshes	4	Salt marshes
Sand dune systems	4	Dunes
Scrub/transitional woodland	4	Scrub
Scrub/transitional woodland/ Cultivated land/ Built land	3	Scrub
Scrub/transitional woodland/ Heath	4	Scrub
Scrub/transitional woodland/ Linear woodland/scrub	4	Scrub
Sea cliffs and islets	3	Rocks and Sedimentary
Semi natural grassland	3	Semi natural grassland

Semi natural grassland/Dense bracken	3	Semi natural grassland
Semi natural grassland/Exposed rock	3	Semi natural grassland
Semi natural grassland/Improved grassland	3	Semi natural grassland
Semi natural woodland	4	Semi natural woodland
Semi natural woodland/ Highly modified/non native woodland	3	Semi natural Woodland
Shingle and gravel banks	3	Littoral and Sublittoral Sediments
Springs	4	Freshwater Swamps and Marshes
Sublittoral rock	3	Rocks and Sedimentary
Sublittoral sediment	3	Littoral and Sublittoral Sediments
Swamps	4	Freshwater Swamps and Marshes
Watercourses	4	Aquatic
Watercourses/Built land	3	Aquatic