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Providing Core Indicators from the European Urban Biodiversity Index (EUBI) for EnRoute cities

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Contents

Background **4**

1 The European Urban Biodiversity Index (EUBI): Methodology **4**

1.1 General approach 5

1.2 Art.12/17 Data preparation – A crosswalk between Urban Atlas (UA) and MAES ecosystem typology 6

1.3 Indicator specific methodology 9

2 Results **13**

2.1 EUBI Factsheets for individual cities 13

2.1.1 BE001L2 Brussel 14

2.1.2 BE002L2 Antwerpen 15

2.1.3 CY501L1 Lemesos 16

2.1.4 DE008L2 Leipzig 17

2.1.5 EE001L1 Tallinn 18

2.1.6 FI001L2 Helsinki 19

2.1.7 IE001L1 Dublin 20

2.1.8 IT001L2 Roma 21

2.1.9 IT014L2 Trento 22

2.1.10 IT028L2 Padova 23

2.1.11 MT001L1 Malta 24

2.1.12 NL001L2 s’ Gravenhage 25

2.1.13 NL004L2 Utrecht 26

2.1.14 PT001L2 Lisboa 27

2.1.15 SE001L1 Stockholm 28

2.1.16 UK004L1 Glasgow 29

2.1.17 UK008L2 Manchester 30

2.2 Comparative results of EUBI over all included cities 31

3 Conclusions and lessons learnt **34**

References **35**

Annex **36**

Background

The current task presents a continuation of the 2017 and 2018 efforts inside the ETC-BD to develop a composite index for urban biodiversity utilizing pan-European datasets from the Copernicus programme and Art.12 and 17 reporting obligations.

The European Urban Biodiversity Index (EUBI) is a work in progress and for the present task the composite index has first been tested on a larger amount of cities. Selected cities include those which have participated in the Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute) – project and for which both, the required Copernicus datasets as well as Art.12 and Art. 17 data are available. The final list of cities (Table 3-1.) includes 17 FUAs (Functional Urban Area) spread across different bioregions in Europe.

The index is composed of a range of individual indicators which act as proxy for different functional components of biodiversity (e.g. habitat availability, species richness, etc.). All indicators are normalised but receive a relative weighting for each individual city. This means that cities from different biogeographic settings can be compared to a certain degree.

The basic spatial reference unit to delineate urban area is the FUA (Eurostat, 2016).

1 The European Urban Biodiversity Index (EUBI): Methodology

The goal of the index is to create a self-assessment tool for urban areas across different bioregions in Europe. Unlike rural areas, urban environments are strongly characterised by the presence of artificial habitats. The urban ecosystem is therefore defined as […] the ecological system located within a city […] composed of physical and biological components that interact with each other (MAES, 2018), i.e. containing grey, green and blue infrastructure components. In this context, urban biodiversity refers to the biological component, which encompasses everything from singular organisms up to e.g. larger forested areas.

Assessing the status of these components across European urban areas is a challenge, as the availability, resolution and coverage of datasets relating to biodiversity-relevant issues varies between municipalities, both within and between countries, and often focus on only a small subset of topics within the larger urban landscape. This essentially mandates a dual approach to data collection, combining European-wide data (e.g. species datasets stemming from the reporting obligations under Art.12 and Art.17 of the EU Nature Directives and land cover mappings such as the Copernicus programs) with local datasets. The former holds a wealth of relevant species data and structural information and offer harmonised, high quality and validated data that is comparable across all MS. However, the Nature Directives data are only published at a 10km scale which is unsuitable for urban analyses. On the other hand, data gathered through local assessments (e.g. available city indexes, award reports, citizens' science initiatives, etc.) feature a higher level of accuracy, but the heterogeneity in terms of their availability drastically limits their use.

The following section presents the indicators that have been selected to form the core index. For the current extension of the EUBI towards EnRoute cities only the core index will be calculated. Justifications are provided together with a short description and explanation on the processing steps taken in the production of the data. The core index provides information at a 1 ha hexagonal grid level for the entire FUA.

1.1 General approach

The current approach provides spatially explicit data. All indicators within the core index are produced on a 10ha hexagonal grid basis. A grid-based approach was selected to enable a spatial representation of the combined indicators.

The hexagonal grid is produced for each city and is filled with the information from each indicator. Unlike square grids hexagonal grids have the advantage that each centroid within the grid cell is equidistant to the neighbouring polygon. It further maintains directionality thus making it a preferential sampling grid when analysing connectivity (Birch, Oom, & Beecham, 2007). A simplified illustration of the processing workflow is provided in Figure 1-1. Due to the complexity and number of processing steps the detailed processing workflow is provided within the annex (Figure 3-1).

One of the goals of the index is to identify and visualize connected biodiversity relevant green spaces and corridors. This information can be evident for certain species within single indicators as for example connected freshwater habitats for fish can be extracted from a map of freshwater areas. However, indicator information is seldom compiled to achieve a composite indicator map. The reason for this is likely that composite figures have to be based on generalization and broad assumptions. Thematic precision is therefore sacrificed at the cost of achieving a simple and easy to understand ordinal scaled value.

In order to facilitate combining datasets from different sources, one has to normalise the inputs. In the selected approach, indicators are first calculated at grid cell level and then converted to a common range of 1-5 using the Jenks Natural Breaks Algorithm (Jenks, 1967). Class assignment is therefore based on reducing variance within and maximizing variance between classes. Indicators are assigned in a manner that “1” corresponds to a low score and “5” to a (positive) and optimal biodiversity value.

The EUBI-Score map shows the average EUBI score per grid cell weighted with the count of indicators for which a value is available within the cell. No specific weighting is applied as it is not possible to define the importance of individual indicators relative to each other without appropriate justification and weighting intensity.

As the value range is normalised this approach resolves the problem of fixed value ranges for individual indicators which are associated with certain scores. Fixed value ranges are for instance applied within the City Biodiversity Index (CBI)[1], but have been criticised as a too rigid system in which individual cities are “stuck” within certain ranges regardless of the relative positive change that was induced within the city itself (Mirko Gregor pers. comm.).

Normalisation further allows a cross comparison between cities whilst maintaining the geographically given potential of the city to host biodiversity. One of the key problems in assessing biodiversity at such a broad scale is the fact that there is a gradient in species richness from North to South, furthermore, coastal areas are greater hubs for biodiversity compared to landlocked areas. If non-normalised values are compared between cities results would clearly be heavily biased by (bio-) geographic factors. In addition, the relative importance of e.g. specific species or habitats for different areas cannot be reflected easily.

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[1] https://www.cbd.int/subnational/partners-and-initiatives/city-biodiversity-index

Within the last step, a hotspot map is produced in which the top tier EUBI class grid cells (defined again using the natural breaks algorithm) are selected and presented by their amount of neighbouring cells. This should show how the grid cells are connected and where core areas with high scores for all indicators and consistent coverage are achieved.

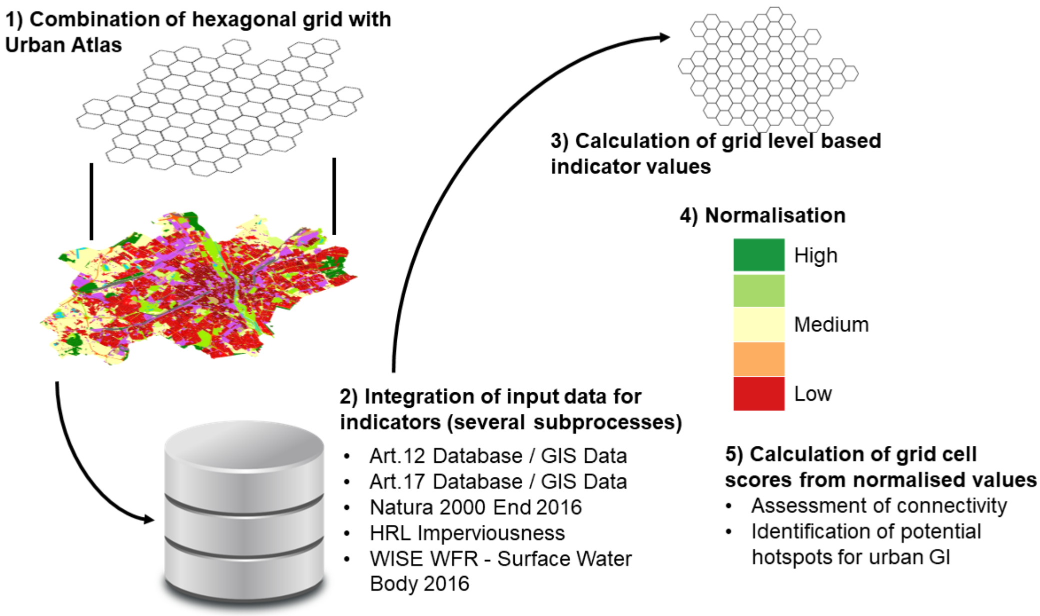


Figure 1-1 General overview of data processing steps to derive the EUBI.

1.2 Art.12/17 Data preparation – A crosswalk between Urban Atlas (UA) and MAES ecosystem typology

The spatial data from the nature directive reporting obligations (Art.12/17) is provided by the MS at a coarse resolution of 10km. Such coarse resolution renders this data unfeasible for application as Indicators within the urban context. To address the knowledge gap concerning species information within urban environments, it may prove useful to explore methods of downscaling this data to finer resolutions. In principle, downscaling can be achieved by:

1) modelling species distribution based on biophysical and climatic parameters, and

2) relating species distribution to land cover.

In previous EEA activities (Roscher, Condé, & Bailly Maitre, 2015), the species and habitats listed in Art. 12/ 17 data were assigned towards specific MAES Ecosystems types. The MAES typology on the other hand, can be linked to the land cover information from Urban Atlas (UA).

By utilizing the MAES typology as commonality between Art. 12/17 and UA, the spatial Art. 12/17 10km grid can be intersected with UA to estimate species distribution at finer resolution. This potentially opens the floor to a range of species-based indicators and analysis.

Links between habitat / land cover classifications are often referred to as crosswalks and are presented as tables. The main challenge with establishing crosswalks is that individual classes do not always relate to another in a “one-to-one” relationship, but rather “one-to-many” relationships occur and may take place bi-directionally.

In the case of one-to-many class relationships, ancillary datasets are required to establish a direct class link. Furthermore, regional aspects are often important to consider. Figure 1-2 identifies these problematic one-to-many relationships.

Not all of these one-to-many relationships could be resolved with ancillary data within the crosswalk applied for translating UA into MAES ecosystem typology. The agricultural classes, complex and mixed cultivation patterns (UA classcode 24000) as well as orchards (25000) were assigned as “cropland”. The class Pastures (23000) as well as “Herbaceous vegetation associations” (32000) were assigned as “grassland” and “heathland and shrub in MAES typology. However, “grassland” may include semi-natural components as well. Likewise, herbaceous vegetation associations include shrubs and semi natural grassland. Mixed classes such as 24000 are the most difficult to assign as they present a mosaic of land-cover classes. Class 24000 was assigned as cropland, based on the fact that most of this area is managed and used for cultivation or recreation purposes.

A limitation identified in the 2017 activities was the incapability to differentiate between marine inlets, wetlands and freshwater habitats, the use of the WISE Surface Water Body dataset enabled a differentiation between fresh and saltwater surfaces. These are mapped in UA as a single class.

		MAES Level 2 Ecosystem Typology												
		Urban	Cropland	Grassland	Woodland and forest	Heathland and shrub	Sparserly vegetated land	Wetlands	Rivers and lakes	Coastal	Marine inlets and transitional waters	Shelf	Open ocean	Relationship type
Urban Atlas 2012	11100	✓								n.a.		n.a.	n.a.	one-to-one
	11210	✓								n.a.		n.a.	n.a.	one-to-one
	11220	✓								n.a.		n.a.	n.a.	one-to-one
	11230	✓								n.a.		n.a.	n.a.	one-to-one
	11240	✓								n.a.		n.a.	n.a.	one-to-one
	11300	✓								n.a.		n.a.	n.a.	one-to-one
	12100	✓								n.a.		n.a.	n.a.	one-to-one
	12210	✓								n.a.		n.a.	n.a.	one-to-one
	12220	✓								n.a.		n.a.	n.a.	one-to-one
	12230	✓								n.a.		n.a.	n.a.	one-to-one
	12300	✓								n.a.		n.a.	n.a.	one-to-one
	12400	✓								n.a.		n.a.	n.a.	one-to-one
	13100	✓								n.a.		n.a.	n.a.	one-to-one
	13300	✓								n.a.		n.a.	n.a.	one-to-one
	13400	✓								n.a.		n.a.	n.a.	one-to-one
	14100	✓								n.a.		n.a.	n.a.	one-to-one
	14200	✓								n.a.		n.a.	n.a.	one-to-one
	21000		✓							n.a.		n.a.	n.a.	one-to-one
	22000		✓							n.a.		n.a.	n.a.	one-to-one
	23000			✓						n.a.		n.a.	n.a.	one-to-one
	24000		✓	✓	✓					n.a.		n.a.	n.a.	one-to-many
	25000		✓							n.a.		n.a.	n.a.	one-to-one
	31000				✓					n.a.		n.a.	n.a.	one-to-one
	32000			✓		✓				n.a.		n.a.	n.a.	one-to-many
	33000						✓			n.a.		n.a.	n.a.	one-to-one
	40000							✓		n.a.	✓	n.a.	n.a.	one-to-many
	50000								✓	n.a.	✓	n.a.	n.a.	one-to-many

✓ = Link n.a = Not available

Figure 1-2 Cross-table between UA nomenclature and MAES ecosystem typology. UA is mainly focused on terrestrial environments, therefore Coastal, Shelf and Open Ocean ecosystems cannot be linked to the UA product.

1.3 Indicator specific methodology

In this chapter, the individual indicators are presented and a short rationale and production methodology described. The full processing workflow is included within the annex (Figure 3-1).

Table 1-1 shows for which component or characteristic of biodiversity the core indicators provide information. Table 3.2 includes descriptions of each of the selected indicators.

Table 1-1 Landscape and species diversity aspects addressed by the core indicators of the EUBI.

Level	Characteristic	Abbreviation	Indicator name/s	Description
Landscape-diversity	Habitat availability	C01, C02, C03, C04	Proportion of Permeable Urban, Green, Blue and protected (N2K) area	Proportion and/or size of semi-/ natural and protected areas acting as potential refugia within urban zones. Calculated per grid cell
	Landscape heterogeneity	C08	Habitat richness (Habitat density)	Habitat diversity measured in terms of count of unique habitats occurring within the grid cell.
	Habitat Connectivity	C05	Length of ecotones	Length of transitions between natural and agricultural classes per grid cell.
Species-diversity	Species density	C06	Bird species density	Calculated on the basis of count of bird species per hexagonal grid cell.
		C07	Art. 17 species density	Calculated on the basis of count of species listed under Art. 17 per hexagonal grid cell.

Table 1-2 Detailed description of core indicators.

Indicator Code	Indicator Name	Unit	Range	Description	Rationale	Methodology	Data Source
C01	Permeable urban area	Median %	0-100	Degree of non-sealed area within mapped UA Urban fabric and industrial, commercial and public class (11X, 121, 123, 124) polygons per grid cell.	Within urban areas, kitchen gardens, small green spaces and other non-sealed areas provide refugia for various plant and bird species. Whereas species within these specific areas are mostly generalists of low concern in terms of their conservation status or could even invasive species they contribute towards green infrastructure in cities. Non-sealed area is also important in terms of flood management for urban environments as it acts as drainage buffer in intensive precipitation events.	The permeable urban areas indicator is calculated for each UA Urban fabric and industrial, commercial and public class (11X, 121, 123, 124) polygon separately. To retrieve more exact values for each polygon 20m HRL Imperviousness layer resolution is downscaled to 2m without resampling. Subsequently, zonal statistics are calculated per polygon. The final indicator value % private green areas is calculated by subtracting 100 by the median value of imperviousness density for each individual grid cell polygon.	Urban Atlas (2012), Imperviousness degree (2012)
C02	Proportion of protected areas	%	0-100	Proportion of FUA area belonging to Natura 2000 network per grid cell.	Areas which fall under special protection by the Natura 2000 directive may include a variety of different sensitive habitats. There are a range of restrictions to agricultural and forestry related activities within these areas which contribute to foster the development and recovery of rare species.	Natura 2000 End 2016 shapefile was clipped to sample city FUA extent. Thereinafter, remaining sites are dissolved to avoid site overlaps. Proportion is calculated from the amount of Natura 2000 area covering the respective grid cell	Urban Atlas (2012), Natura 2000 End 2016
C03	Proportion of green areas	%	0-100	Proportion of non-sealed terrestrial UA classes within grid cell	Indicates amount of (semi-) natural and urban green spaces within FUA landscape.	Proportion is calculated on the basis of below listed UA 2012 classes divided by total area including no-data areas: • 14100, 14200 • 21000, 22000, 23000, 24000, 25000, 25400 • 31000, 32000,33000 • 40000	Urban Atlas (2012)
C04	Proportion of blue areas	%	0-100	Proportion of aquatic UA class within per grid cell.	Indicates amount of aquatic habitat within FUA landscape.	Proportion is calculated on the basis of UA 2012 class 50000 divided by total area including no-data areas.	Urban Atlas (2012)

C05	Length of Ecotones	km^2 / grid cell	0 – Max. length of ecotone within FUA	Length of transitions between agricultural and forest classes.	Transitional areas between different land cover classes present highly important habitats. Highly diverse landscapes generally feature a larger degree of ecotones and thus, spatial heterogeneity. Forest fringes and hedgerow have shown to improve regional biodiversity (Duelli, 1997).	All UA level 2 (croplands) and 3 (forests) are extracted at FUA level and converted to line polygons. These separate line polygon layers are intersected and dissolved. Total length of transitions per grid cell is calculated from length of all remaining polygons.	Urban Atlas (2012)
C06	Bird species richness	No. species per grid cell	0 – Max. no bird species inside FUA	Count of bird species per hexagonal grid cell, derived from modified Art.12 dataset.	Species richness is a crucial component of biodiversity and species density describes how many bird species are encountered within the FUA.	The process involves several steps to obtain the Art. 12 species count per hexagonal cell. At first a hexagonal grid with a unique identifier for each grid cell is created. This grid is merged with UA polygons which have been assigned towards specific MAES habitats with a crosswalk using the GIS Tool "Union". In a second step the Art. 12 GIS- data is clipped to the FUA Boundary and also merged with the grid. Through this process the created datasets obtain a common identifier within the hexagonal grid, which is the basis for further processing steps. The data is imported into a database system (MS-SQL) for further processing and cleaning operation. Art. 12 hex-grid data are assigned towards specific MAES habitats using the species-habitat linkages database. The data is then joined using the common identifier assigned by the as well as the MAES habitat. This allows to filter out species which may cover a grid cell, but which are not assigned to a habitat within the cell and thus are unlikely to occur at that location.	Urban Atlas (2012), Art. 12, WISE WFD reference spatial data sets – Surface Water Body (2016), Linkages of species and habitat types to MAES ecosystems

C07	Species richness of Art. 17 species	No. species per grid cell	0 – Max. no bird species inside FUA	Count of Art. 17 species per hexagonal grid cell, derived from modified Art. 17 dataset.	Species richness is a crucial component of biodiversity and species density describes how many species are encountered within the FUA.	The process involves several steps to obtain the Art. 17 species count per hexagonal cell. At first a hexagonal grid with a unique identifier for each grid cell is created. This grid is merged with UA polygons which have been assigned towards specific MAES habitats with a crosswalk using the GIS Tool "Union". In a second step the Art. 17 GIS- data is clipped to the FUA Boundary and also merged with the grid. Through this process the created datasets obtain a common identifier within the hexagonal grid, which is the basis for further processing steps. The data is imported into a database system (MS-SQL) for further processing and cleaning operation. Art. 17 hex-grid data are assigned towards specific MAES habitats using the species-habitat linkages database. The data is then joined using the common identifier assigned within the hexagonal grid as well as the MAES habitat. This allows to filter out species which may cover a grid cell, but which are not assigned to a habitat within the cell and thus are unlikely to occur at that location.	Urban Atlas (2012), Art. 17, WISE WFD reference spatial data sets – Surface Water Body (2016), Linkages of species and habitat types to MAES ecosystems
C08	Habitat richness of Art. 17 habitats	No. species per grid cell	0 – Max. no habitats inside FUA	Count of Art. 17 habitat types per hexagonal grid cell, derived from modified Art. 17 dataset.	Likewise to species richness, habitat richness is also a crucial component of biodiversity and habitat density describes how many bird habitats are encountered within the FUA.	The process involves several steps to obtain the Art. 17 habitat count per hexagonal cell. At first a hexagonal grid with a unique identifier for each grid cell is created. This grid is merged with UA polygons which have been assigned towards specific MAES habitats with a crosswalk using the GIS Tool "Union". In a second step the Art. 17 GIS- data is clipped to the FUA Boundary and also merged with the grid. Through this process the created datasets obtain a common identifier within the hexagonal grid, which is the basis for further processing steps. The data is imported into a database system (MS-SQL) for further processing and cleaning operation. Art. 17 hex-grid data are assigned towards specific MAES habitats using the species-habitat linkages database.	Urban Atlas (2012), Art. 17, WISE WFD reference spatial data sets – Surface Water Body (2016), Linkages of species and habitat types to MAES ecosystems

2 Results

The results of the EUBI are presented subsequently on a per FUA basis using a factsheet format. Section 2.2 contains comparative results over all 17 cities for which the indicator was compiled.

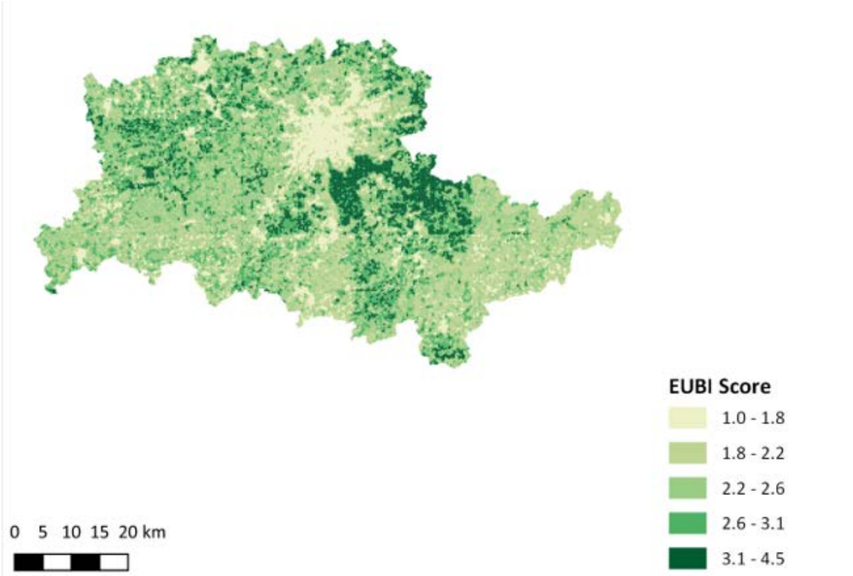
2.1 EUBI Factsheets for individual cities

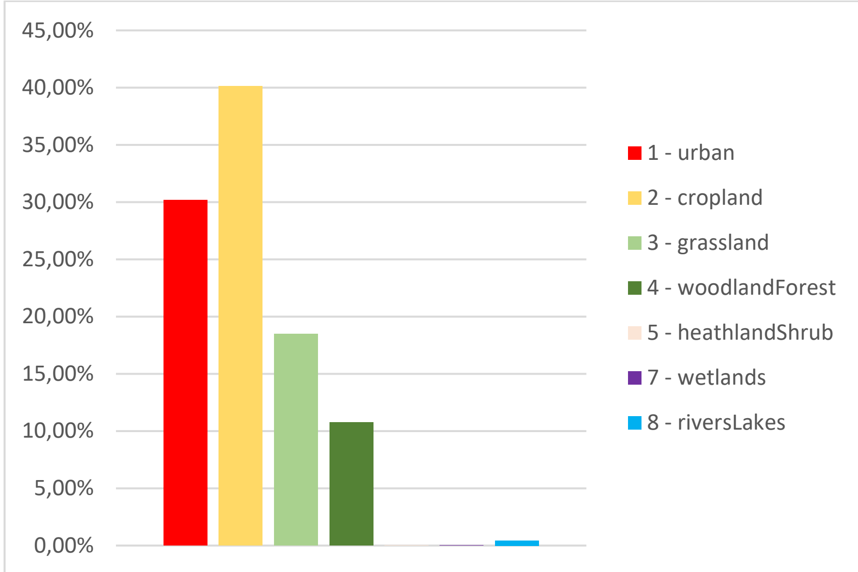
The factsheets for each FUA include a mapping of the EUBI using a 10ha hexagonal grid. The grid-based score ranges between 1 – 5, where 1 is the lowest values and 5 the highest. The EUBI is the sum of the achieved score (1-5) over all indicators per grid cell weighted by the number of indicators present in that grid cell.

For a better understanding of the habitat composition within the respective FUA a bar chart was added which displays the proportion of MAES habitats. This is based on the crosswalk between Urban Atlas classes and MAES habitats described in chapter 1.2.

Then, underneath the map and the bar chart the calculated mean values for each core indicator within the FUA are presented to allow for their integration into the short narrative description of the situation which is the last content item in the factsheet.

2.1.1 BE001L2 Brussel

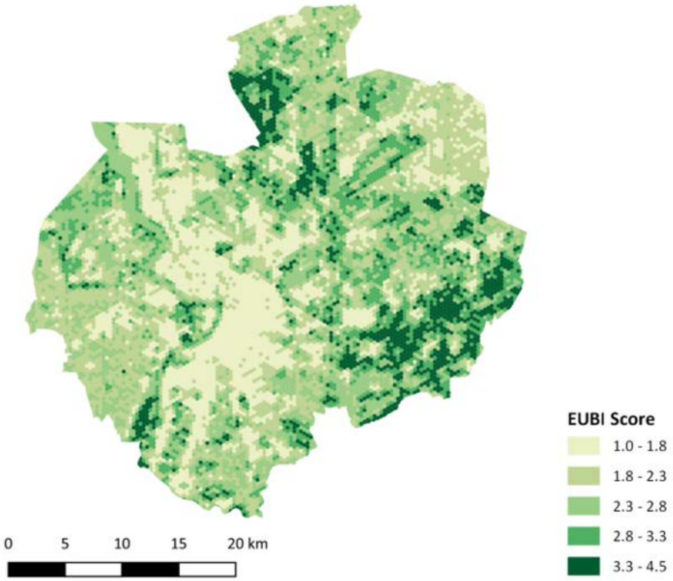


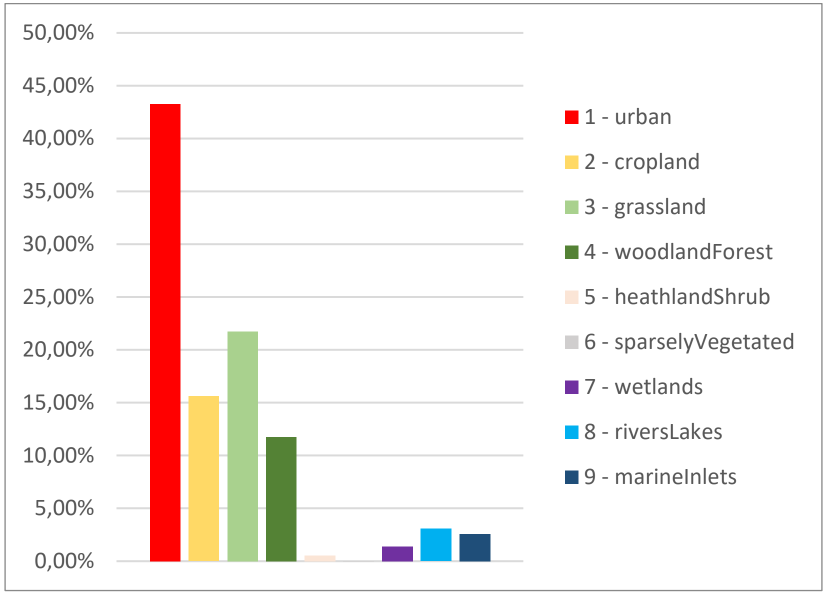


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
BE001L2	Brussels	88.6	5.8	72.1	0.4	92.3	47.3	4.2	13.1

Brussels possesses a very large Functional Urban Area which shows on the one hand the clearly recognisable footprints of the city of Brussels (the large patch in centre-north with continuous low EUBI values) as well as the neighbouring smaller cities and towns. On the other hand, large contiguous patches with high EUBI scores are visible south and south-east of the city and more isolated ones in the north-western part of the FUA. The former correspond to several large Natura 2000 sites, i.e. the Zonien forest (codes BE1000001 and BE2400008), the Haller forest (BE2400009) and the valleys of the rivers Dijle, Laan and IJse (BE2400011), while the latter represent patches of forest that intersect the highly urbanized region around Brussels. In general, the FUA is characterised by highly managed surfaces, either urban areas (30 %) or croplands (40 %). The remaining areas are covered by grasslands (around 18 %) and forest and woodlands (around 11 %). Water and wetland areas are almost inexistent. Finally, Brussels also shows below-average mean values for most of the indicators except for share of permeable surfaces and appearances of bird species.

2.1.2 BE002L2 Antwerpen

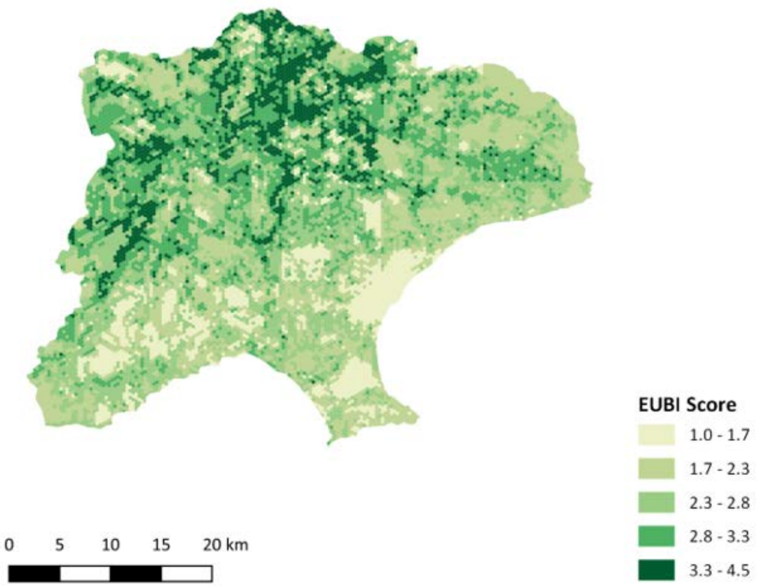


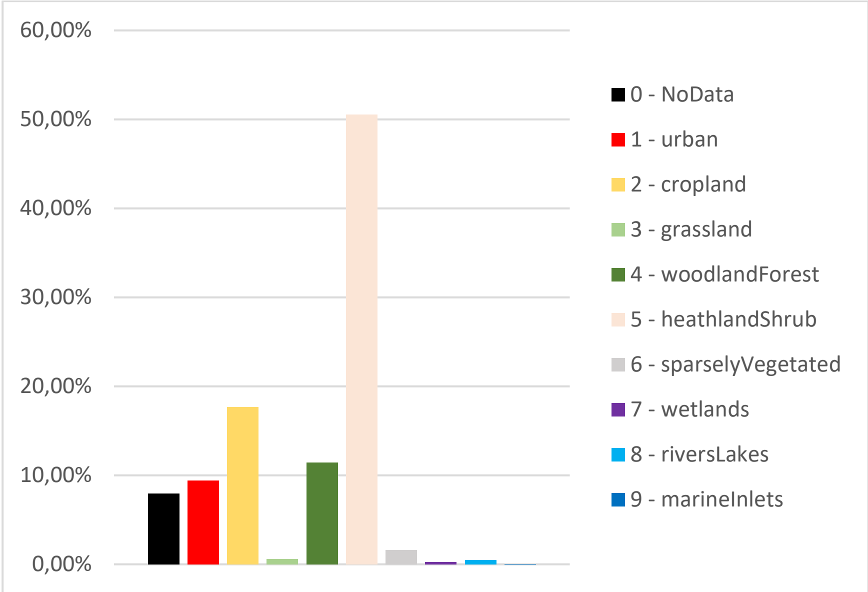


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
BE002L2	Antwerpen	73.4	18.3	54.6	5.9	62.8	48.6	4.1	16.2

The much smaller FUA of Antwerp, compared to its compatriot FUA of Brussels, displays a much higher proportion of urban areas (43 %), and a relatively equal share of cropland, grassland and woodland and forest (16 %, 22 % and 12 %, resp.). The densest urbanization is visible along the river Schelde in the centre of the FUA, consisting of the city and the large harbour area. Two larger areas with high EUBI scores can be found in the north as well as in the south-east of the FUA. The northern green zone covers the Kalmthoutse Heide (BE2100015) and the Klein en Groot Schietveld (BE2100016). The areas in the south-east are a forest and heath areas aggregated in the N2K site BE2100017. In total, around 18 % of the FUA are covered by N2K sites. Due to the location of Antwerp along the Schelde and its estuary, the FUA contains wetland and water surfaces (both rivers/lakes and marine inlets). The larger proportion of urban areas also brings with it lower shares of permeable surfaces and urban green areas.

2.1.3 CY501L1 Lemesos

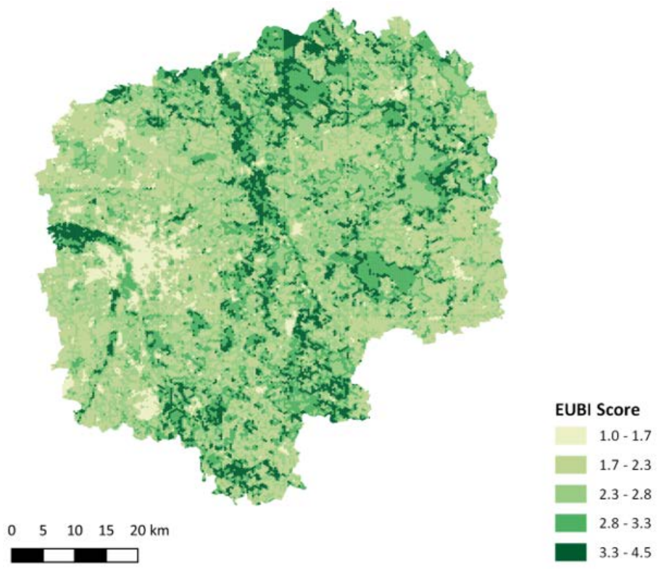


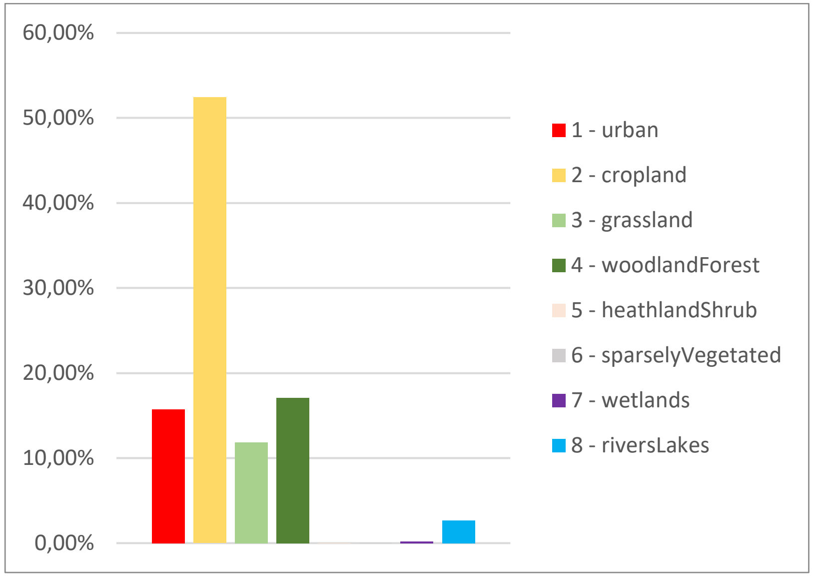


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
CY501L1	Lemesos	87.9	21.3	82.3	0.4	113.1	19.7	3.5	21.6

The FUA of Limassol/Lemesos is divided in two distinct areas, a region with lower EUBI scores in the south and another region with higher EUBI scores in the north. The southern part is a relatively flat area along the coast and at the foothills of the mountainous core of the island of Cyprus affected by urban and agricultural areas. The northern part of the FUA contains four N2K sites, i.e. two Habitat Directive sites (SCIs, Site Codes CY5000001 and CY5000006) and two Bird Directive sites (SPAs, Site Codes CY5000011 and CY5000009), N2K sites in total covering more than 20 % of the FUA which is the highest value of all FUAs in this analysis. It is particularly in those regions of the mountainous northern part of the FUA that heathland and shrubs dominate which cover around 50 % of the entire surface. Urban and forest/woodland areas cover around 10 %, whereas 18 % are occupied by croplands. At the same time, Lemesos possesses above-average shares of permeable surfaces and urban green areas.

2.1.4 DE008L2 Leipzig

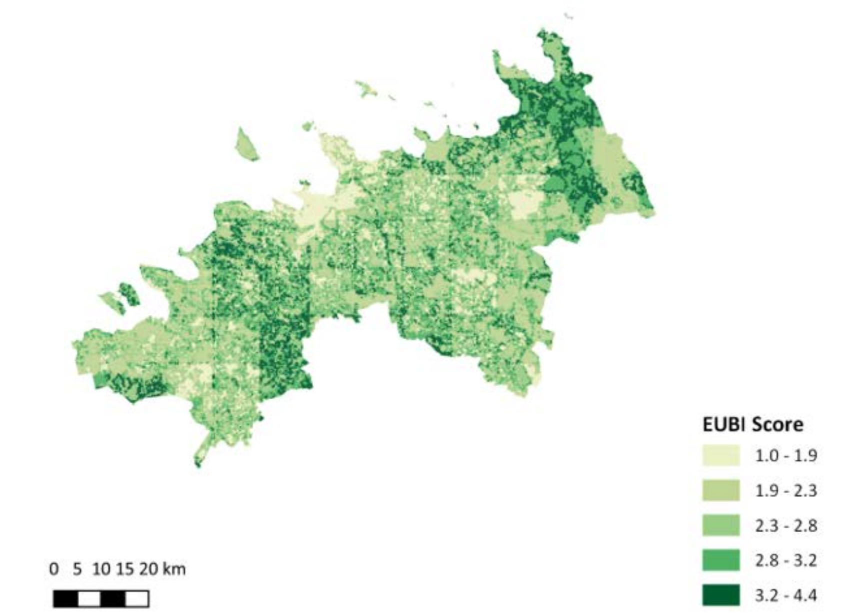


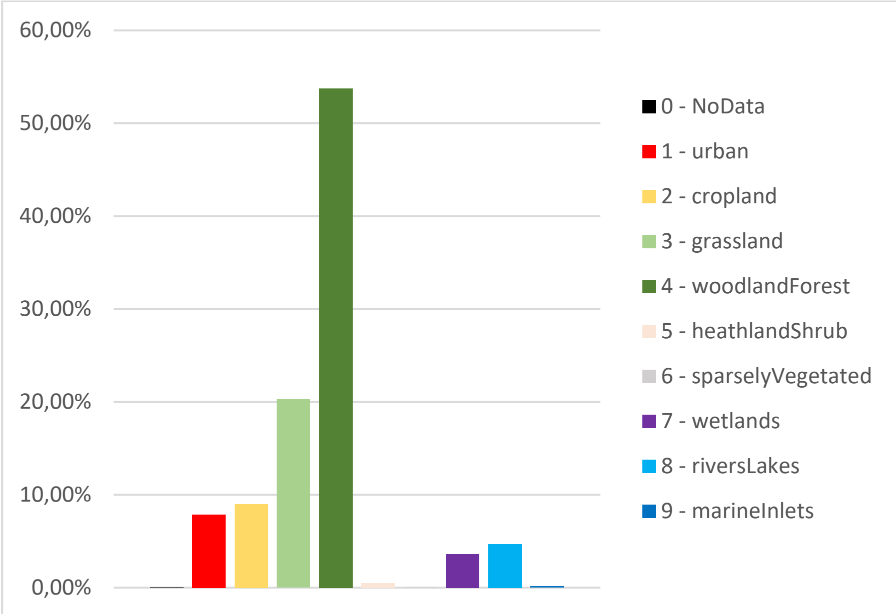


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
DE008L2	Leipzig	73.3	18.5	83.8	2.7	72.1	55.1	4.6	24.1

The city of Leipzig is visible in the west of the FUA as centre of a vertical zone of landscape with lower EUBI scores, even though there are several connected N2K sites in the north-west of the city that continue as an almost linear element south of Leipzig. It is an extensive riparian zone and water meadow system of several rivers. To the east of the city the EUBI scores in general increase, caused by large water meadows, heath and forest areas (all categorized as SPIs or SCAs, leading to an overall share of around 18 % N2K sites within the FUA confines which is also clearly above-average). Overall, around half of the FUA is covered by cropland, a remnant of the former socialist agricultural system with its large uniform fields. Another 30 % is woodland/forest and grassland, whereas the remaining 20 % are covered by urban fabric and rivers and lakes. The uniformity of the landscape determined by the large cropland and small forest surfaces also leads to a clearly below-average length of ecotones; on the other hand, one can observe an above-average species richness, both for Articles 12 and 17.

2.1.5 *EE001L1 Tallinn*

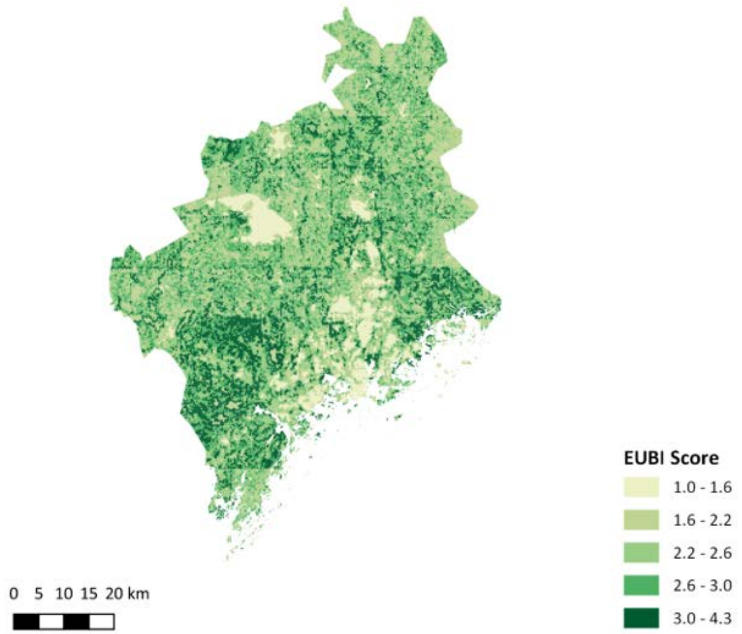


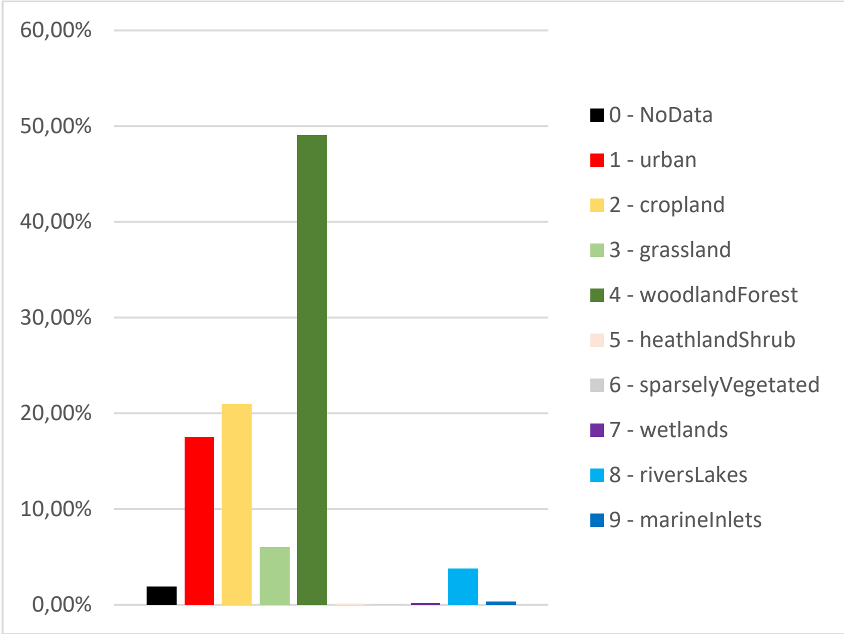


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
EE001L1	Tallinn	93.1	18.1	91.2	1.2	178.6	62.6	6.8	15.1

The FUA of Tallinn is characterised by a high proportion of forest and grassland (almost three quarters of the total surface), only very limited cropland areas, some urban and a comparably high share of wetlands and rivers/lakes (together covering more than 8 % of the FUA surface). In addition, several large protected sites cover the east and the north/north-west of the FUA including almost all of the small islands, representing in total almost 20 % of the FUA surface which is also clearly above-average. Tallinn possesses a very high proportion of both permeable and green areas and only mediocre values for habitat and species richness.

2.1.6 FI001L2 Helsinki

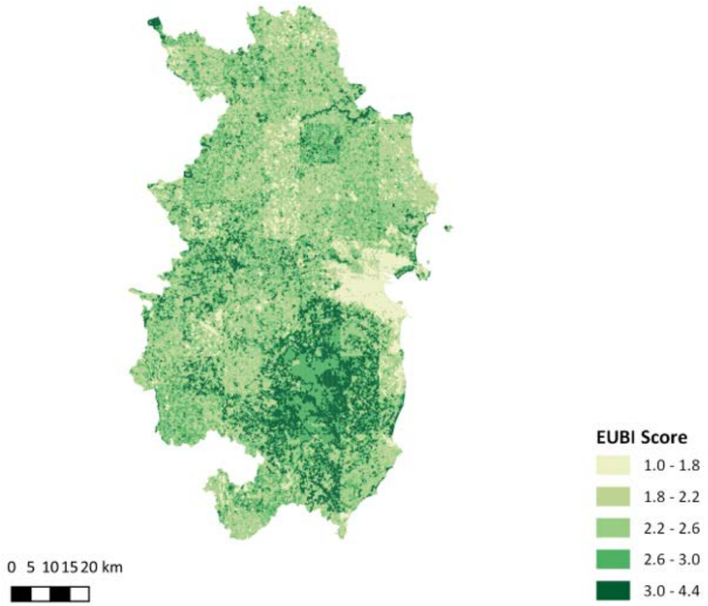


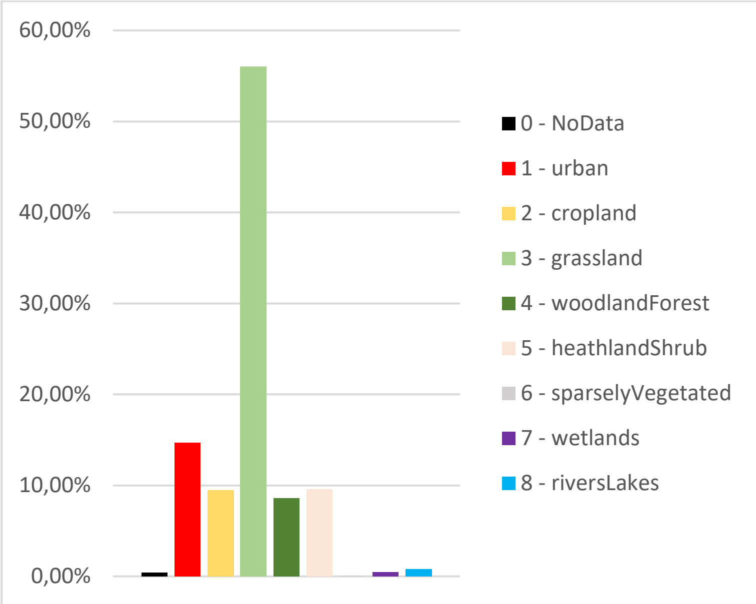


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
FI001L2	Helsinki	83.7	5.2	78.4	4.5	179.9	68.4	5.9	11.1

Because the FUA of Helsinki is to a large extent characterised by woodland and forests habitats, a large proportion of the surface of the FUA show a medium to high EUBI score, particularly the south-western and south-eastern regions, but also more isolated patches in the centre and north of the FUA. Helsinki has one of the lowest shares of protected sites within its boundaries (a larger SCI and SPA site north of the city and a large SPA site covering the archipelago south-west of Helsinki) which is also reflected by a low to mediocre scores of species and habitat richness. On the other hand, the cropland structure with smaller plots leads to one of the highest values of ecotones length.

2.1.7 *IE001L1 Dublin*

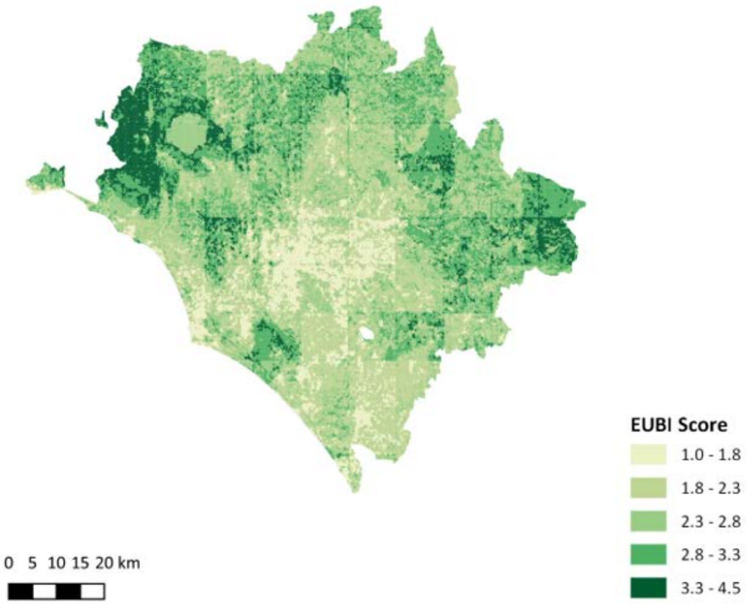


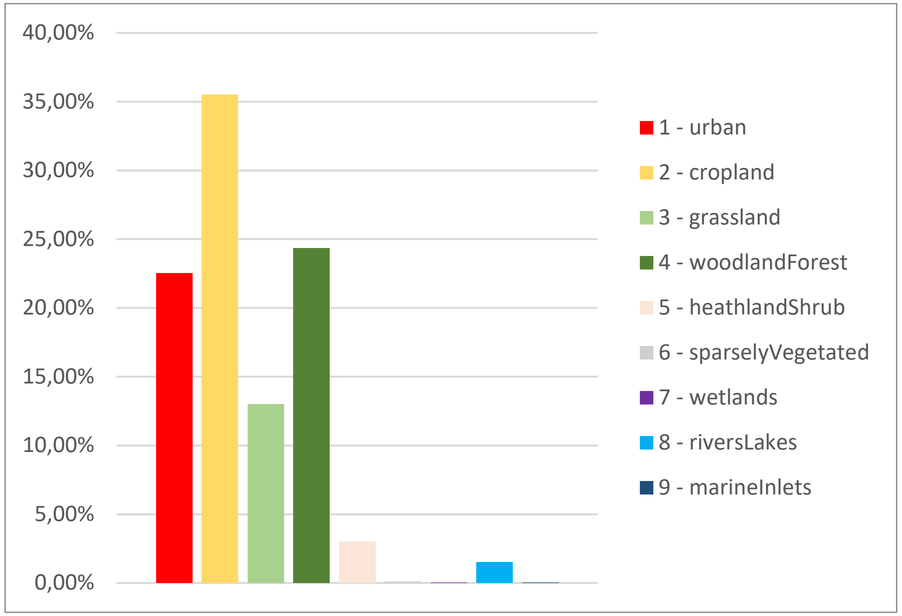


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
IE001L1	Dublin	91.4	7.1	86.6	0.9	97.8	24.7	2.4	8.1

The city of Dublin is located on the eastern side of the FUA along the Dublin Bay. A large area with contiguous high EUBI values is located south of the city, other more isolated patches with higher values can be found in the west and the north of the FUA. The large region in the south is the Wicklow Mountains National Park that is protected both for birds and habitats. The distributed patches in the west of the FUA are moor- and peatlands while the more linear feature in the north represents protected riverine and riparian landscapes as well as the estuary of the river Boyne. However, the average EUBI scores for species and habitat richness are only mediocre to low and below-average. More than half of the FUA is covered by grassland habitats, together with heathland and woodland/forests constituting more than 75 % of the coverage. By consequence, the shares of permeable surfaces and urban green areas are above-average.

2.1.8 IT001L2 Roma

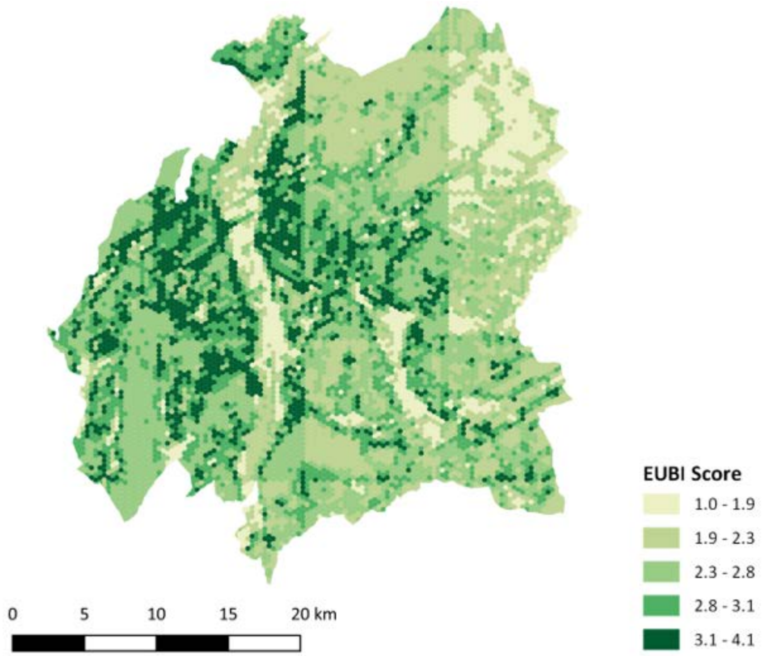


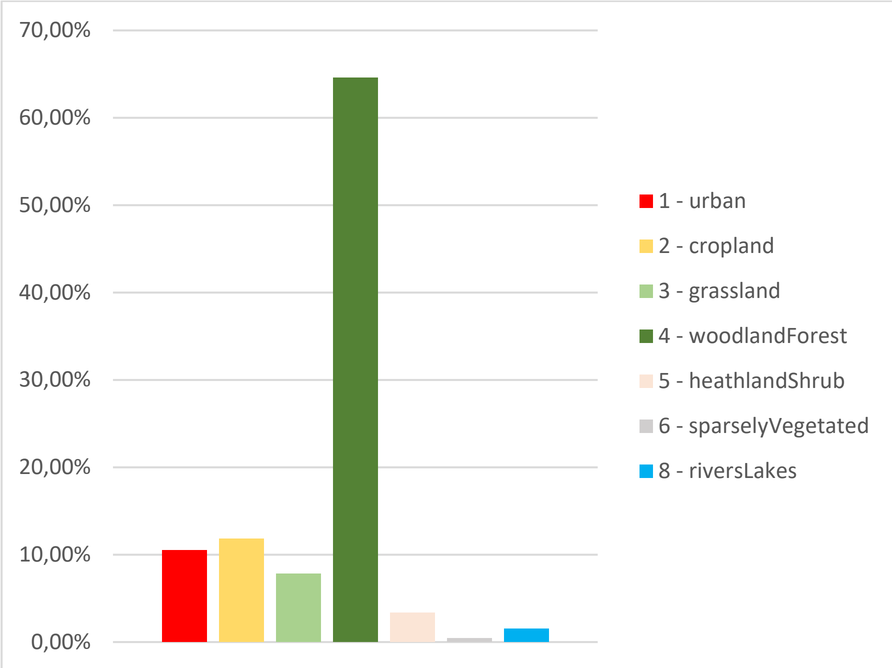


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
IT001L2	Roma	85.4	16.5	77.6	1.6	146.9	38.4	5.2	17.8

On the EUBI score map of Rome, it becomes immediately visible that there are densely urbanised areas in the centre (Rome and suburbs), in the south (several smaller cities) and along most parts of the coastline, while the north and the east are better off in terms of EUBI scores. Both larger patches of high EUBI scores are made up of mountainous landscapes, in the north around the Lago Bracciano (also visible on the map, bird sites Comprensorio Tolfetano-Cerite-Manziate and Bracciano-Martigniano) and in the east the Abruzzi (also several bird sites). There are also smaller patches around Rome (in the south and the west) which all represent national reserves or forested regions (such as the bird site Castel Porziano at the coast or the habitat site Maschio dell'Artemisio). The landscape is mostly made up of cropland, woodland/forest and urban with a high permeability and a comparably high share of N2K sites.

2.1.9 IT014L2 Trento

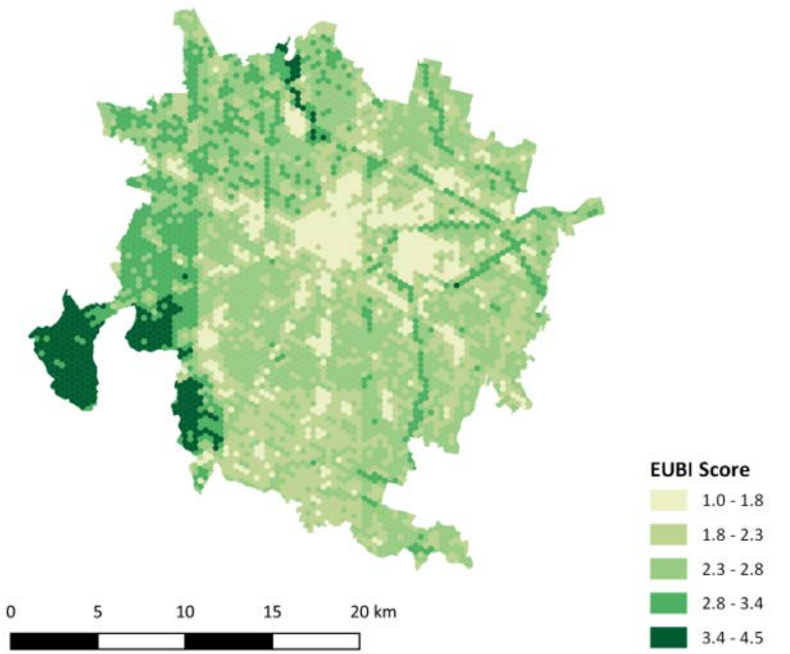


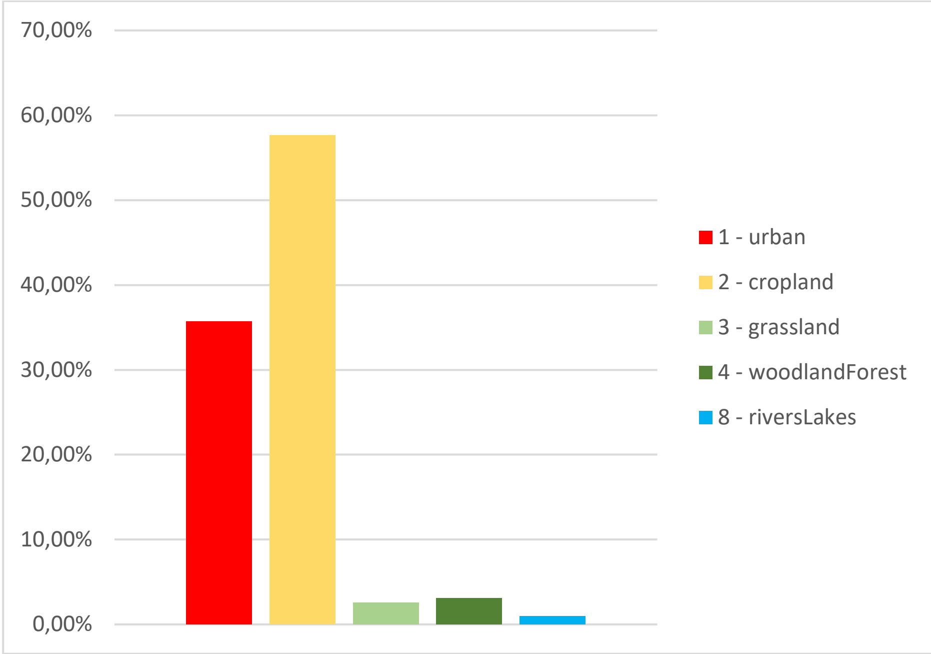


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
IT014L2	Trento	85.6	2.7	88.5	1.6	133.2	63.6	11.1	26.8

The EUBI score map shows the city of Trento in the narrow valley in the centre of the FUA, surrounded by mountain ranges that descend on the eastern side of the FUA into a wider valley. Trento is located at the foothills of the Alps just north of Lago di Garda. Apart from a bit of cropland and urban surfaces, the vast majority of the FUA is covered by woodland/forests (almost two third of the surface). It therefore also exhibits large proportions of permeable surfaces and urban green spaces, but on the other hand a low proportion of ecotones. Likewise, the share of N2K sites is very low (i.e. the lowest of all cities in the analysis), only a few smaller scattered habitat sites can be found inside the FUA.

2.1.10 IT028L2 Padova

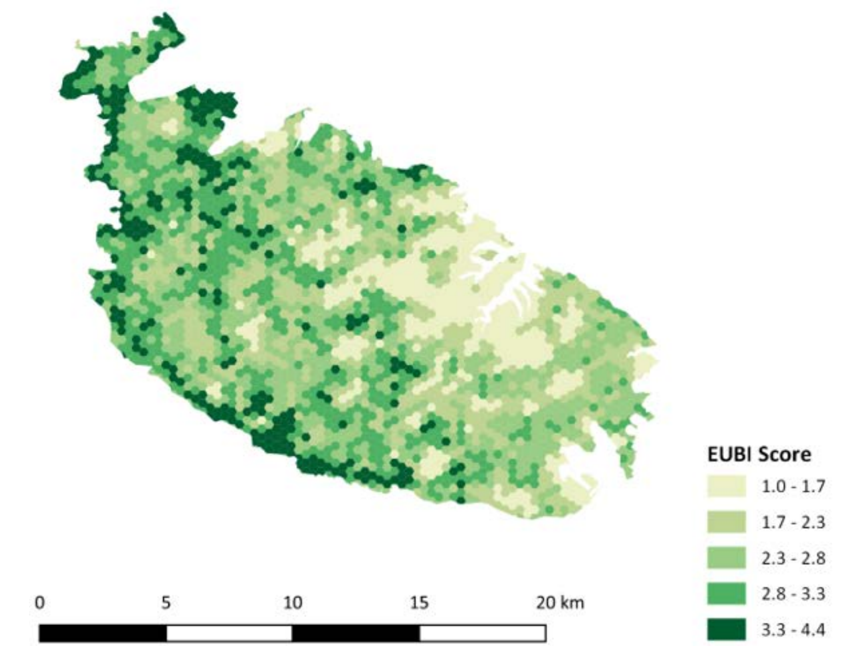


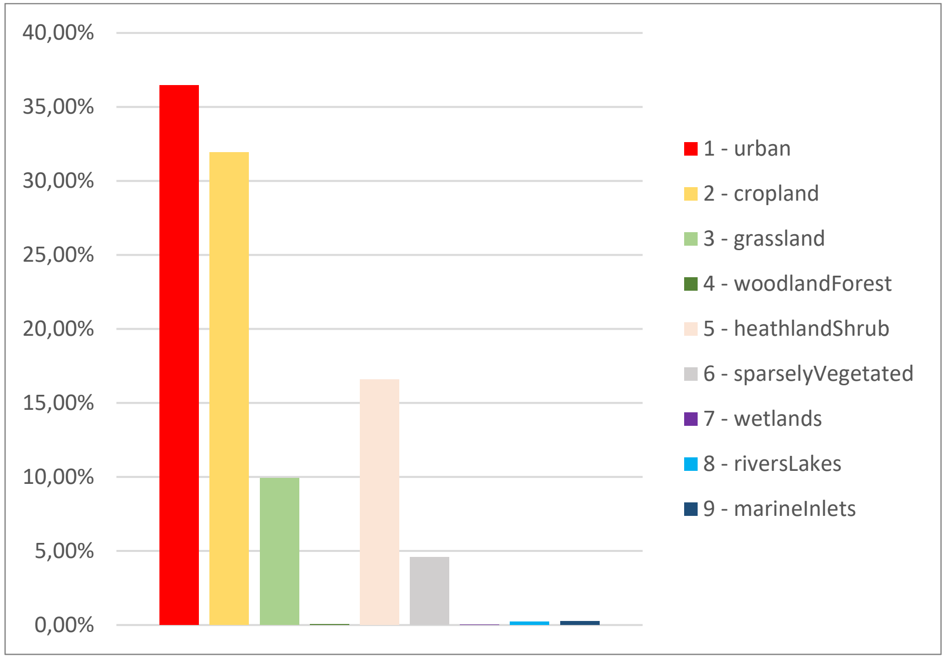


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
IT028L2	Padova	80.3	7.7	65.6	1.1	18.1	34.7	2.4	12.5

Padova is located in an agricultural-urban landscape, cropland and urban surfaces making up more than 90 % of the FUA. The only patches with high EUBI scores are located in the south-west of the FUA (a big habitat and birds site called Colli Euganei-Monte Lozzo-Monte Ricco that extends over the boundaries of the FUA) and in the north (a wetland and riparian area along the river Brenta, both classified as habitats and birds' site). Urban green spaces are scarce as are ecotones due to the lack of forests and blue areas. Padova is the only city that shows below-average values for all indicators.

2.1.11 MT001L1 Malta

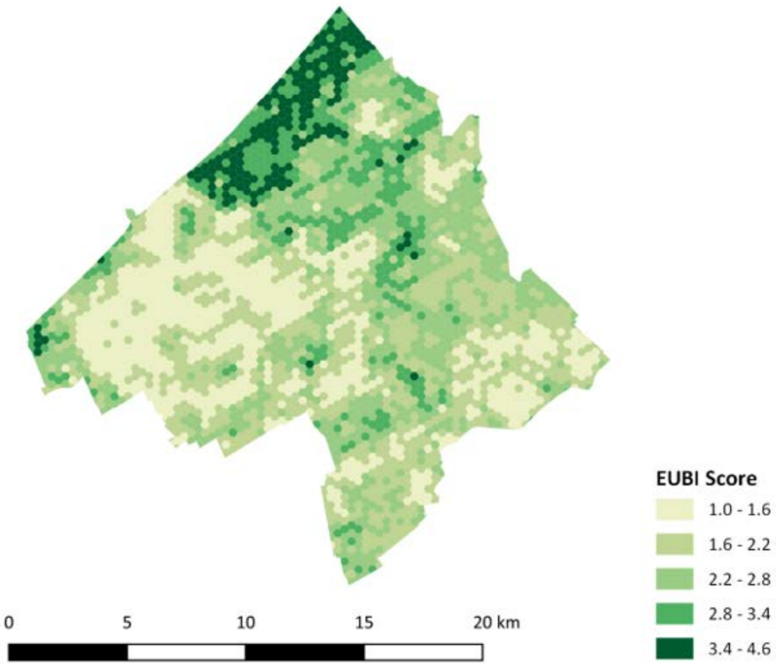


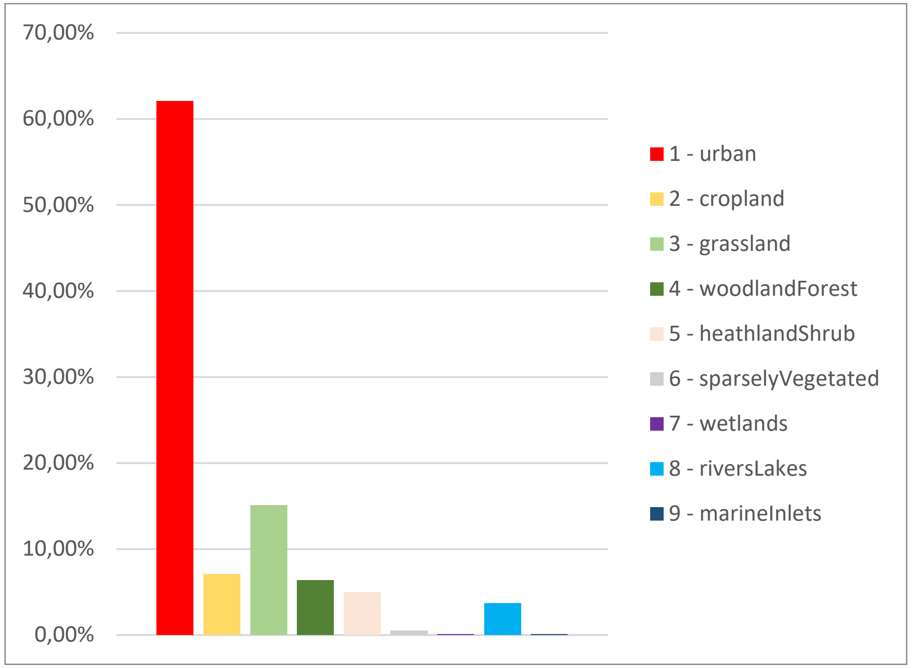


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
MT001L1	Valletta	63.3	15.8	63.7	1.4	131.3	9.0	5.5	15.8

The island of Malta does not possess any distinct forests, but the vegetated landscape is covered by croplands, heathland/shrub and some grasslands. More than one third of the island is urbanized with the centre of the urbanisation on the north-eastern coast where also its capital Valletta is located. Malta possesses very extended N2K sites, but the vast majority of them are marine sites and do not or only marginally extend on terrestrial surfaces. Where they do is visible on the map by the higher EUBI scores, i.e. along the southern coast and in the north of the island.

2.1.12 NL001L2 s’ Gravenhage

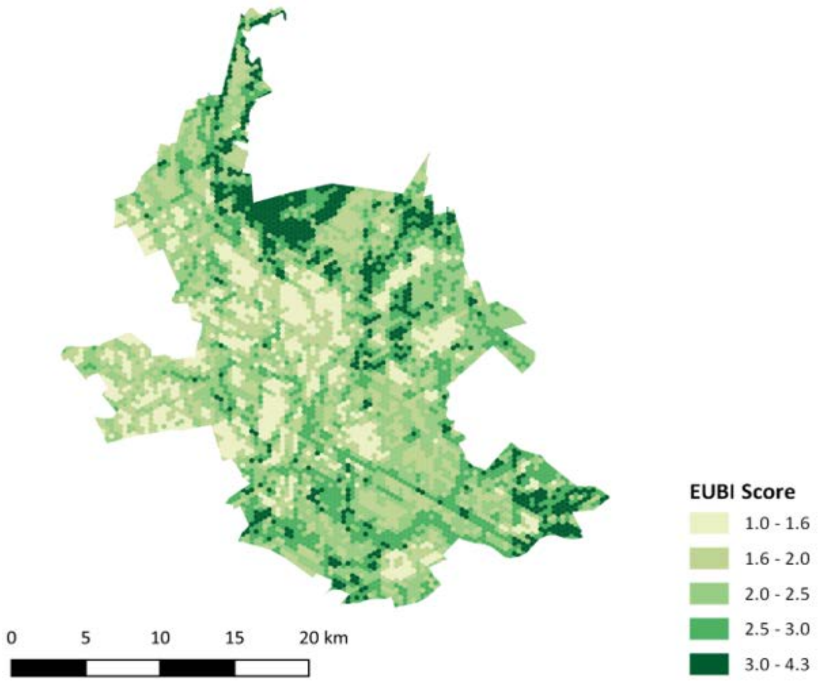


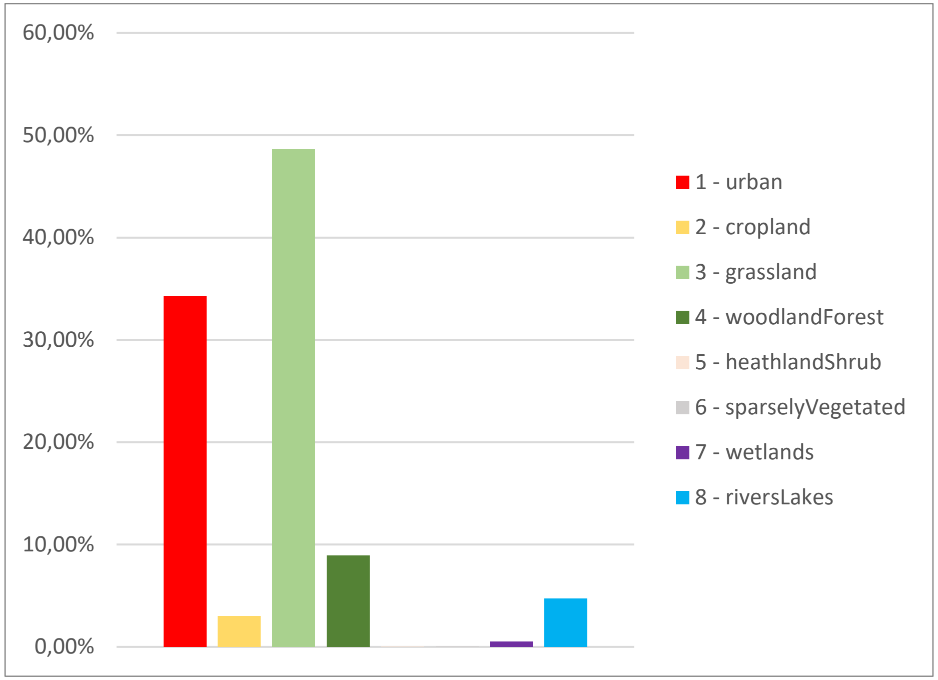


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
NL001L2	Gravenhage	53.5	10.6	48.5	3.8	43.6	38.6	2.1	15.8

The comparably small FUA of s’Gravenhage does show large areas with low EUBI scores because it is highly urbanized (almost 60 % urban land cover). The Hague is the city with the highest share of urban areas, therefore logically also shows the largest negative deviations from the average for permeable and green urban areas. The visible exception of this high urbanisation is the habitat site Meijendel & Bergheide, a large protected dune area north-east of the city of s’Gravenhage. The dunes consist of grassland dunes and woody dunes.

2.1.13 NL004L2 Utrecht

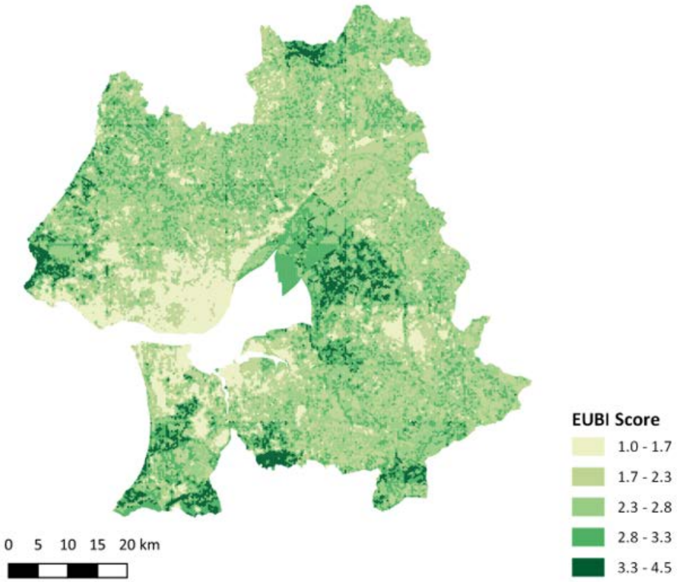


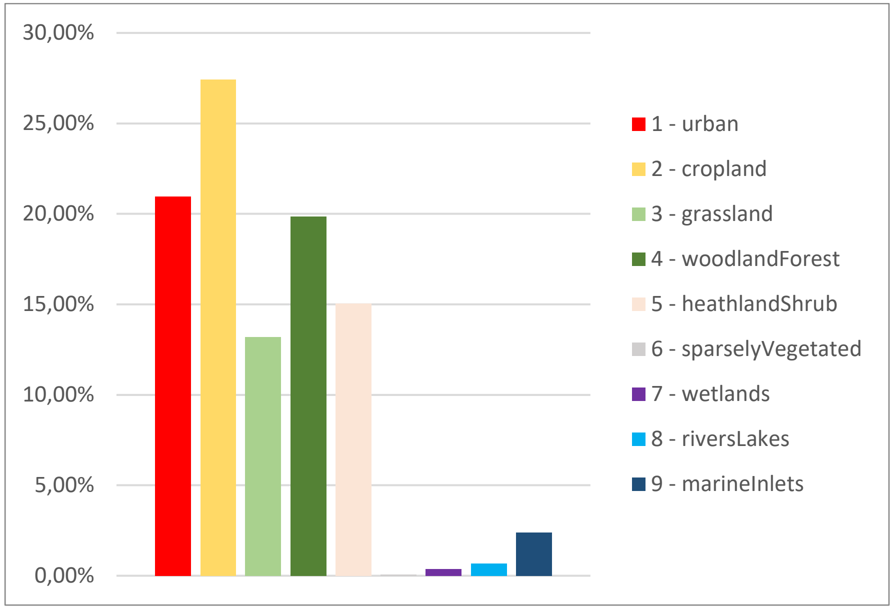


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
NL004L2	Utrecht	75.2	3.4	66.8	5.1	54.7	41.5	2.4	18.7

The city of Utrecht is located in the centre and in the west of the FUA and it is surrounded by regions that show a higher EUBI score, in particular north of the city and in the south-eastern corner of the FUA. The area in the north belongs to the larger birds and habitat sites of Oostelijke Vechtplassen, extended areas of wetlands and lakes, while the area in the south-east are the outermost parts of the bird site Rijntakken. Almost half of the FUA is covered by grasslands and another around 30 % are urban.

2.1.14 PT001L2 Lisboa

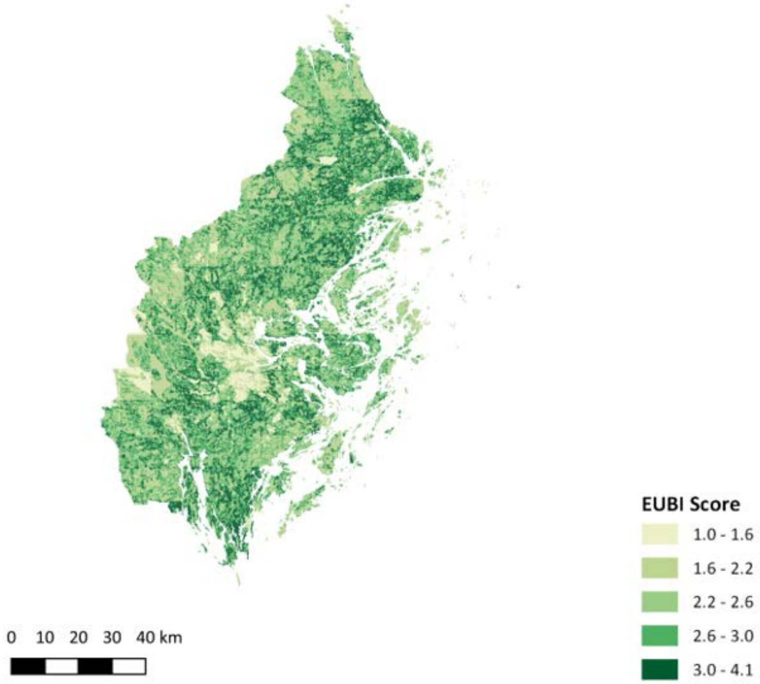


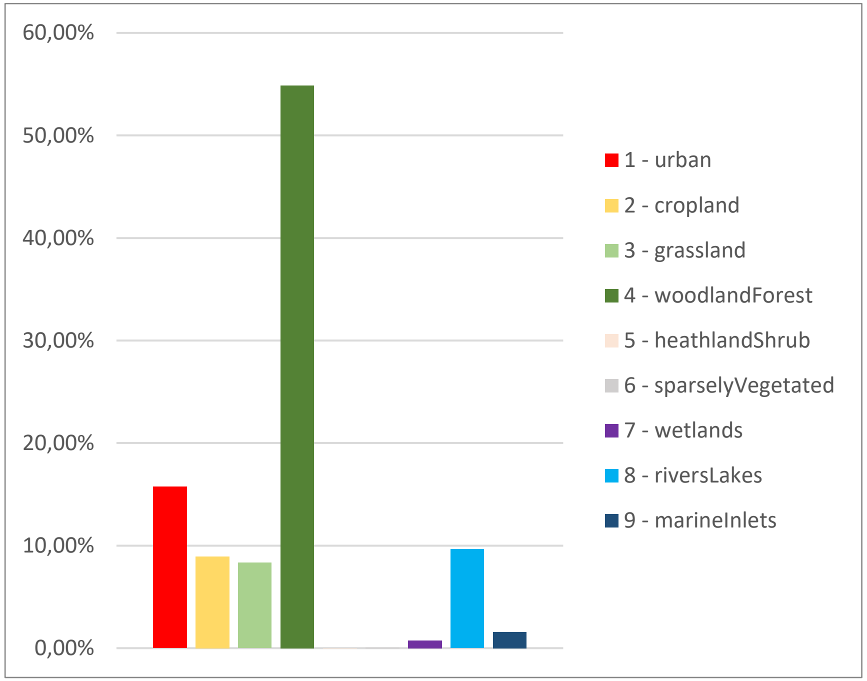


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
PT001L2	Lisboa	72.6	15.3	77.2	2.9	209.7	42.0	3.8	12.4

The FUA of Lisbon is very large and encompasses a lot of different landscapes with many classes having between 13 and 27 % of area coverage. Croplands (including rice) cover the largest proportion of Lisbon, followed by woodland/forest, urban, heathland/shrub and grassland. It is therefore not surprising that Lisbon possesses the largest ecotones length value. The map shows on average mediocre EUBI scores, but there are several regions that stand out with higher scores. In the north, the high values belong to the southern ends of some mountain ranges of the central highlands. The region at the western end of the FUA represents the nature park Sintra-Cascais which is also a habitat site. South of the Tejo estuary, two other habitat sites show up on the map by high EUBI scores, i.e. Fernao Ferro/Lagoa de Albufeira and Arrabida/Espichel. Further to the east the large natural reserve Estuario do Sado and the habitat site Cabrela manifest on the map. Last but not least the vast area of the Tejo estuary itself, being both habitat and bird site, covers the centre of the FUA.

2.1.15 SE001L1 Stockholm

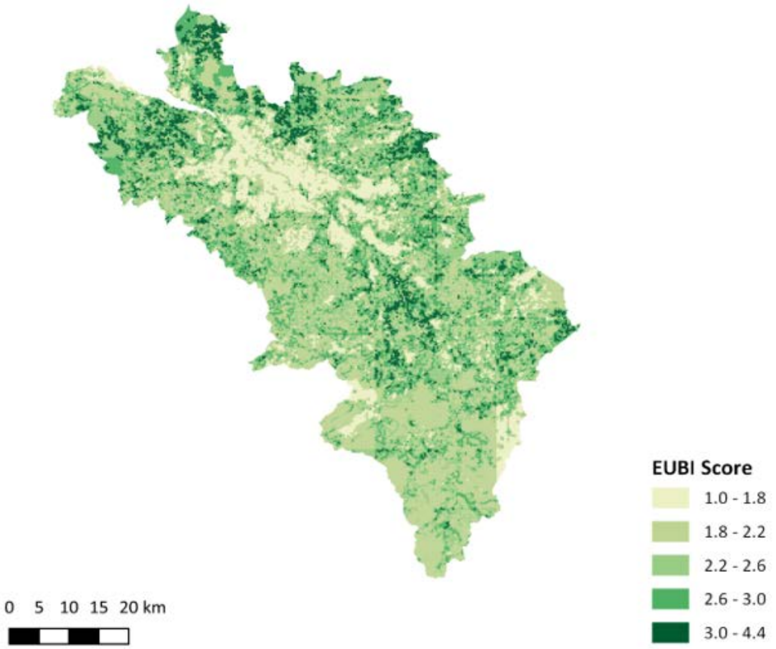


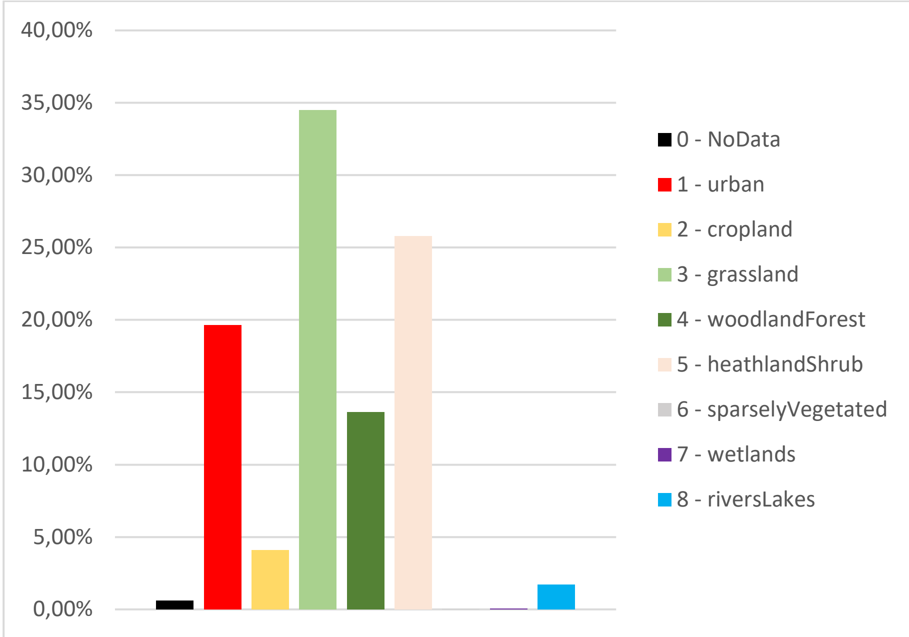


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
SE001L1	Stockholm	92.6	3.0	75.0	11.8	156.1	67.0	6.9	18.6

The very large FUA of Stockholm is characterized by a high share of woodland/forest (around 55 %), but also by almost 15 % of urban surfaces and an almost equal proportion of inland water surfaces due to the many Swedish lakes. The city of Stockholm is located in the centre of the map. The FUA does not contain a lot of protected sites (the second-lowest value of all analysed cities), but still shows high EUBI values due to the many natural landscapes. Also, above-average values of ecotones and bird species richness as well as blue areas and permeable surfaces can be observed.

2.1.16 UK004L1 Glasgow

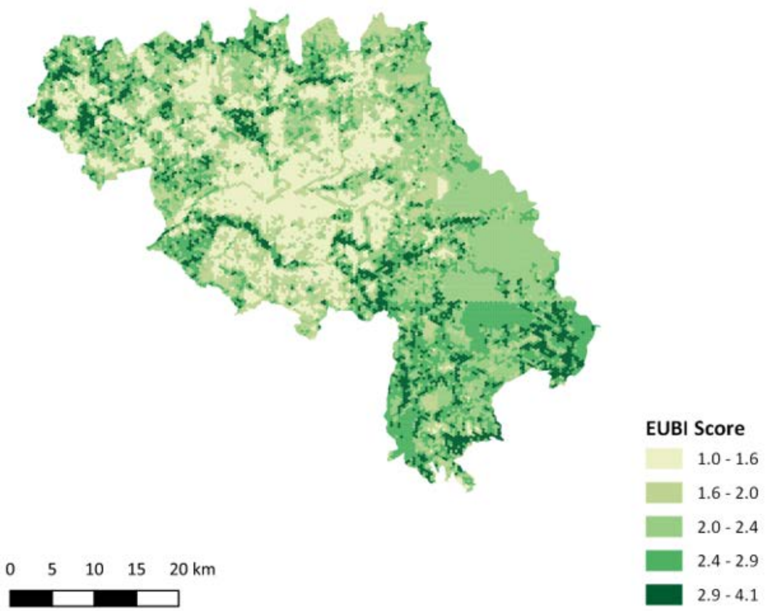


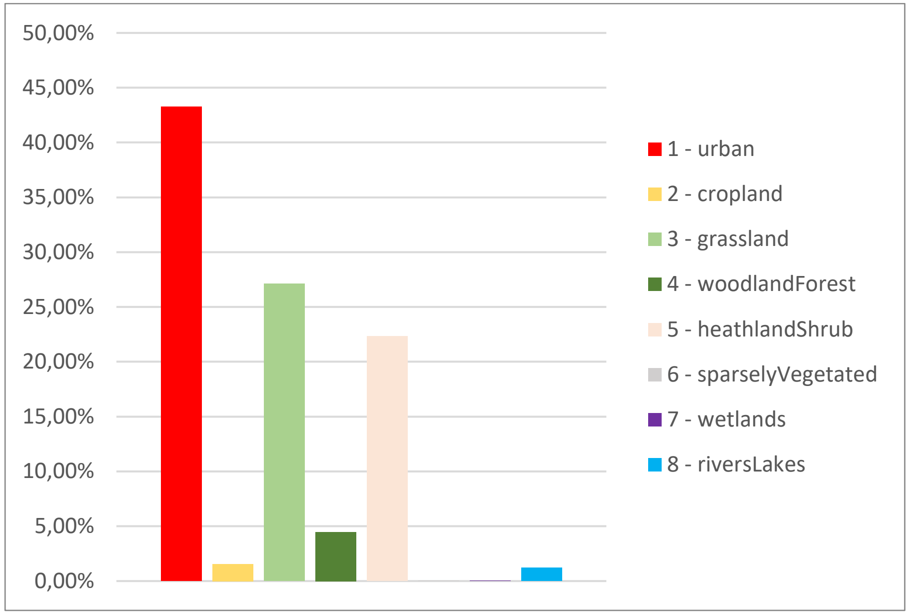


FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
UK004L1	Glasgow	69.0	4.0	81.7	1.8	151.4	30.7	2.0	6.4

The city of Glasgow is located along the river Clyde and can be seen in the northern-centre part of the FUA. Regions with higher EUBI scores can be found in the north-west of the FUA as well as north-east and south of the city. However, the share of N2K sites is very low (4 %), the largest being in the north-west south of the Clyde estuary. In terms of land cover, around 60 % of the FUA are covered by grassland and heathland/shrub, the rest is urban, forest, cropland and inland water. Glasgow also shows above-average values for the length of ecotones and the share of green urban areas, this despite a below-average share of permeable surfaces.

2.1.17 UK008L2 Manchester





FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
UK008L2	Manchester	66.4	13.7	64.2	1.2	81.8	31.0	1.8	8.4

The city of Manchester covers the western part of the FUA while the eastern part extends into the surrounding countryside, demonstrated also by the generally higher EUBI score values. This eastern region of the FUA belongs to the bigger habitat and birds site Peak District Moors and South Pennine Moors, which are characterized by bogs and heathland. N2K sites cover almost 14 % of the FUA, which is slightly above-average. Next to a large share of urban surfaces (43 %), grasslands (27 %) and heathland/shrubs (22 %) are the main land cover characteristics. Yet, the high rate of urban areas leads to strongly below-average shares of permeable surfaces and green urban areas.

2.2 Comparative results of EUBI over all included cities

Erreur ! Source du renvoi introuvable. contains calculated mean values for each core indicator within the selected FUAs. The values for permeable urban spaces are generally quite high due to the fact that these areas mostly cover large parts of grid cells if they are indeed present. This is also the case for the proportion of green spaces (C03 Green area). There is large variation between cities in terms of average grid cell coverage by protected areas. The highest value mean values over all grid cells was determined for Lemesos (Cyprus). Here, on average more than 20% of a cell may be covered by protected area. Surprisingly, Antwerp, which is a densely populated FUA, also reaches comparatively high mean values indicating that large areas of the FUA are regulated under Natura2000.

Blue spaces naturally vary between FUAs with the highest value obtained in Stockholm, followed by Antwerp and Utrecht. Concerning EcoTones, i.e. the transitional borders between natural and cultivated habitats, the lowest values were calculated for the Padova and The Hague FUAs. Lisbon featured the highest mean amount of ecotones per grid cell which reflects the many transitions occurring between natural and cultivated habitat within the Lisboan (PT001L1) FUA.

The count of bird species designated under the Art.12 varies substantially between the different FUAs with island FUAs (MT001L1 and CY501L1) featuring the lowest amount of registered species. In terms of art17 species and habitats the two UK FUAs feature among the lowest values per grid cell.

Table 2-1: Calculated mean values per hexagonal grid cell for all core indicators. Each FUA is subdivided by a 10ha hexagonal grid.

FUA Code	Name	C01 Permeable urban area	C02 N2000 area	C03 Green area	C04 Blue area	C05 Length EcoTones	C06 Art12 species richness	C07 Art17 habitat richness	C08 Art17 species richness
BE001L2	Brussels	88.6	5.8	72.1	0.4	92.3	47.3	4.2	13.1
BE002L2	Antwerpen	73.4	18.3	54.6	5.9	62.8	48.6	4.1	16.2
CY501L1	Lemesos	87.9	21.3	82.3	0.4	113.1	19.7	3.5	21.6
DE008L2	Leipzig	73.3	18.5	83.8	2.7	72.1	55.1	4.6	24.1
EE001L1	Tallinn	93.1	18.1	91.2	1.2	178.6	62.6	6.8	15.1
FI001L2	Helsinki	83.7	5.2	78.4	4.5	179.9	68.4	5.9	11.1
IE001L1	Dublin	91.4	7.1	86.6	0.9	97.8	24.7	2.4	8.1
IT001L2	Roma	85.4	16.5	77.6	1.6	146.9	38.4	5.2	17.8
IT014L2	Trento	85.6	2.7	88.5	1.6	133.2	63.6	11.1	26.8
IT028L2	Padova	80.3	7.7	65.6	1.1	18.1	34.7	2.4	12.5
MT001L1	Valletta	63.3	15.8	63.7	1.4	131.3	9.0	5.5	15.8
NL001L2	Gravenhage	53.5	10.6	48.5	3.8	43.6	38.6	2.1	15.8
NL004L2	Utrecht	75.2	3.4	66.8	5.1	54.7	41.5	2.4	18.7
PT001L2	Lisboa	72.6	15.3	77.2	2.9	209.7	42.0	3.8	12.4
SE001L1	Stockholm	92.6	3.0	75.0	11.8	156.1	67.0	6.9	18.6
UK004L1	Glasgow	69.0	4.0	81.7	1.8	151.4	30.7	2.0	6.4
UK008L2	Manchester	66.4	13.7	64.2	1.2	81.8	31.0	1.8	8.4

Looking at the share of the main land cover classes summarised over all 17 FUAs (see Figure 2-1), it becomes obvious that woodlands/forest dominate with a coverage of almost 30 %, followed by croplands, urban surfaces and grasslands with between 22 % and 18 %. Heathland and shrubs follow with around 7 %, although there exist large variations between FUAs with Lemesos as FUA with the maximum value of around 50 %. Water covers around 3 % of all FUAs, whereas wetlands, marine inlets and sparsely vegetated areas are over all cities negligible.

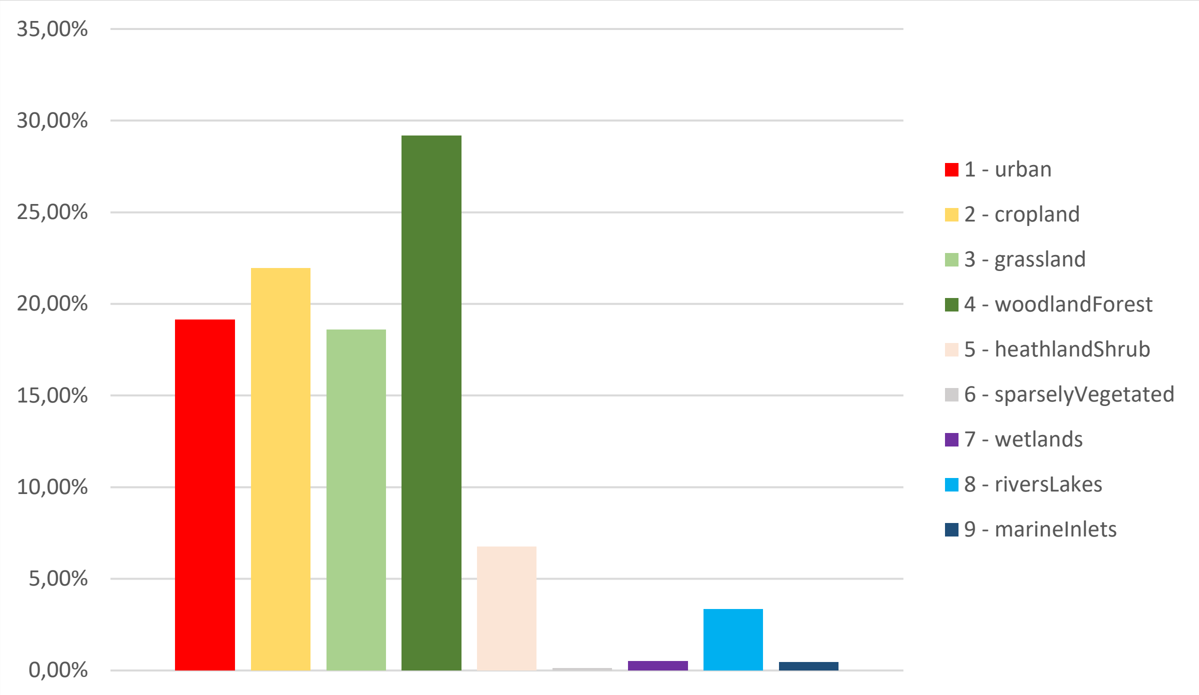


Figure 2-1: Share of the main land cover classes summarised over all 17 FUAs

Figure 2-2 shows the proportion of each land cover class for all 17 FUAs separately in a stacked bar chart, so that all single units add up to 100 %. From this bar chart it becomes immediately visible that there are very large variations between cities regarding their respective shares of land cover. The highly urban FUAs The Hague, Antwerp and Manchester (with more than 40 % to around 60 % of urban areas) are clearly different than, for example, Lemesos/Limassol (with a dominance of heathland/shrubs), Tallinn, Trento or Stockholm that are all dominated by forest and woodland. Then, Leipzig and Padova show a very large proportion of croplands, whereas Dublin, but also Utrecht and Glasgow possess a lot of grasslands within their boundaries. Tallinn and Antwerp are the only cities that show visible wetlands, whereas Stockholm possesses the highest share of rivers and lakes.

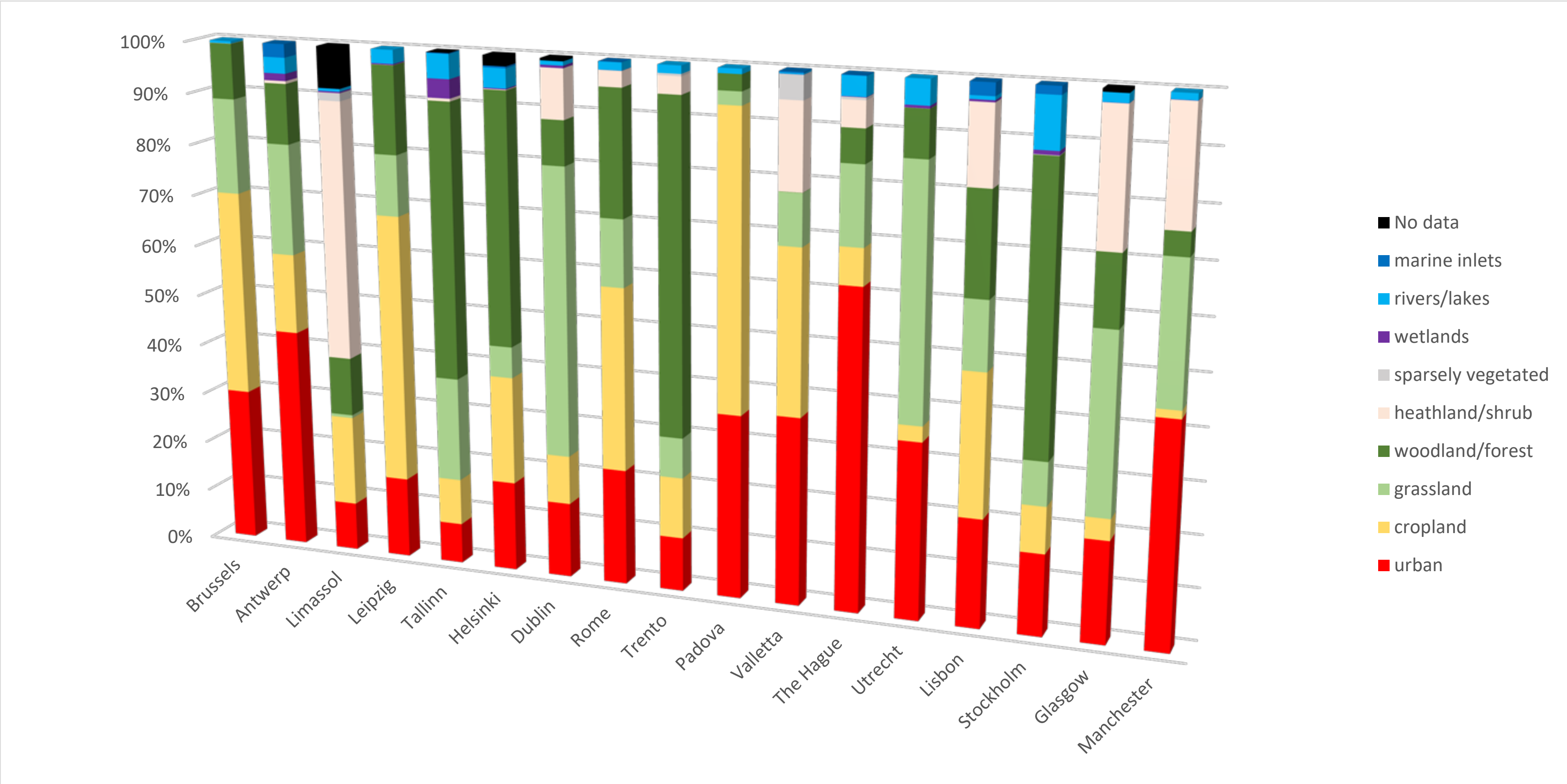


Figure 2-2: Stacked bar chart of the distribution of land cover classes within the FUAs

3 Conclusions and lessons learnt

The European Urban Biodiversity Index provides aggregated information on structural components of biodiversity in urban and peri –urban areas. Although the goal of the index is to address biodiversity in urban areas, high scores for the index are predominantly only achieved within more (semi-) natural areas. This is also due to the fact that Urban Atlas cities often have a relatively large Functional Urban Area assigned to it that extends into the surrounding rural landscape. Half of the selected input indicators that form the composite index specify biophysical landscape aspects.

Biodiversity in terms of species distribution within urban areas can only be depicted at a limited scale with the present index. This circumstance is mainly due to the coarse resolution of the input datasets which do not facilitate an assessment of parameters which characterise biodiversity beyond the characteristics listed under Table 1-1. Therefore, the results for the different indicators are largely dependent on the landscape composition of the FUA which in turn follows a specific methodology driven by population centres and commuting zones. What landscapes are included within a FUA can differ substantially between countries and even neighbouring regions.

The absence of comparable datasets which highlight biodiversity components such as species and habitat distribution continues to be a major challenge for any undertaking of an assessment of biodiversity in (multiple) cities. City planners are in need of very detailed information on species distribution in order to tailor conservation management to local requirements. The current index utilizes the Art.12 and Art.17 species and habitat distribution data to address the aspect of species richness within cities. Species and habitats within these databases were assigned to a range of different MAES habitat types which are cross-linked with Urban Atlas classes in order to achieve a simple downscaling of the data. These datasets therefore provide a rough indication of presence/absence of species and habitats within a given area.

The integration of the species and habitat distribution data into the 10ha hexagonal grid can often be seen as artefact in the mappings where the hexagonal grid shows visible traces of the 10km grid at which Art. 12 and Art.17 data are reported. The removal of these artefacts, e.g. by filtering or smoothing techniques, would be an element of future work on this index. Highly resolved data concerning biodiversity in cities has yet to be compiled at the required spatial resolution for urban assessments. The absence of required species data therefore justifies the use of these coarse datasets to at least be able to address the component of species richness within the index.

Nevertheless, the index should for the moment mainly be seen as a self-assessment tool with which city stakeholders can evaluate the situation within their area of policy- or decision-making authority. Applying the Jenks algorithm normalises the data within their value range, but does as such not give the minimum and maximum values between which the stretch has been performed. Therefore, the ranges of values within categories are not the same and categories cannot be compared among cities. Secondly, the total reference area is not given, i.e. how many of the hexagonal cells are taken into account. Therefore, a certain percentage value in one city does not necessarily equal to the same value in another city. For a rough comparison, these computational conditions can be accepted and cities could still look at other cities how they score and why. But quantitative, statistical analyses should not be undertaken. Improving this and making the EUBI fully comparative would be another pathway for future work.

Without a time series the present exercise can only provide an overview of the current state. Upcoming updates of the Copernicus datasets used as input for the EUBI could facilitate the production of change layers which would then allow for an assessment of temporal developments of the index for the targeted cities.

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Annex

Table 3-1 List of cities for which the EUBI was produced

FUA Code	Name
BE001L2	Brussels
BE002L2	Antwerpen
CY501L1	Lemesos
DE008L2	Leipzig
EE001L1	Tallinn
FI001L2	Helsinki
IE001L1	Dublin
IT001L2	Roma
IT014L2	Trento
IT028L2	Padova
MT001L1	Valletta
NL001L2	Gravenhage
NL004L2	Utrecht
PT001L2	Lisboa
SE001L1	Stockholm
UK004L1	Glasgow
UK008L2	Manchester

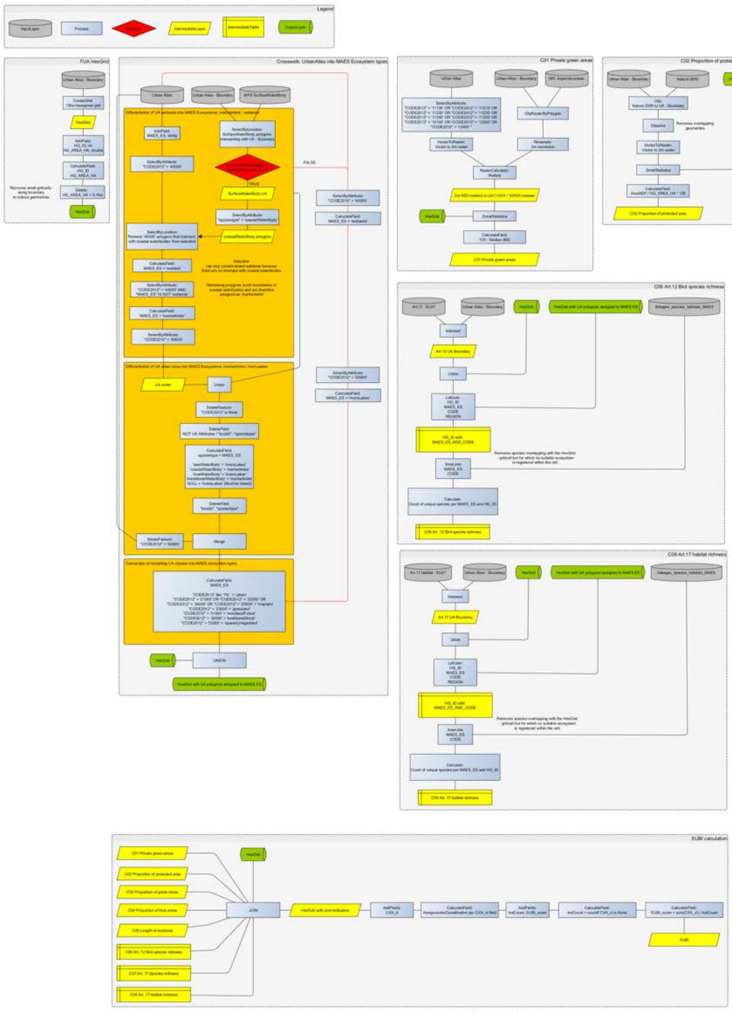

Figure 3-1 Detailed processing workflow to derive the EUBI from the input datasets. Most steps are conducted using SQL / python scripting using open-source repositories and PostGIS and QGIS (3.4)