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# The European Urban Biodiversity Index (EUBI): a composite indicator for biodiversity in cities

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# List of Abbreviations

| | |
|---|---|
| CBI | City Biodiversity Index |
| EUBI | European Urban Biodiversity Index |
| N2K | Natura 2000 |
| UA | Urban Atlas |
| WFD | Water Framework Directive |

# 1 Introduction

Over 75% of the EU population currently resides in or lives in close proximity to cities (World Bank, 2015), with foreseen increases by 2050 (Eurostat, 2016b). A frequent consequence of this ongoing urbanization process is the densification and expansion of urban areas, resulting in the loss of urban green spaces and biodiversity and subsequent decreases in human well-being and health, amongst other societal repercussions (Regional Public Health, 2010). Given these potential negative impacts, there is growing interest in assessing urban biodiversity status as a means to identify trends and critical shortcomings and therewith create a robust foundation for mandating conservation measures to protect biodiversity and ensure the continued supply of integral ecosystem services. However, the urban environment, human well-being and the health, and the diversity of the species and habitats contained therein are part of a complex and intricate system and are thus challenging to evaluate. While some indicator frameworks look at specific aspects of local development and a restricted set of environmental parameters, there is no standardised methodology or dataset existing to date for conducting an urban biodiversity assessment.

In response to this gap, the present report continues the effort to elaborate a test composite index for biodiversity in urban environments, first proposed in 2017[1]. This entails further investigating the potential of integrating Copernicus layers and biodiversity-related European datasets as well as additional city-specific data as indicator sources for urban assessments. Ultimately, the aim is to develop a conceptual methodology and derive indicators for a European Urban Biodiversity Index (EUBI), underscored by test-case examples. The Index will be based primarily on these available datasets and build on existing urban biodiversity frameworks as a basis for conceptualising the evaluation of ecosystem condition. This pan-European assessment framework could create synergies with the ongoing MAES activities in the field of ecosystem condition assessment as well as the EnRoute (Enhancing Resilience of Urban Ecosystems through Green Infrastructure) project, and will ultimately allow cities to gain information on biodiversity development in a European context using easily accessible and free datasets.

# 2 The European Urban Biodiversity Index (EUBI): overall approach

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* p.25 Maes et al., (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.

[1] Rf, K. and al., 2017, Integration of biodiversity data in urban assessments, ETC/BD Working paper N°B/2017 https://bd.eionet.europa.eu/Reports/ETCBDTechnicalWorkingpapers/Biodiversity_in_urban_assessments

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 hold 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 and presents challenges for tailored 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.

## 2.1 Functional Urban Area as basic reporting unit

The most convenient choice for the basic spatial unit of the analysis is given by the Functional Urban Area (FUA). A FUA encompasses the urban city perimeter and its commuting zone (Eurostat, 2016a) and includes all aspects of the urban ecosystem, i.e. built-up grey infrastructure as well as green and blue 'nature-based' infrastructure components. Given the complexity of distinguishing urban from peri- and non-urban areas, using the FUA as basic spatial unit has the advantage that urban population and commuting dynamics are represented in the sampling unit. Furthermore, it is based on a reproducible typology enabling European comparison and is also used within Mapping and Assessment of Ecosystems and their Services (MAES) and related activities. However, it should be noted that due to their focus on population and transit patterns, FUA's may vary considerably in size, shape and population density and distribution.

The Urban Atlas (UA) is a land cover map of all 697 FUA's in Europe and counts 27 individual classes. This atlas provides a good baseline to define these urban components and derive many essential indicators and will serve as a backbone for the index.

## 2.2 Selecting indicators for a dual-index approach

Taking the previously outlined considerations into account, the EUBI aims to capitalise on the potential of the Copernicus products as well as more detailed local datasets from individual urban areas. For this reason, the indicators within the index have been structured into two components:

1. **Core Index** - based on Copernicus products and Art. 12 & 17 data
2. **Local Index -** ancillary indicators depending on availability within each city

Table 2.1 contains an overview of the indicators selected for both components. For the methodology of the different indicators please refer to the chapters: 3.3 and 4.2.

**Table 2.1 Overview of selected indicators for the core and local components of the EUBI**

| Core Index | Local Index |
|---|---|
| C01 Proportion of permeable urban area | L01 Number of native species |
| C02 Proportion of protected area | L02 Proportion of invasive alien species |
| C03 Proportion of green areas | L03 Proportion of Natural Areas in the City |
| C04 Proportion of blue areas | L04 Access to urban green areas |
| C05 Length of ecotones | |
| C06 Art. 12 Species richness | |
| C07 Art. 17 Species richness | |
| C08 Art. 17 Habitat richness | |

The local index is thus a flexible component for which only guidelines will be proposed in the current report. The advantage of separating the index into two components is to enable cities to increase their potential to perform more holistic, low-cost self-assessments regarding biodiversity issues. As some cities are also quite restricted in terms of geographical and environmental factors, future intentions and actions should also be considered as they are the drivers of change. These are best portrayed and outlined by municipal actors as they require more in-depth local knowledge.

## 2.3 Selection of test cities

The proposed dual-index has been tested in four larger European cities. The cities were not selected at random, but rather on the basis of pre-existing engagement and contact with local stakeholders. This experience and potential local knowledge within the consortium outweighed the benefits of a random selection. Furthermore, some cities also participated in the production of the City Biodiversity Index, which follows a similar aim as the present index. Lastly, the cities provide a large geographic spread across Europe including the Baltics, Scandinavia, Western Europe and the Mediterranean. Unlike the 2017 exercise, an update of the methodology now allows coastal cities to be included within the selected sample.

The cities in which the index has been tested include Brussels, Lisbon, Stockholm and Tallinn. These cities, their FUA-code, and related engagements and projects are outlined in Table 2.2 below.

**Table 2.2 Overview of test cities and related engagements/projects**

| City Name | FUA-Code | Related engagements/projects |
|---|---|---|
| Brussels | BE001l | City Biodiversity Index |
| Lisbon | PT001l | City Biodiversity Index, European Green Capital Award |
| Stockholm | SE001 | City Biodiversity Index, European Green Capital Award, ENABLE project |
| Tallinn | EE001l | City Biodiversity Index, European Green Capital Award |

## 2.4 Data collection

The datasets listed in Table 2.3 were used for the production of the indicators used to compile the core and local index.

**Table 2.3 Data sources used for core and local indicators**

| Dataset | Source / Link |
|---|---|
| **Core indicators** | |
| Urban Atlas 2012 | https://www.eea.europa.eu/data-and-maps/data/urban-atlas |
| Reporting under Art. 12 of the Birds Directive (period 2008 - 2012) - Database | https://www.eea.europa.eu/data-and-maps/data/article-12-database-birds-directive-2009-147-ec |
| Reporting under Art. 12 of the Birds Directive (period 2008 - 2012) – Database – GIS Data | https://www.eea.europa.eu/data-and-maps/data/article-12-database-birds-directive-2009-147-ec#tab-gis-data |
| Reporting under Art. 17 Habitats Directive - Database | https://www.eea.europa.eu/data-and-maps/data/article-17-database-habitats-directive-92-43-eec-1 |
| Reporting under Art. 17 Habitats Directive – GIS Data | https://www.eea.europa.eu/data-and-maps/data/article-17-database-habitats-directive-92-43-eec-1#tab-gis-data |
| WISE WFD reference spatial data sets – Surface Water Body (2016) | https://www.eea.europa.eu/data-and-maps/data/wise-wfd-spatial |
| Imperviousness degree (2012) | https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-imperviousness-2 |
| Natura 2000 End 2016 | https://www.eea.europa.eu/data-and-maps/data/natura-9 |
| Linkages of species and habitat types to MAES ecosystems database (2015) | https://www.eea.europa.eu/data-and-maps/data/linkages-of-species-and-habitat |
| **Local indicators** | |
| Urban Atlas/Access to urban green areas | http://ec.europa.eu/regional_policy/sources/docgener/work/data_wp_01_2016_green_urban_areas.xls |
| City Biodiversity Index (CBI) | https://www.nparks.gov.sg/biodiversity/urban-biodiversity/the-singapore-index-on-cities-biodiversity_ |
| European Capital of Biodiversity | https://www.capital-biodiversity.eu/uploads/media/Indicators_on_urban_biodiversity_-_LIST_-_European_Capitals_of_Biodiversity.pdf |
| European Green Capital Award | http://ec.europa.eu/environment/europeangreencapital/index_en.htm |

There are no comprehensive datasets available for the local indicators (apart from the data on the access to green urban areas). Such data could be retrieved from existing city indexes or local assessments.

# 3 EUBI Core Index

The following section presents the indicators that have been selected to form the core index. 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 10 ha hexagonal grid level for the entire FUA. Although 10ha is still a comparatively coarse scale for urban assessments for which very detailed spatial information, such as the location of individual trees is more desirable. Finer scales increase the volume of data to be processed substantially.

The size of 1ha as reference unit therefore provides a compromise between spatial accuracy and data volume.

## 3.1 General approach

Unlike the previous year in which an index was developed for entire cities, the current approach is spatially explicit, meaning that 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. Thereby, many indicators from the previous activities were also incorporated in the current approach.

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 3.1. Due to the complexity and number of processing steps the detailed processing workflow is provided within the annex (
Figure 8.1).

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 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 CBI, 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 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 the poles to the tropics (Hansen & DiCastri, 2012). Local geographic and climatic factors may also play a key role for species richness encountered within city boundaries. A Northern Scandinavian city might therefore feature a lower species richness than a Southern Mediterranean despite investing more effort into species protection.
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.

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.

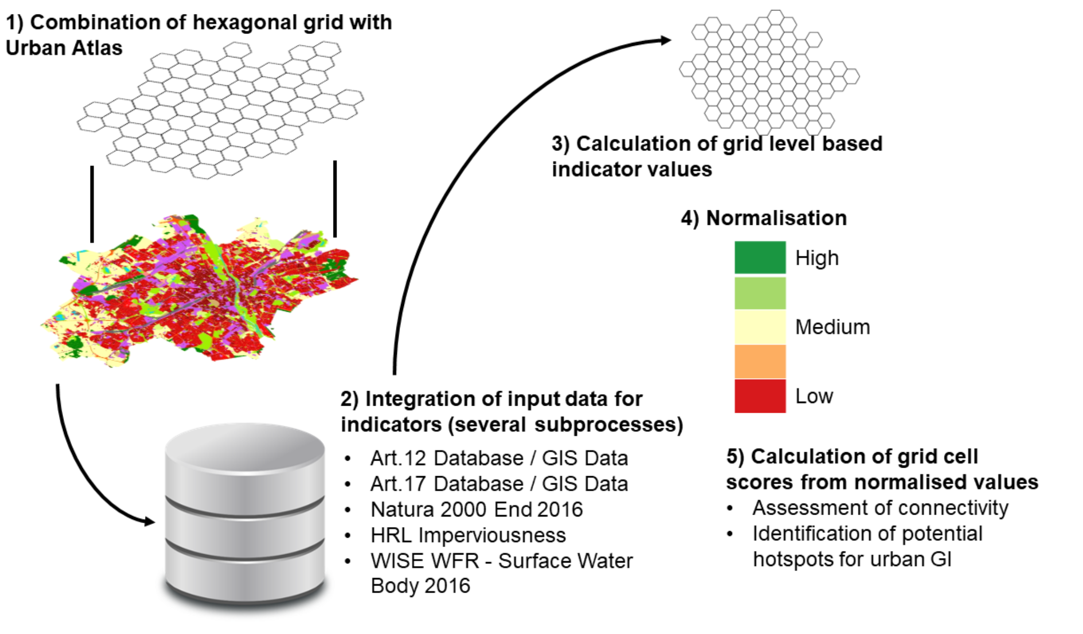


**Figure 3.1 General overview of data processing steps to derive the EUBI**

## 3.2 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.

Due to the diversity and amount of different species involved the second approach is used to derive species information.

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. A brief description of the workflow is given within Figure 3.1.

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.

Table 3.1 identifies 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 includes 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[1]. The designated class "agriMosaic" within the species-habitat linkages database (Roscher et al., 2015), could not be directly utilized for mixed classes due to thematic overlaps with many classes.

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.

[1] A similar approach is also applied within the MAES –Corine Land Cover (CLC) crosswalk. See Annex 2 Maes et al., (2013).

**Table 3.1 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**

| | | 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

## 3.3 Indicator methodology

In this chapter, the individual indicators are presented along with a short rationale and production methodology. As a description of individual steps is better explained visually, the full processing workflow diagram is included within the annex (

Figure 8.1).

Table 3.2 shows for which component or characteristic of biodiversity the core indicators provide information. Table 3.3 includes descriptions of each of the selected core indicators.

**Table 3.2 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 gridcell |
| | 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 3.3 Description of core index indicators**

| **C01 Permeable urban area** | | |
|---|---|---|
| **Unit** | Median % | 0-100 |
| **Description** | Degree of non-sealed area within mapped UA Urban fabric and industrial, commercial and public class (11X, 121, 123, 124) polygons per grid cell. | |
| **Rationale** | 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 even invasive species they can are cornerstones of green infrastructure in cities. | |

| | |
|---|---|
| | Non-sealed area is also important in terms of flood management for urban environments as it acts as buffer in intensive precipitation events. |
| **Methodology** | 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. |
| **Data source** | Urban Atlas (2012), Imperviousness degree (2012) |

| **C02 Proportion of protected areas** | | |
|---|---|---|
| **Unit** | % | 0-100 |
| **Description** | Proportion of FUA area belonging to Natura 2000 network per grid cell. | |
| **Rationale** | 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. | |
| **Methodology** | 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 | |
| **Data source** | Urban Atlas (2012), Natura 2000 End 2016 | |

| **C03 Proportion of green areas** | | |
|---|---|---|
| **Label** | Prop. Green | |
| **Unit / Range** | % | 0-100 |
| **Description** | Proportion of non-sealed terrestrial UA classes within grid cell | |
| **Rationale** | Provides an overview of FUA landscape structure. | |
| **Methodology** | Proportion is calculated on the basis of below listed UA 2012 classes divided by total area including no-data areas:<br>• 14100, 14200<br>• 21000, 22000, 23000, 24000, 25000, 25400<br>• 31000, 32000,33000<br>• 40000 | |
| **Data source** | Urban Atlas (2012) | |

| **C04 Proportion of blue areas** | | |
|---|---|---|
| **Label** | Prop. Blue | |
| **Unit / Range** | % | 0-100 |
| **Description** | Proportion of aquatic UA class within per gridcell | |
| **Rationale** | Provides insights into FUA landscape structure. | |
| **Methodology** | Proportion is calculated on the basis of UA 2012 class 50000 divided by total area including no-data areas. | |
| **Data source** | Urban Atlas (2012) | |

| C05 Length of Ecotones | | |
|---|---|---|
| **Label** | Ecotone length | |
| **Unit / Range** | $km^2$ / gridcell | >0 |
| **Description** | Length of transitions between agricultural and forest classes. | |
| **Rationale** | 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). | |
| **Methodology** | 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. | |
| **Data source** | Urban Atlas (2012) | |

| C06 Art. 12 Bird species richness | | |
|---|---|---|
| **Label** | Bird species richness | |
| **Unit / Range** | No. species per hexagonal grid cell | >0 |
| **Description** | Count of bird species per hexagonal grid cell, derived from modified Art.12 dataset. | |
| **Rationale** | Species richness is a crucial component of biodiversity and species density describes how many bird species are encountered within the FUA. | |
| **Methodology** | 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”.<br>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.<br>The data is imported into a database system (MS-SQL) for further processing and cleaning operation.<br>Art. 12 hex-grid data are assigned towards specific MAES habitats using the species-habitat linkages database.<br>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. | |
| **Data source** | 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 Art. 17 Species richness | | |
|---|---|---|
| **Label** | Species richness of Art. 17 species | |
| **Unit / Range** | No. species per hexagonal grid cell | >0 |
| **Description** | Count of Art. 17 species per hexagonal grid cell, derived from modified Art. 17 dataset. | |
| **Rationale** | Species richness is a crucial component of biodiversity and species density describes how many species are encountered within the FUA. | |
| **Methodology** | 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”.<br>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.<br>The data is imported into a database system (MS-SQL) for further processing and cleaning operation.<br>Art. 17 hex-grid data are assigned towards specific MAES habitats using the species-habitat linkages database.<br>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. |
| **Data source** | 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 Art 17 Habitat richness** | | |
|---|---|---|
| **Label** | Bird species density | |
| **Unit / Range** | No. species per hexagonal grid cell | >0 |
| **Description** | Count of Art. 17 habitat types per hexagonal grid cell, derived from modified Art. 17 dataset. | |
| **Rationale** | 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. | |
| **Methodology** | 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”.<br>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.<br>The data is imported into a database system (MS-SQL) for further processing and cleaning operation.<br>Art. 17 hex-grid data are assigned towards specific MAES habitats using the species-habitat linkages database.<br>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 habitats which may cover a grid cell, but which are not assigned to a MAES habitat within the cell and thus are unlikely to occur at that location. | |
| **Data source** | Urban Atlas (2012), Art. 17, WISE WFD reference spatial data sets – Surface Water Body (2016), Linkages of species and habitat types to MAES ecosystems | |

# 4 EUBI Local Index

The following section presents the indicators that have been selected to form the local index. Justifications are provided together with a short description and explanation on the processing steps taken in the production of the data. The local indicators allow to give a picture of biodiversity in the city that complements the core index values with different types of information. It should be noted, however, that while these detailed indicators would be optional for cities wishing to complete the EUBI, their inclusion would provide a high added value and a far more robust snapshot of urban biodiversity status than that provided only by the Core Index.

## 4.1 General approach

Data for the local indicators is gathered primarily from existing datasets. These include the City Biodiversity Index/Singapore Index (CBI), Urban Atlas data, European Capitals of Biodiversity, and the European Green Capital Awards. With the exception of the Urban Atlas, these datasets represent one-time measurements and are not datasets from regular monitoring. Cities who have not yet participated in the CBI or one of the above mentioned competitions can use the guidelines from either to guide data collection (see Table 2.3 for links).

For the four test cities, data was taken from existing CBI Factsheets and Urban Atlas derived data. A key challenge in using the data to complement an assessment of the core indicators is the inconsistency in methodologies and definitions. For each of the local indicators, each city may use a slightly different methodology, so comparisons of results between cities should be interpreted with caution. Additionally, it is not always clear from existing data which exact urban area definition each city uses in the data sourced for the local indicators. The values for the local indicators may therefore not refer to the same spatial area as the core indicators.

## 4.2 Indicator methodology

For the indicators listed, the information should be applicable/current at the time of evaluation or - as relevant - to the year of submission as a whole.

The following table presents a list of the local indicators that could serve to compliment the core index.

**Table 4.1 Description of local indicators to complement core index**

| **L01 Native species** | |
|---|---|
| **Unit** | No. of species |
| **Description** | The total number of native species within FUA. This can compromise one or more of the following taxonomic groups (it should be specified which groups are covered):<br>a. Plants<br>b. Birds<br>c. Butterflies<br>d. Invertebrates<br>e. Mammals |
| **Rationale** | Provides an overview of the species diversity, with distinctions able to be made across taxonomic groups if multiple groups can be covered. Moreover, some these species can also serve as an indirect “indicator” for the habitat quality. |

| | |
|---|---|
| **Methodology** | The sum for each taxonomic group is to be provided; additionally, it should be stated whether this is the exact number, an estimation or – if is the case – not available. |
| **Data source and linkages** | CBI Indicator 3; European Capital of Biodiversity Indicators 4-9; Federal Capital of Biodiversity Indicators 2-7 |

| **L02 Invasive alien species** | |
|---|---|
| **Unit** | % |
| **Description** | Proportion of invasive alien species within FUA. |
| **Rationale** | Provides an overview of the prevalence of potentially harmful species within the FUA. |
| **Methodology** | Proportion is calculated on the basis of the number of invasive alien species divided by the total number of species (i.e. the number of invasive alien species plus the total number of native species identified in Indicator 01) |
| **Data source and linkages** | CBI Indicator 10; European Capital of Biodiversity Indicator 10 |

| **L03 Proportion of Natural Areas in the City** | |
|---|---|
| **Unit** | ha and % |
| **Description** | Proportion of natural areas in the total city area<br>"Natural areas comprise predominantly native species and natural ecosystems, which are not, or no longer, or only slightly influenced by human actions, except where such actions are intended to conserve, enhance or restore native biodiversity**."** (Chan et al. 2014) |
| **Rationale** | "Natural ecosystems harbour more species than disturbed or man-made landscapes, hence, the higher the percentage of natural areas compared to that of the total city area gives a proxy indication of the amount of biodiversity there" (Chan et al. 2014) |
| **Methodology** | Proportion is calculated on the basis of the total area of natural, restored and naturalised Areas (in ha) divided by the total area of city |
| **Data source and linkages** | CBI Indicator 1, European Capital of Biodiversity Indicator 1 |

| **L04 Access to green urban areas** | |
|---|---|
| **Unit** | % |
| **Description** | Percentage of population with green urban areas in their neighbourhood (i.e. that can be reached within 10 min. walking distance). |
| **Rationale** | Provides an overview of the population's access to biodiversity in the form of green areas within the city. |
| **Methodology** | Local proximity analysis based in Urban Atlas polygons and total residential population estimates; For further details please refer to Poelman, (2018). The value listed here is the inverse of the " Proportion of population without access to green urban areas in the neighborhood". |
| **Data source and linkages** | Urban Atlas; European Capital of Biodiversity Indicator 14 |

# 5 Test results: Core and local indexes

The following section details the results of the core and local indexes for the fours test cities.

The following maps show the calculated EUBI for the selected test cities. For each city, a graduated colour map of the EUBI score grid is provided along with the Urban Atlas FUA classified into MAES habitats. The MAES habitat map is provided for an improved understanding and cross-checking of the results with local land cover. EUBI hotspots are a subset of top-tier grid cells from the EUBI score grid (i.e. grid cells that qualify as class 5 within a Jenks classification of the EUBI-Score). The colourisation indicates the amount of neighbouring hexagonal grid cells and thus visualizes the spatial connectivity of grid cells with high relative biodiversity value. Please refer to chapter 3.1 for more details about the methodological approach followed.

Tables including the local results are subsequently presented for each city. Results for indicators L01-L03 are taken from the CBI if not indicated otherwise. L04 is calculated from data developed by Poelman (2018). Where possible, a comparison is made between local and core results and between cities.

## 5.1 BE001l – Brussels

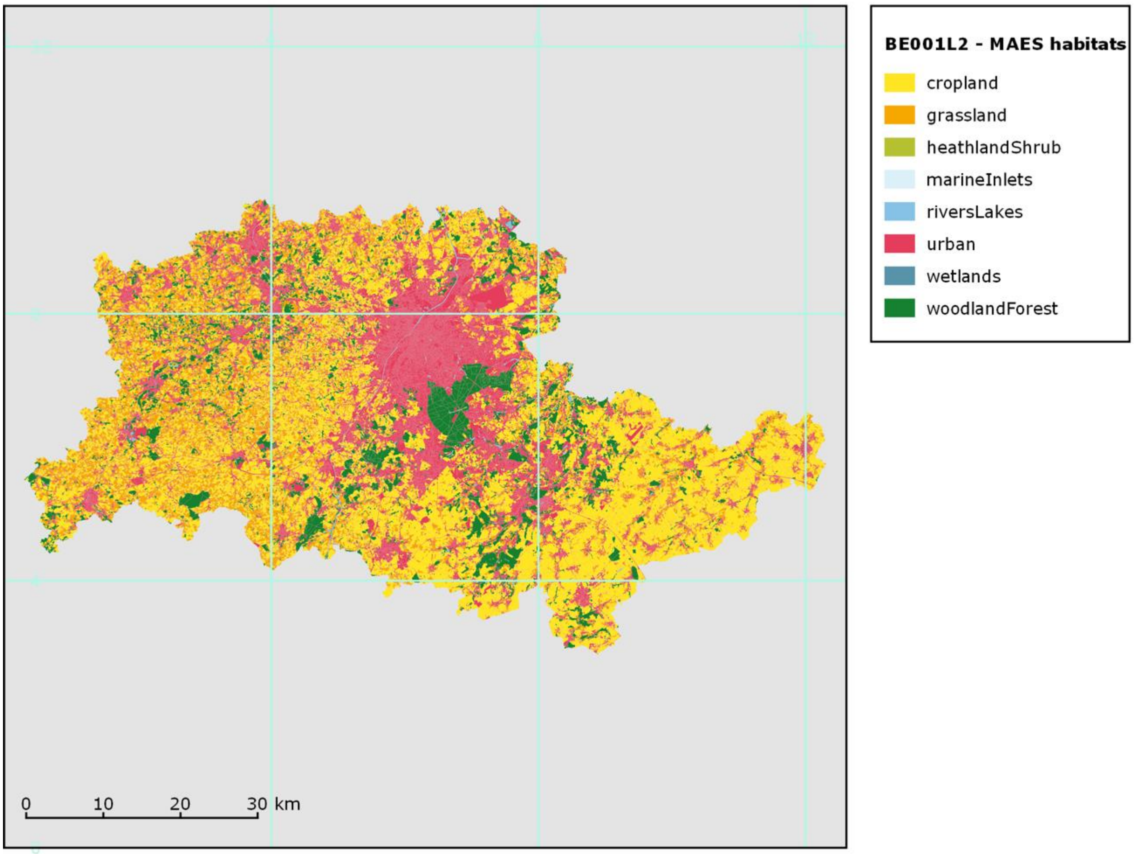


**Figure 5.1 Urban Atlas converted into MAES habitats using the legend crosswalk portrayed in Table 3.1**

The Brussels FUA is highly urbanised and characterised by a comparatively large proportion of sealed area. The more rural areas are dominated by cropland. Whereas in the south-east cropland occurs in larger patches this is not the case in the Northern section, where small urban areas sprawl into the agricultural landscape. Forested areas occur in larger patches towards the south of the central city. Aquatic habitats are quite sparse.

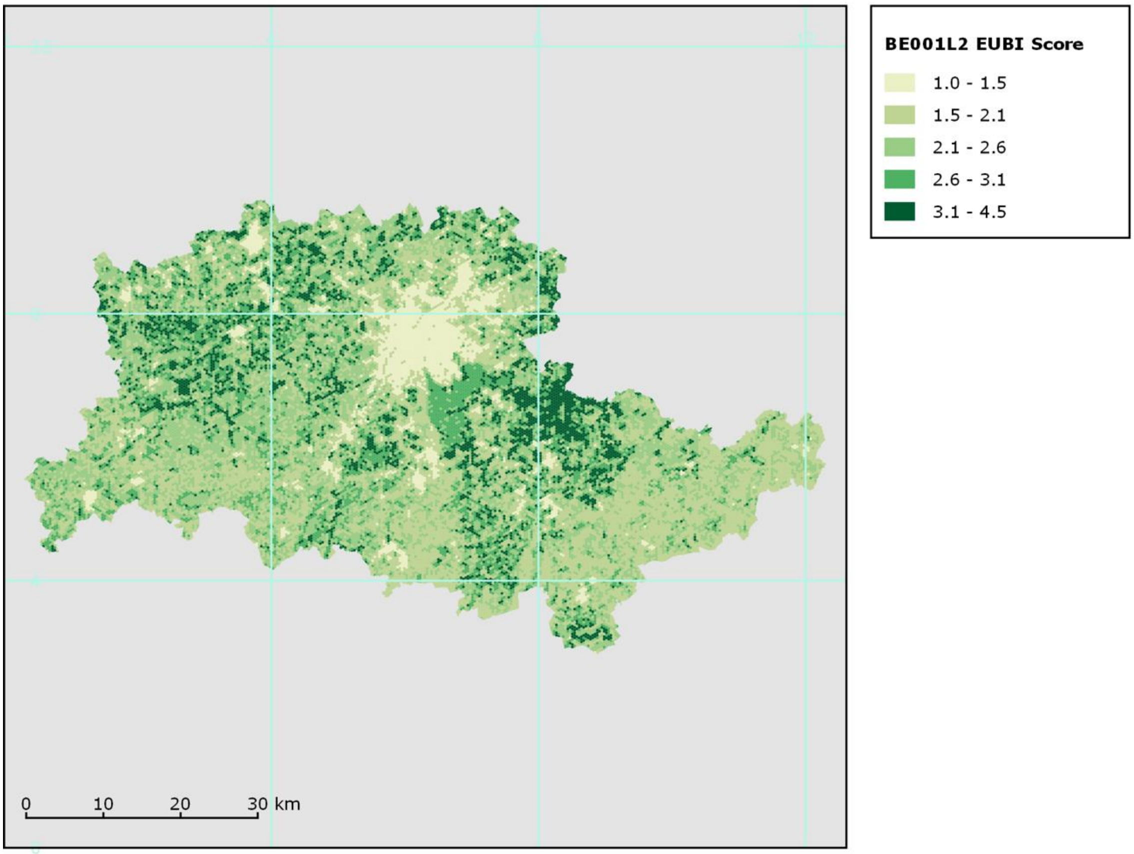


**Figure 5.2 Representation of the calculated EUBI Score based on a hexagonal grid. The score integrates the normalized value ranges of all eight core indicators and is classified into five classes (1-5) using a weighted average. High scores correspond to positive indicator performance**

In general, it is of little surprise that most of the central city area features the smallest score values for the EUBI. Towards the fringe of the city there is an apparent gradient towards higher score values. Within the north east the index increases indicating both a more diverse landscape structure as well as higher overall indicator performance.

Most of the large forest towards the south of the city centre is not included within the top tier category. However, those areas in the vicinity of this patch that feature a mix of landscapes achieve higher scores. This corresponds to the fact that a range of landscape diversity indicators are included within the index.

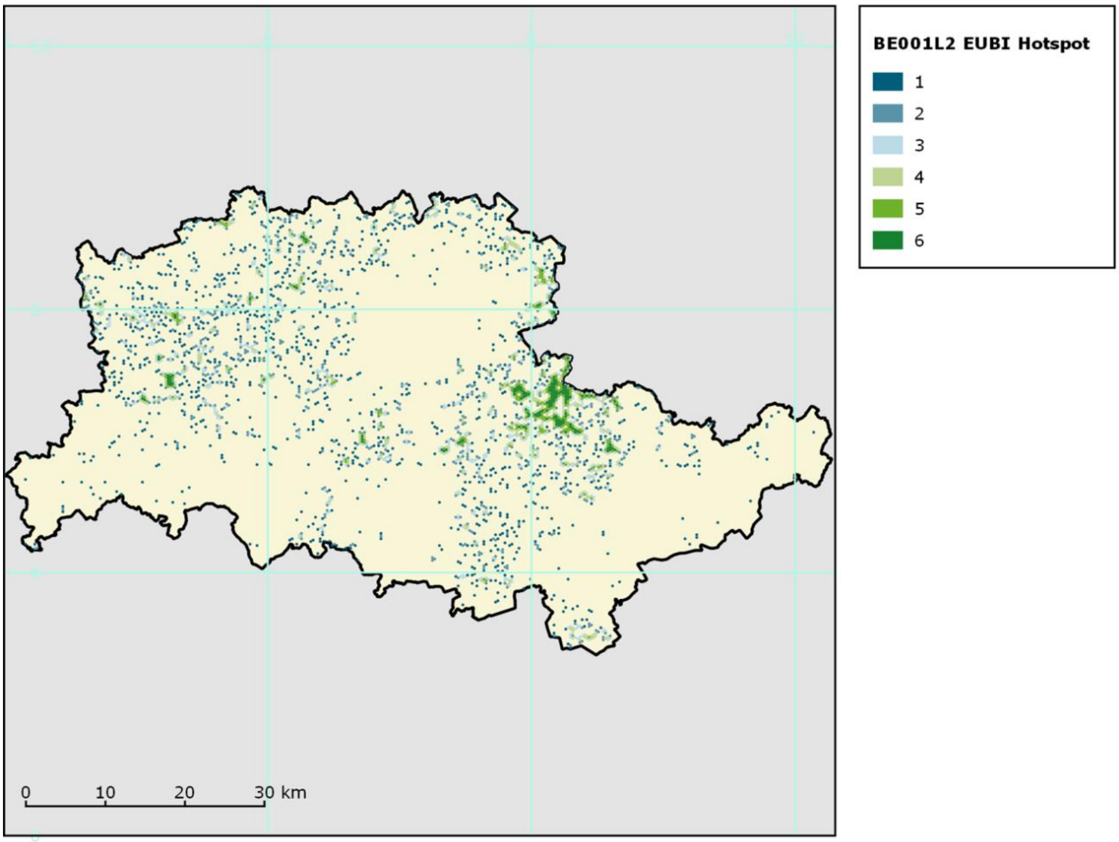


**Figure 5.3 EUBI Hotspots are a subset of EUBI score gridcells of the highest tier grid cells defined by a 5 class - natural breaks clustering approach. The map shows these gridcells separated into 6 classes according to their count of neighbouring hexagonal (max. 6) grid cells**

The hotspot map shows different clustering patterns for the FUA. Larger patches of connected top-tier grid cells are only found in the central eastern area south-east of the city. This area south of the city of Leuven partly corresponds to a Natura 2000 site, i.e. the Dijle, Laan and Ijse valleys (BE2400011)[1].

Within the north a network of smaller patches is apparent. Interestingly, no hotspots can be identified for large sections within the Southern areas. This cannot be explained by the habitat structure as this is mostly similar in these areas. There is an apparent lack of Natura 2000 sites from Liege over Namur towards Tournai which corresponds with the observation of low natural value.

**Table 5.1 Local index results for Brussels**

| **Local Index** | **Brussels** |
|---|---|
| L01 Number of native species | 2,115 bird species (CBI) |
| L02 Proportion of invasive alien species | 4.35% (CBI) |
| L03 Proportion of Natural Areas in the City | 3,308ha of natural areas, covering 20.4% of the total city area (CBI) |
| L04 Access to urban green areas | 97% of population |

[1] http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=BE2400011

The local index results add complementary detail to the core EUBI scores for Brussels. Compared to other cities in the CBI, Brussels has an unusually high native bird biodiversity.

## 5.2 PT001l – Lisbon

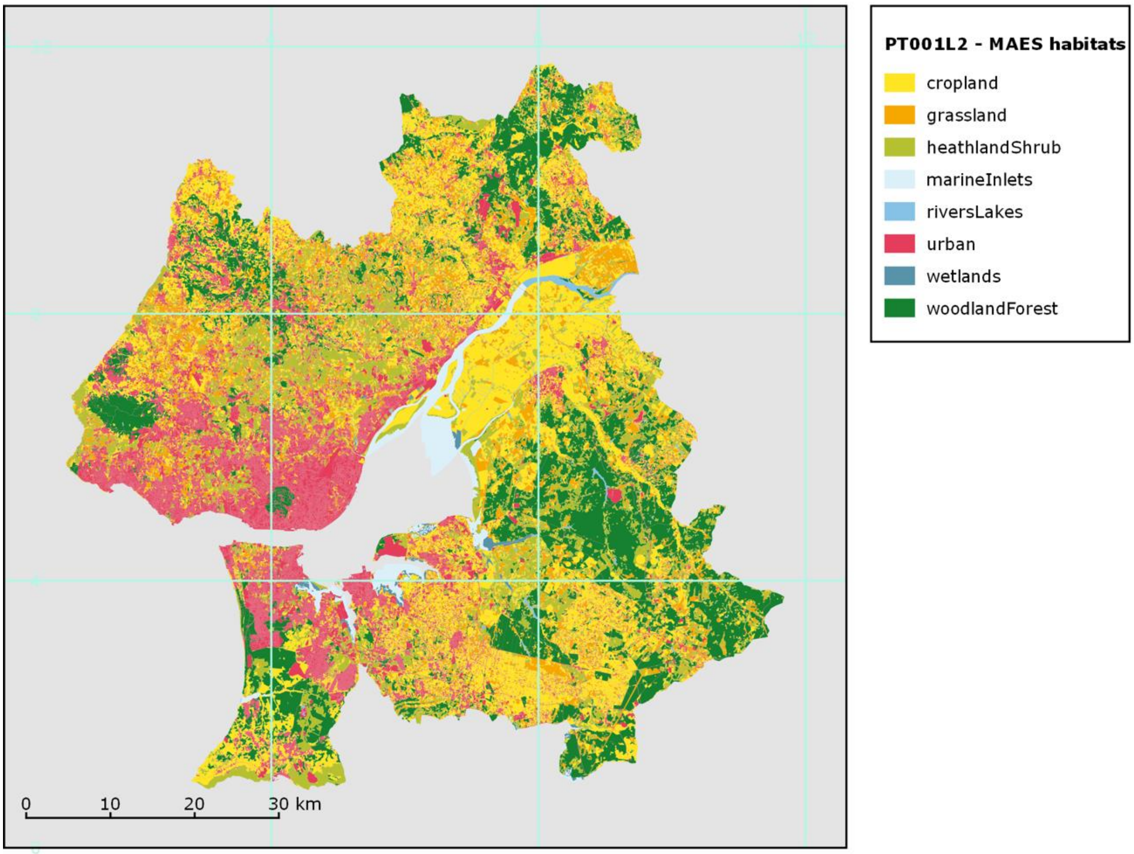


**Figure 5.4 Urban Atlas converted into MAES habitats using the legend crosswalk portrayed in Table 3.1**

Lisbon is highly urbanised around the mouth of the river Tejo, towards the sea and along the river banks within the estuary (in particular the northern banks). On the other hand, the south-eastern region is largely dominated by croplands (large proportions of which are rice cultivations, especially south of the river before it opens into the estuary) and forests and woodlands with some grasslands. Dissection and fragmentation of the landscape is much less pronounced in that region. Also, aquatic ecosystems are sparse on the maps; however, the entire estuary ads well as the Atlantic Ocean are not represented on the maps, but exert a large influence on the whole FUA.

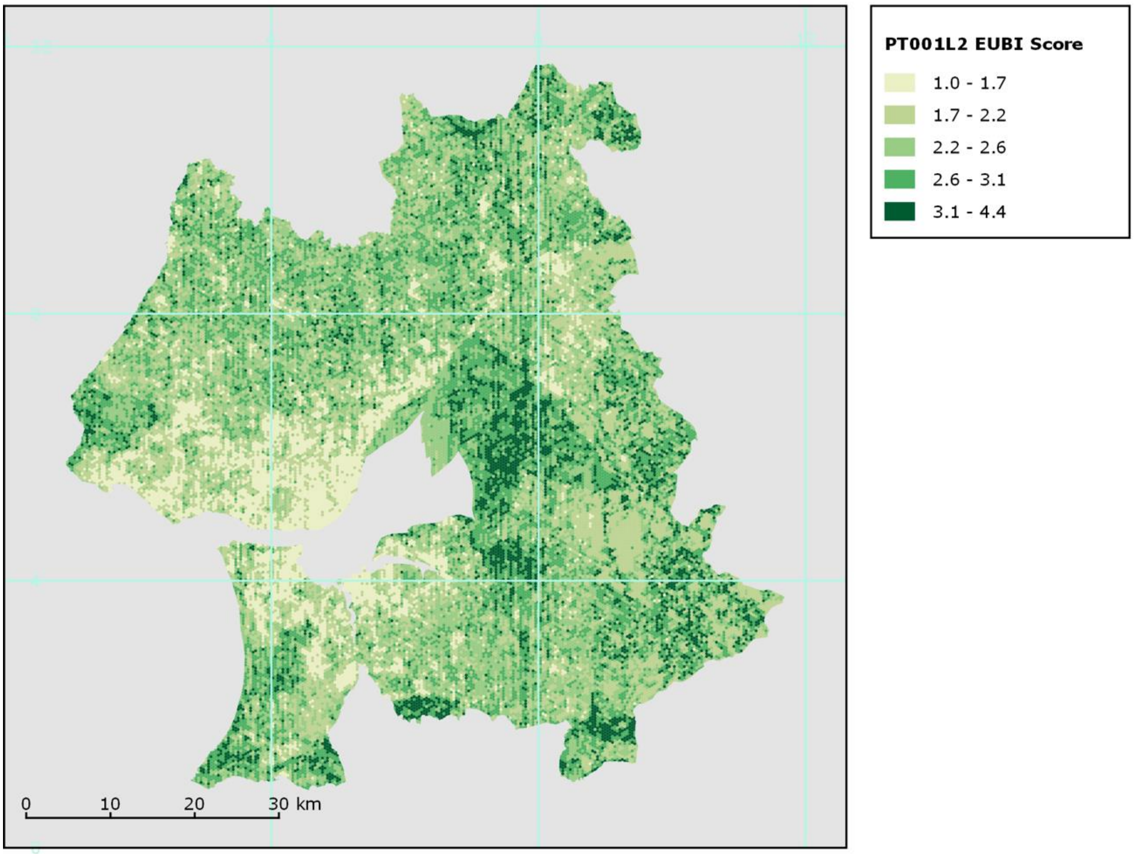


**Figure 5.5 Representation of the calculated EUBI Score based on a hexagonal grid. The score integrates the normalized value ranges of all eight core indicators and is classified into five classes (1-5) using a weighted average. High scores correspond to positive indicator performance**

It becomes directly obvious that the urban areas possess to a large extent low EUBI scores. But unlike Brussels, these areas also contain patches with intermediate values, mostly caused by large inner city green areas (such as the Monsanto parc). Another region close to the city is the Natural Park Sintra-Cascais, located on the western edge of the FUA. In general, a distribution of high scores throughout entire FUA can be observed. Inlets and river mouths have higher biodiversity than surrounding urban area

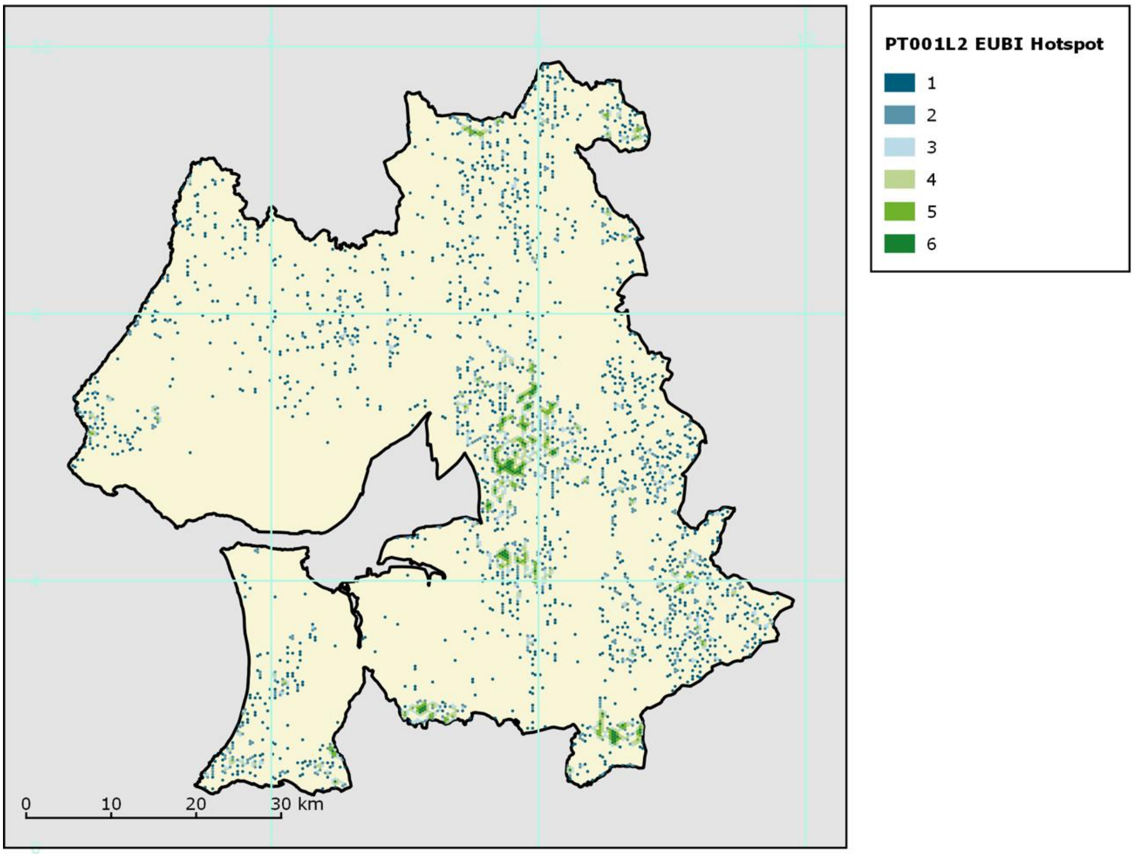


**Figure 5.6 EUBI Hotspots are a subset of EUBI score gridcells of the highest tier grid cells defined by a 5 class - natural breaks clustering approach. The map shows these gridcells separated into 6 classes according to their count of neighbouring hexagonal (max. 6) grid cells**

Interestingly, hotspots are only located in a few places, the largest east of the estuary. This region is characterised by a mixture of (degraded) forest and agriculture (both pasture and cropland). When forests are associated with pasture land, the landscape is called montado, the Portuguese counterpart of the Spanish dehesas (agro-forestry). Because of its diverse landscape elements, it is assumed that diverse habitat structures acting as hubs for biodiversity cause such large number of connections.

**Table 5.2 Local index results for Lisbon**

| Local Index | Lisbon |
|---|---|
| L01 Number of native species | 76 bird species (CBI) |
| L02 Proportion of invasive alien species | 32 invasive alien plant species; proportion of invasive alien species to native species is 9% (CBI) |
| L03 Proportion of Natural Areas in the City | 1857ha of natural areas, covering about 22% of the total land area. There is in addition 1,512ha of green spaces, parks and gardens (CBI) |
| L04 Access to urban green areas | 75.9% of population |

Given Lisbon's high percentage of natural areas, it is surprising that the percentage of the population with access to urban green areas is significantly lower than the other cities, especially when compared to the local indicator results for the other cities. This might be explained by different reference areas used for the EUBI (FUA) and CBI (Administrative boundaries).

## 5.3 SE001l – Stockholm

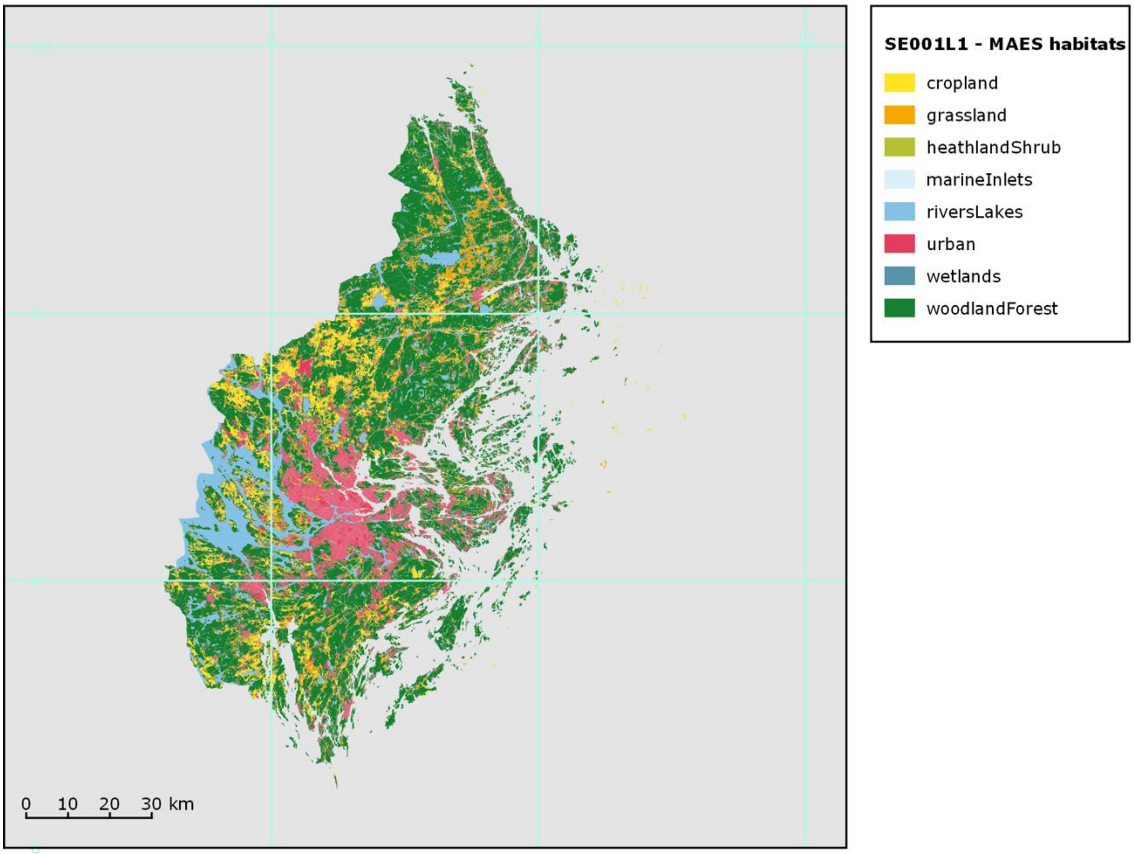


**Figure 5.7 Urban Atlas converted into MAES habitats using the legend crosswalk portrayed in Table 3.1**

The landscape in the Stockholm FUA is much less diverse than the ones in the Brussels and Lisbon FUAs. Urban, forest and rivers and lakes dominate with some crop- and grassland interspersed in the southern and northern parts of the region. Presumably, this low diversity also impacts the EUBI scores that show fewer areas with high scores than for Brussels and Lisbon. Moreover, the patches with high scores are less contiguous and therefore also less connected. This is clearly visible on the maps of the hotspots where only very few clusters of often less than four neighbouring cells can be detected.

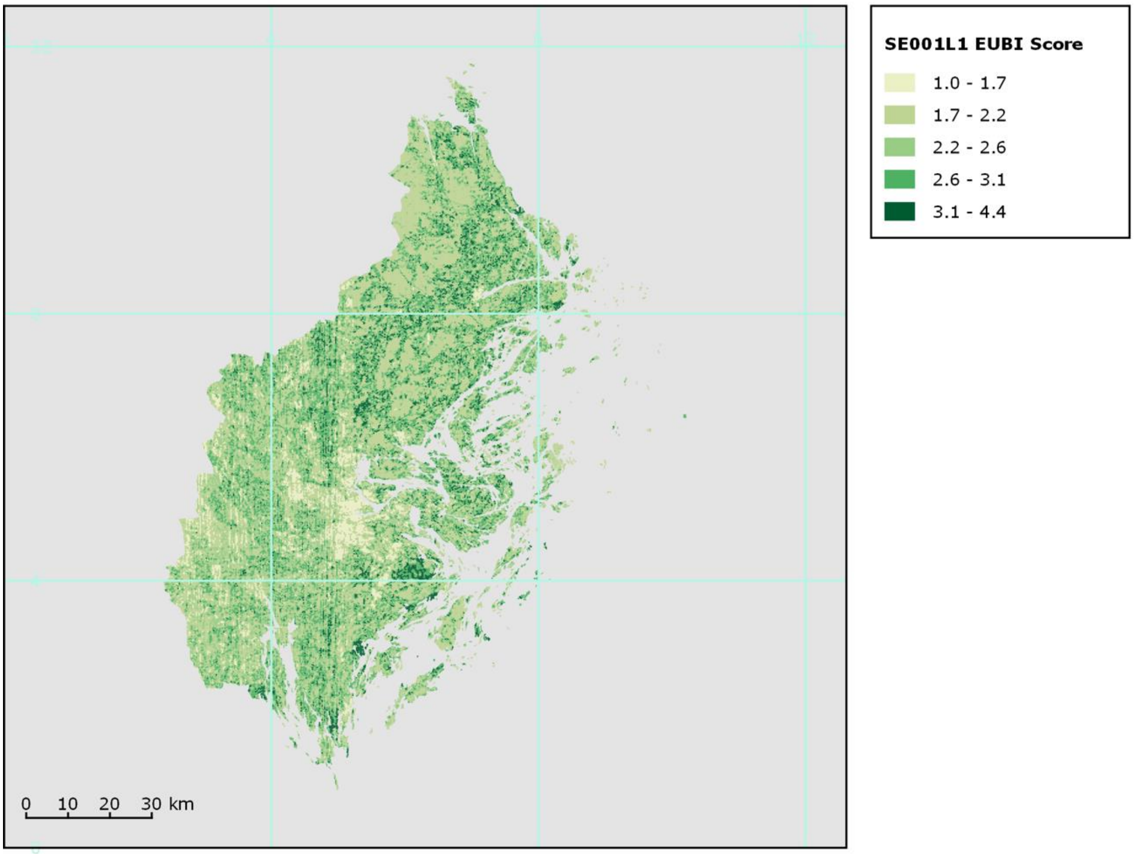


**Figure 5.8 Representation of the calculated EUBI Score based on a hexagonal grid. The score integrates the normalized value ranges of all eight core indicators and is classified into five classes (1-5) using a weighted average. High scores correspond to positive indicator performance**

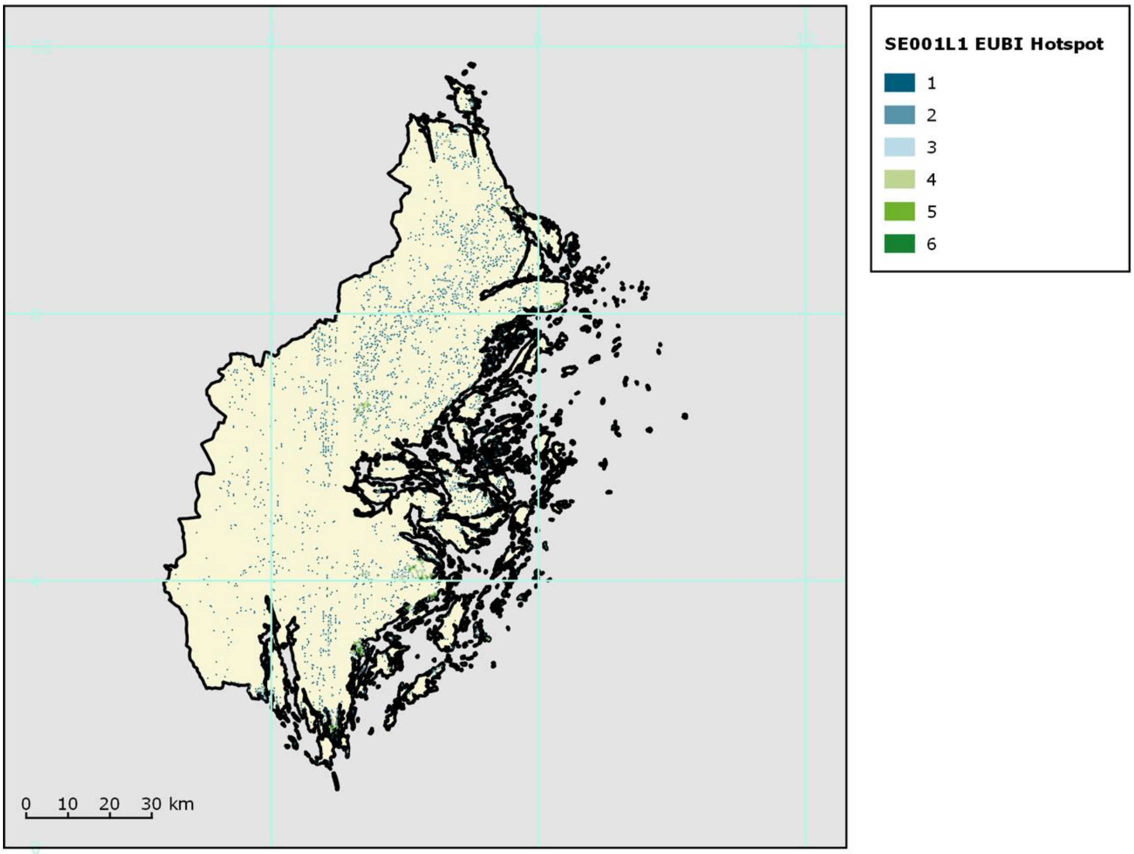


**Figure 5.9** **EUBI Hotspots are a subset of EUBI score gridcells of the highest tier grid cells defined by a 5 class - natural breaks clustering approach. The map shows these gridcells separated into 6 classes according to their count of neighbouring hexagonal (max. 6) grid cells**

**Table 5.3** **Local index results for Stockholm**

| **Local Index** | **Stockholm** |
|---|---|
| L01 Number of native species | 110 bird species (CBI) |
| L02 Proportion of invasive alien species | - |
| L03 Proportion of Natural Areas in the City | 25.5% of total city area[1] |
| L04 Access to urban green areas | 99.6% of population |

[1] Data cited from estimation in ESA DUE Innovator III Earth Observation in support of City Biodiversity Index Project deliverable D2.1: Product Delivery Documentation Stockholm. (Internal Documentation).

## 5.4 EE001L – Tallinn

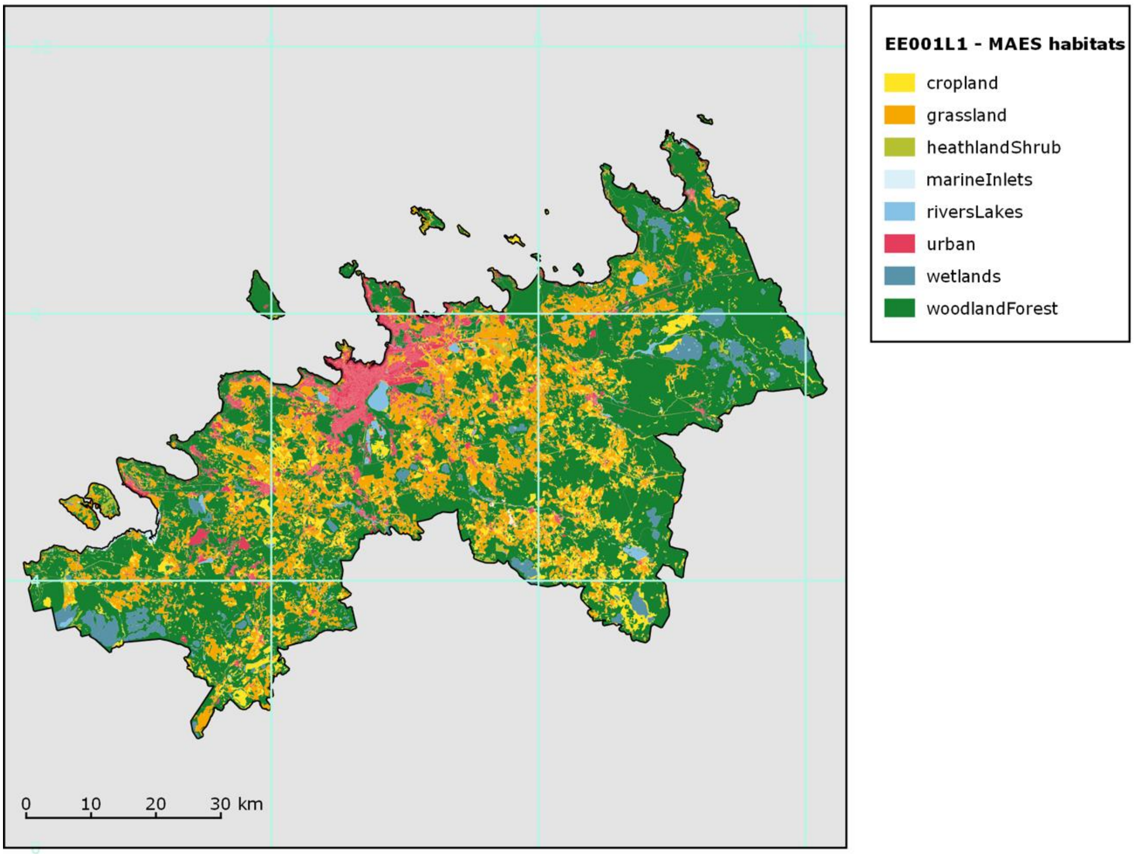


**Figure 5.10 Urban Atlas converted into MAES habitats using the legend crosswalk portrayed in Table 3.1**

The MAES habitat map of the Tallinn FUA shows high amounts of wetland and freshwater habitats together with some forests, grassland and fewer cropland. On the other hand, the relatively compact urban area does not seem to experience a lot of sprawl as the landscape outside of the city is also very much dominated by non-urban ecosystems. This also implies that the rural landscape is only minimally fragmented.

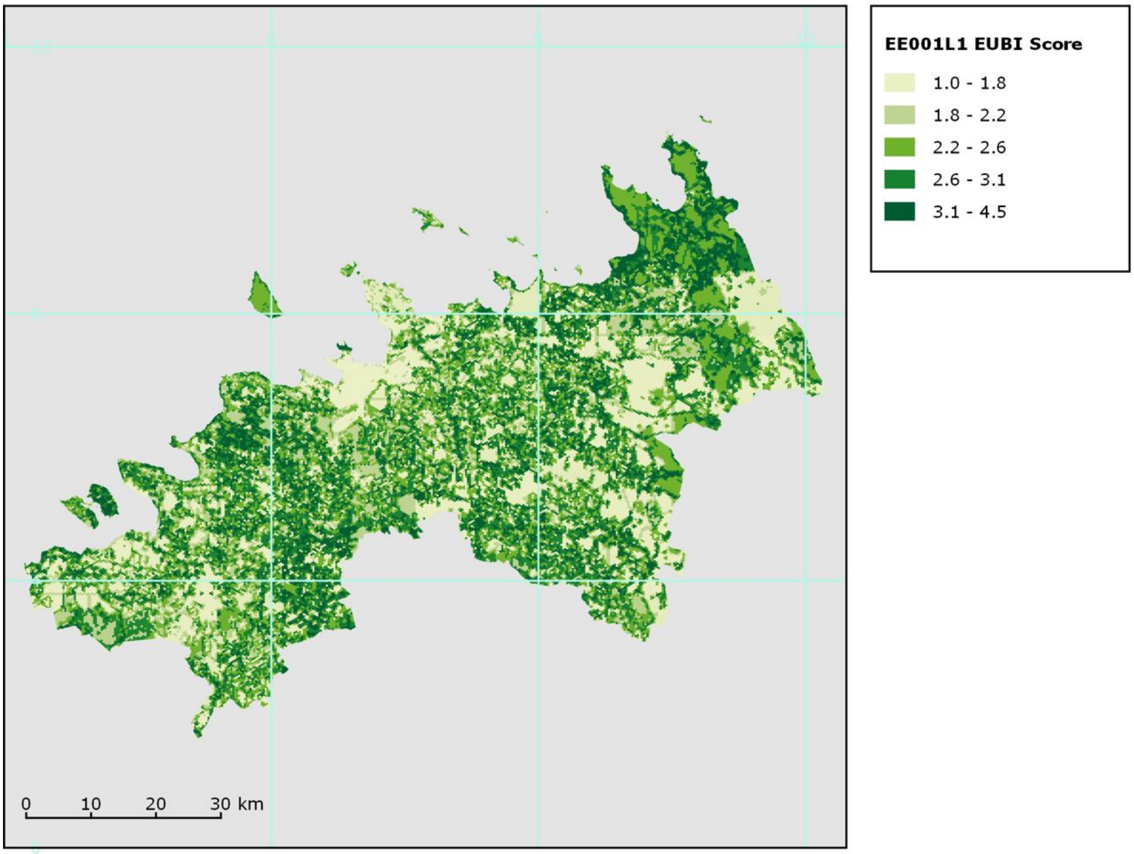


**Figure 5.11 Representation of the calculated EUBI Score based on a hexagonal grid. The score integrates the normalized value ranges of all eight core indicators and is classified into five classes (1-5) using a weighted average. High scores correspond to positive indicator performance**

Consequently, Tallinn possesses many and often contiguous patches with a high to very high EUBI score. The largest of these patches can be seen in the north-east of the FUA. It corresponds to a Natura 2000 site, i.e. Lahemaa (EE0010173)[1]. It is also this region that shows a large number of connections.

[1] http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=EE0010173

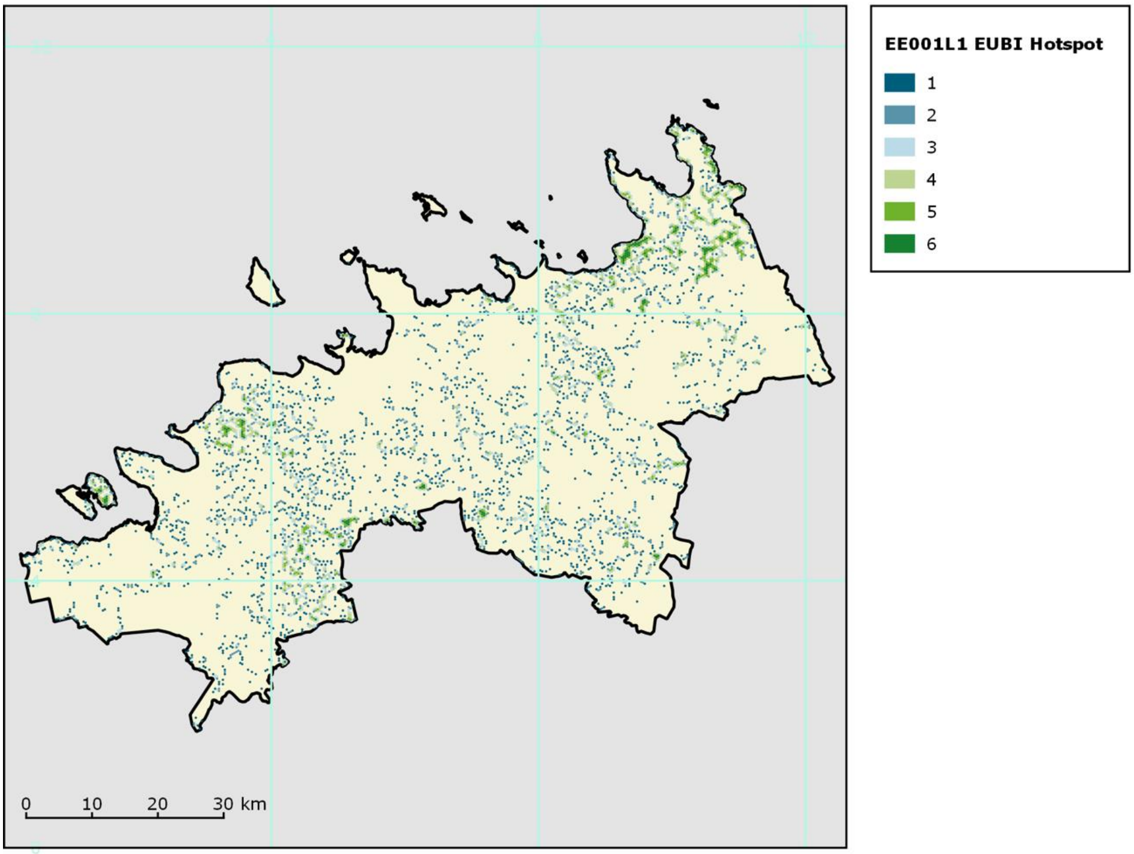


**Figure 5.12 EUBI Hotspots showing top tier grid cells defined by a 5 class - natural breaks clustering approach, separated into 6 classes according to their count of neighbouring grid cells**

**Table 5.4 Local index results for Tallinn**

| **Local Index** | **Tallinn** |
|---|---|
| L01 Number of native species | 40-50 bird species (CBI) |
| L02 Proportion of invasive alien species | fewer than 20 invasive alien species (CBI) |
| L03 Proportion of Natural Areas in the City | 4000ha of natural areas, covering more than 25% of the total city area (CBI) |
| L04 Access to urban green areas | 96.7% of population |

The area covered in the CBI for Tallinn is significantly smaller than the area covered in the core indicators. Therefore, the information provided by the local indicators can only provide insights into the area covered by the city's administrative boundaries.

# 6 Discussion / Conclusions

Developing an aggregate index for biodiversity in cities is a challenging task. This is especially true when a fundamental requirement for evaluating biodiversity - data on species abundance and distribution - is somewhat lacking at the required urban scale. City planners are in need of very detailed information on species distribution in order to tailor conservation management to local requirements. Non-processed Art. 12 and 17 provided species and habitats' distribution atlases are not a useful source of information for these stakeholders due to their coarse resolution.

Along with a range of additional indicators that address further aspects of biodiversity at landscape level this index attempted to downscale these datasets to be able to incorporate them into a composite index.

The 2017' approach calculated single, aggregate statistics for each FUA. In 2018 this was changed to obtain a spatially explicit map which may be used for further analysis and cross comparison. Due to the time invested in restructuring the methodological approach, supplementing the core index with information from direct local sources and local priorities was not possible at a later stage.

In contrast to the efforts undertaken here, the MAES study focusing on urban ecosystem condition has specifically selected not to include a composite indicator, but has left room for future suggestions (J. Maes et al., 2018).

The EUBI may be seen as an initial step to gather considerations and experiences to obtain such a composite measure. The calculated results show that cities in very different biogeographic settings and landscapes also perform quite differently. Connected clusters of top-tier cells mostly overlapped with Natura2000 areas, which may also be promoted by the fact that Natura2000 area are included as an indicator itself, but may also reflect that these areas may feature a higher species or habitat density. A key target of the index is to have a strong link between the index and urban ecosystem condition. Whereas core urban areas of the test cities mostly featured few hotspots, more rural parts of the FUA showed higher EUBI scores. Whereas this likely reflects the situation of higher species and habitat diversity to be found outside of urban sectors it raises the question as to whether to include the entire FUA or only calculate the index for the core section, which is highly urbanised. The entire FUA was selected in the current approach to include areas in the vicinity of large cities that have a clear urban influence and also to have a clear methodology concerning the definition of a "city".

The local indicators can serve to provide useful information on the city level. However, since the local indicators are not spatially explicit, they cannot significantly assist in interpretation of the EUBI data on the polygon level as it is provided by the core indicators. Due to methodological and definitional inconsistencies both for local indicators between cities as well as between local and core indicators, there is limited possibility for robust analysis and comparisons. The local indicators should therefore be taken as optional sources of additional biodiversity information for cities.

For a full validation of the results a cross-check with spatially explicit local data and knowledge is needed. It was quickly evident that it is challenging to derive concrete recommendations from the index, however, this is also not its goal. As the index is composed of mainly structural landscape components it cannot reflect substantially on conservation goals or priorities of each city. City specific targets are likely to be only reflected within the local component, for which data is difficult to obtain.

However, due to the methodological design of the index one can compare both, relative improvements within a city and differences between cities. This is important given that the index is mainly based on pan-European datasets and allows a comparison within a framework of validated and homogeneous datasets.

Evaluating the condition of biodiversity in urban ecosystems is inherently biased by the fact that urban environments have displaced and destroyed native habitats and favour non-native species(Müller, Ignatieva, Nilon, Werner, & Zipperer, 2013). Any condition assessment will thus only be able to evaluate the status quo – and not the deviation from the potential native flora and fauna which would be a more precise analysis approach.

The approach taken here is to define a good urban ecosystem condition by splitting up biodiversity into its structural components (e.g. habitat availability, connectivity, species richness etc.) and using the aggregate performance of these components as yardstick. This appears as feasible approach to characterise biodiversity with the given means and has also been applied with different datasets within urban ecosystems assessment performed by Maes et al., (2016). One of the key achievements is cross-walking urban atlas classes into MAES nomenclature. Even though this crosswalk may still be improved, it provides means to better link biodiversity datasets using this nomenclature with land cover information.

Overall, the main challenge for the EUBI remains the lack of harmonised species and green infrastructure data at local level. Landscape elements relevant for urban biodiversity include small structures such as green roofs, small gardens and or single trees. These elements, although important, could not be integrated in the current approach due to absence of these datasets.

Citizen science projects or open source data-sets such as Inaturalist, natusfera or OSM can be considered to address this gap. The main problem here is the spatial heterogeneity of recorded species

An initial testing of these suitability of OSM data to for an indicator using presence individual trees showed extremely heterogeneous mapping of these within cities and even suburbs. OSM data is already widely used in the UA where it provides the transport network skeleton for mapping. Unlike roads, small scale natural elements are presumably less obvious and are therefore more heterogeneously recorded. Populating UA data with OSM elements or basing an analysis of landscape structure on OSM data should optimally go hand in hand with a validation to obtain information on the quality of these valuable elements.

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# 8 Annex

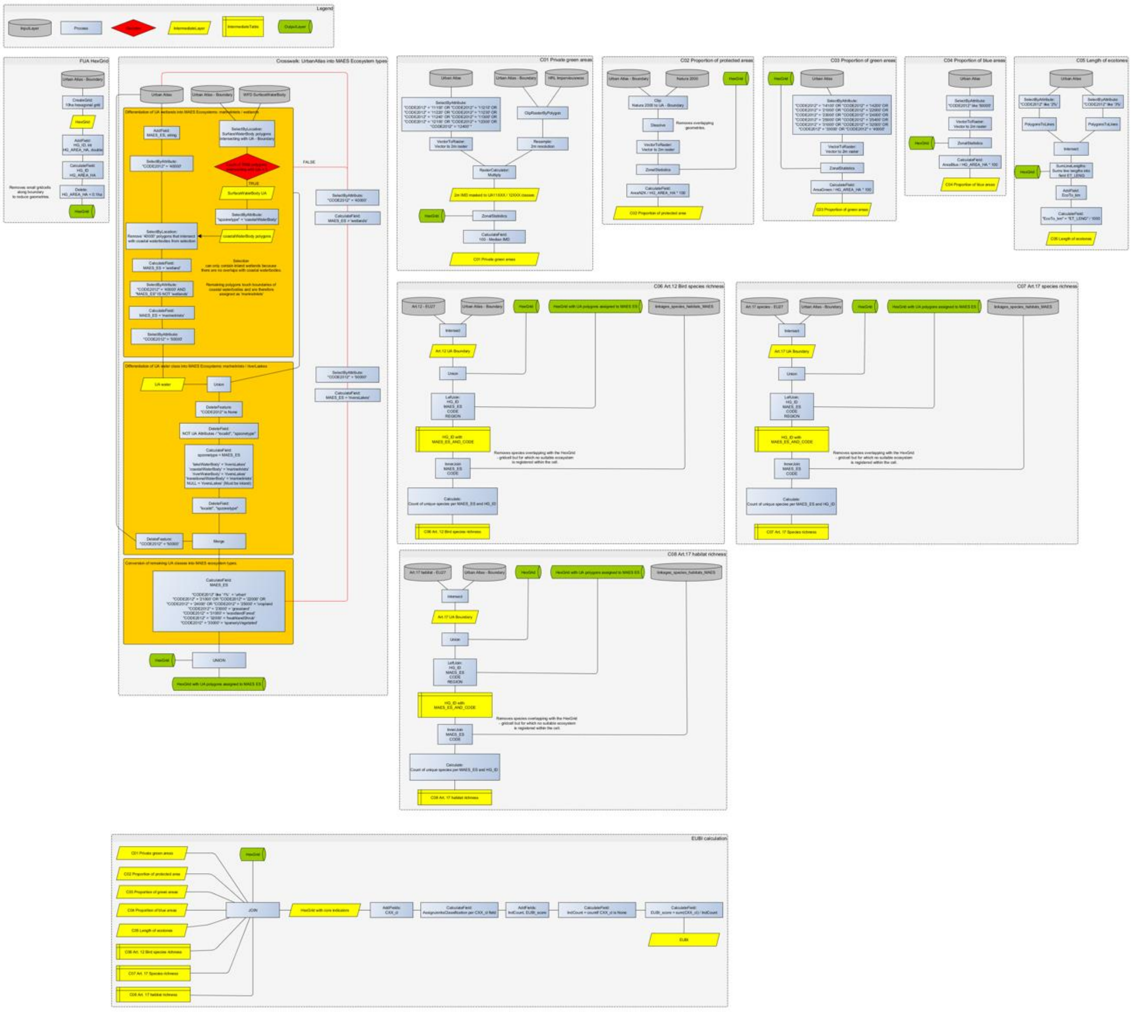

**Figure 8.1 Detailed processing workflow to derive the EUBI from the input datasets. Most steps are conducted using python scripting using open-source repositories and GIS. For sections of Art.12 / 17 data processing Feature Manipulation Engine (FME) and Microsoft SQL Server had to be used to handle the large amounts of produced data**

**Table 8.1 Overview of local indicators**

| Local Index | Brussels | Lisbon | Stockholm | Tallinn |
|---|---|---|---|---|
| L01 Number of native species | 2,115 | 76 bird species | 110 bird species | 40-50 bird species |
| L02 Proportion of invasive alien species | 4.35% | 32 invasive alien plant species; proportion of invasive alien species to native species is 9% | - | fewer than 20 invasive alien species |
| L03 Proportion of Natural Areas in the City | 3,308ha of natural areas, covering 20.4% of the total city are | 1857ha of natural areas, covering about 22% of the total land area. There is in addition 1,512ha of green spaces, parks and gardens | 25.5% of total city area. | 4000ha of natural areas, covering more than 25% of the total city area |
| L04 Access to urban green areas | 97% of population | 75.9% of population | 99.6% of population | 96.7% of population |