REGREEN
NATURE-BASED SOLUTIONS

Fostering nature-based solutions for smart, green and healthy urban transitions in Europe and China

WP N°3 Mapping and modelling ecosystem services

FACT SHEETS FOR MAPPING AND MODELLING PROCEDURES

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no.821016 This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 FACTSHEETS

The following sections contain factsheets for key mapping and modelling approaches, which have been developed and applied in the REGREEN project. The purpose of the factsheets is to describe applied methods and outputs in a short and comprehensible way. More exhaustive documentation can be found in other REGREEN documents or highlighted scientific articles. These factsheets were designed as living documents, representing ongoing status of the specific mapping and modelling approaches and their application within REGREEN.

The factsheets are structured as follows:

- **Title of the mapping or modelling approach**
- **Main contact, (and other people involved) and E-mail for main contact**
- **Short description of output**

  A short description of the output of the mapping or modelling approach with an illustration, e.g., a map, diagram, or table.
- **Method**

  Brief description of the applied methodology.
- **Approach for REGREEN**

  Description of the applied approach for REGREEN, including:
  - Table with basic information on the output from mapping / modelling approach
  - Table with required data inputs for the mapping / modelling approach
- **How NBS are incorporated**

  Explanation of how Nature-Based Solutions are incorporated or addressed.
- **Upscaling/Downscaling**

  Explanation of how the approach can be up- and downscaled.
- **Transferability**

  Short description of how easily the developed methodology can be transferred/applied to other cities / regions.
- **Comparability and consistency**

  Brief discussion of the comparability and consistency of the applied approach in comparison with other existing approaches.
- **Trade-off between detail and resources**

  Reflection on trade-off between desired output details and needed resources.
- **From maps and models to ecosystem service assessment**

  Short summary of how far the mapping / modelling approach has been applied with regard to ecosystem service assessment. Such as:
  - Mapping
  - Ecosystem service assessment based on look-up values
  - Ecosystem service assessment using spatial or process-based model
  - Economic assessment of benefit
- **Current applications in REGREEN**

  Description of how the mapping / modelling approach has been applied so far and in which ULLs.

- **Outputs**
  - Publications – Any publications produced so far as part of the mapping / modelling approach in REGREEN.
  - Datasets - Information on produced datasets and any reference to publicly available datasets if any.
- **References**
  - List of any relevant references.

1.1 Urban land-use / land-cover mapping

Main contact, (and other people involved) Wanben Wu (FU/AU), (Ellen Banzhaf (UFZ))

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Short description of output

Mono- and multi-temporal refined mapping products of the urban land-use / land-cover (LULC) and their changes and development over time for all the 6 ULLs. These products represent coherent spaces of the same categories for eight LULC classes, i.e., densely built-up, dispersed built-up, cropland, deciduous forest, coniferous forest, grassland, water bodies and bare land.

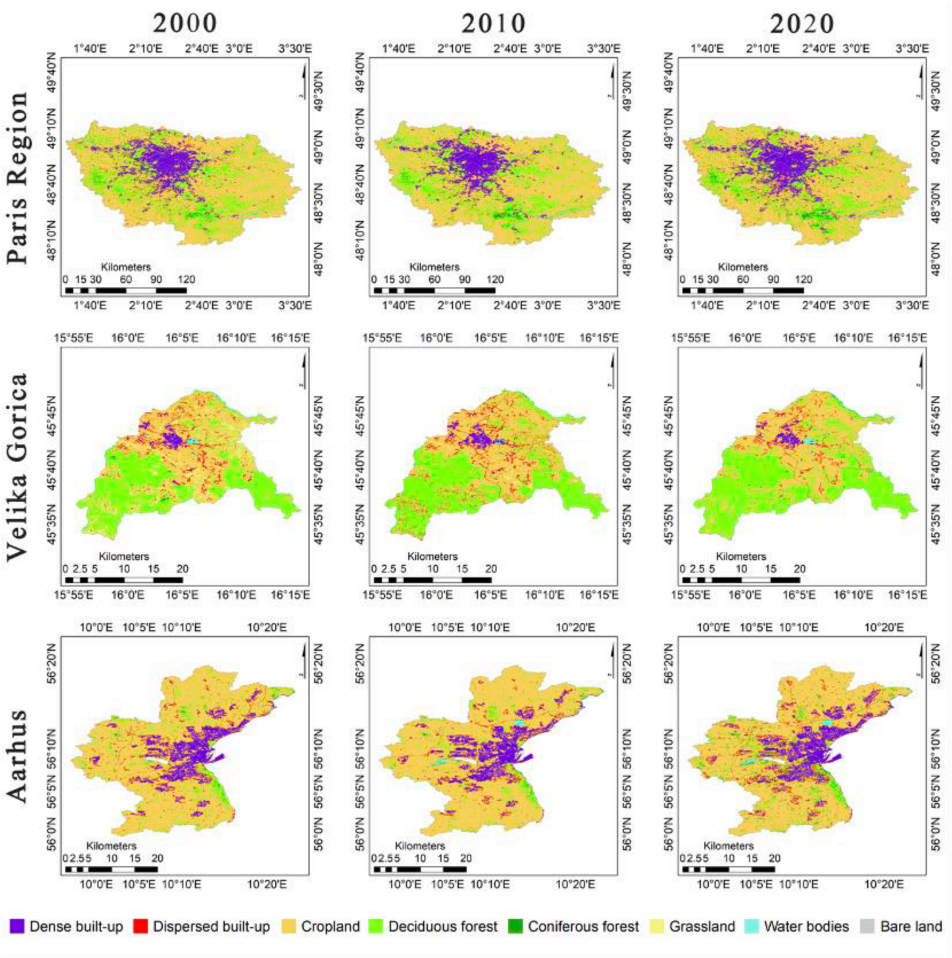

Figure 1: Land cover maps with 30m spatial resolution of the three European ULLs for 2000, 2010, and 2020

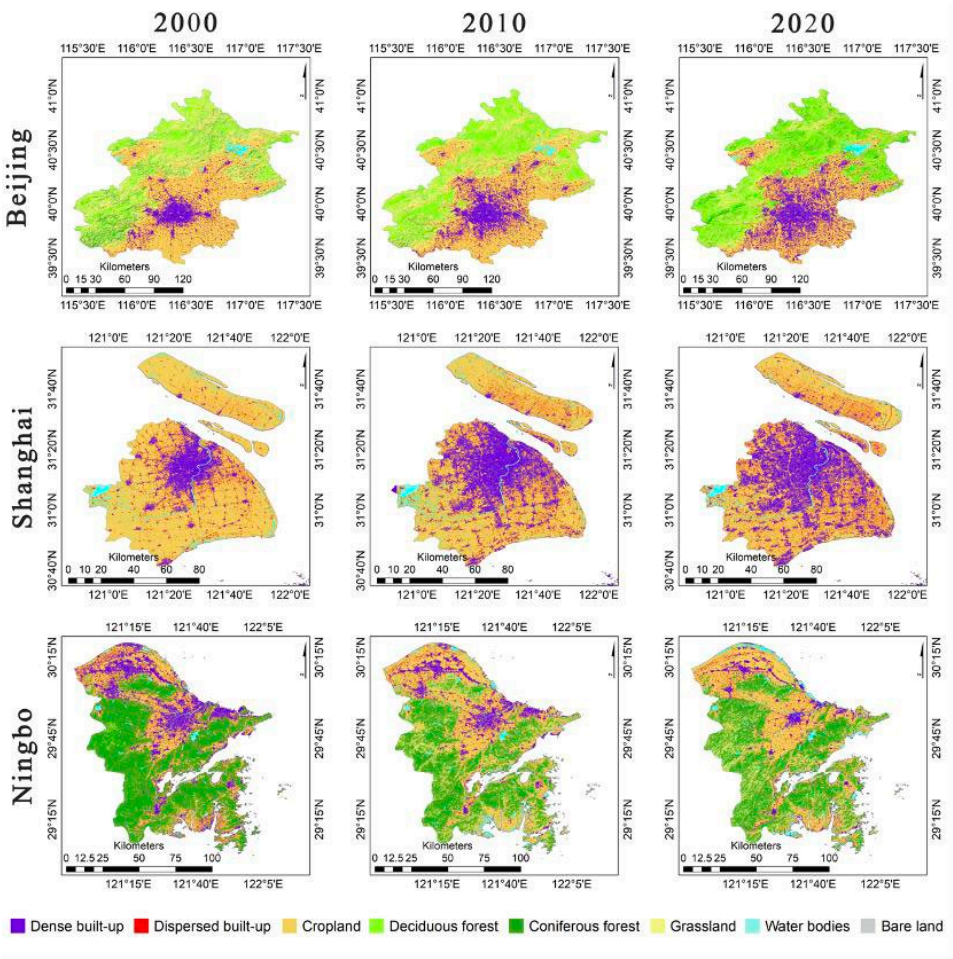

Figure 2: Land cover maps with 30m spatial resolution of the three Chinese ULLs for 2000, 2010, and 2020

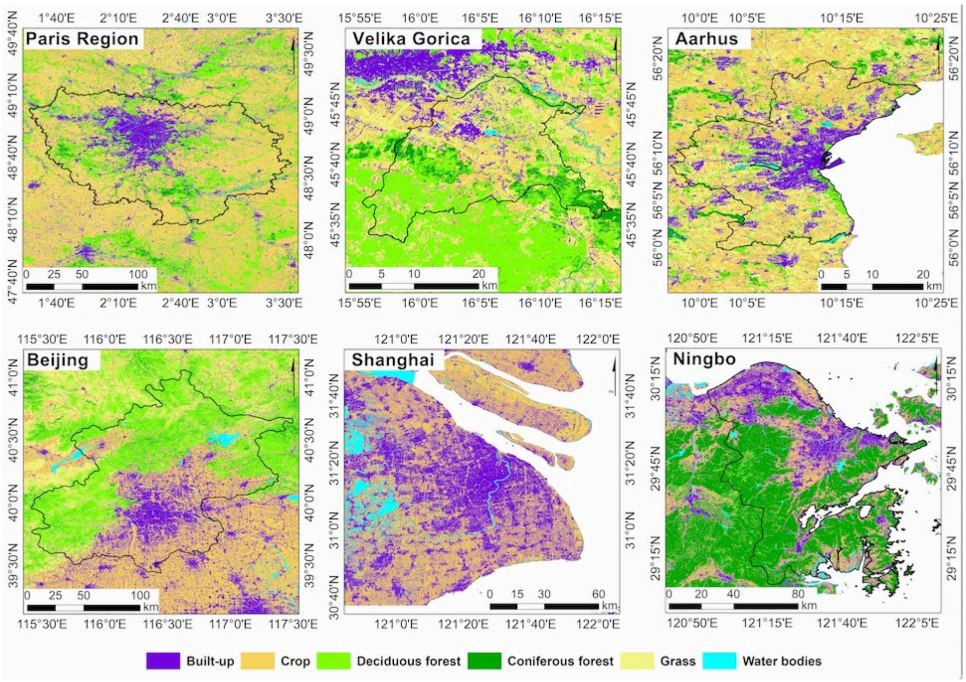

Figure 3: Land cover maps with 10m spatial resolution of the six ULLs for 2020

Method

Google Earth Engine (GEE) efficiently allows online processing of earth observation data, along with a vast set of remote sensing data, such as Sentinel and Landsat imageries. Based on all available clear-sky Landsat and Sentinel-1&2 images and our elaborated automatic mapping workflow, we produced refined LULC products for all the 6 ULLs at two different scales, i.e., 30m LULC products for 2000, 2010 and 2020, and 10m LULC products for 2020 (See Figures 1-3).

It is worth noting that our automated mapping workflow not only has high classification accuracy (the overall classification accuracies range between 73% and 95%), but also high generalisation, allowing to be transferrable to other ULLs. The final products also help us to better understand dynamics of urbanisation and potential future development. They are applicable as an important input for ecosystem services models.

Approach for REGREEN

- Assessing the dynamics of urban development
- Monitoring and evaluating the valuation of NBS
- Exploring environmental justice and the demands
- Simulating the ecosystem services for the future

Table 1: Basic information on map outputs from urban land-use/land-cover mapping

Code	Spatial resolution	Years	Categories	Data availability
1	30 m	2000	8 classes: densely built-up, dispersed built-up, cropland, deciduous forest, coniferous forest, grassland, water and bare land	https://zenodo.org/record/5502635#.Yv9KbOxBz0p
2	10 m	2010	7 classes: densely built-up, dispersed built-up, cropland, deciduous forest, coniferous forest, grassland, water	https://zenodo.org/record/5846090#.Yv9LauxBz0o
3	60 m	2030	4 classes: built-up, cropland, green space, water	https://zenodo.org/record/6997232#.Yv9M7OxBz0o

Table 2: Data requirements for urban land-use/land-cover mapping

Data name	Data resolution	Acquisition year(s)
CORINE LC	vector	1990, 2000, 2010, 2018
Urban Atlas	vector	2006, 2012, 2018
LUCAS	vector	2018
GlobeLand 30	30m	2000, 2010, 2020
Forest maps	30m	2010
CAS LC	30m	2000, 2005, 2010, 2015
GAIA	30m	1985-2018
Landsat 5-8	30m	1985-present
Sentinel-1	10 m	2014-present
Sentinel-2	10 m	2015-present

How NBS are incorporated

We cannot map NBS as such. However, our mapping products are important base maps for better understanding the demand of green infrastructure (GI) and related specific ecosystem services (ES). Furthermore, with our quantitative method, indicators are calculated over space and time to derive ES from. Our products can be used to evaluate the effectiveness of NBS.

Upscaling/Downscaling

Downscaling of LULC mapping results is not feasible. We produce different spatial-scale products to overcome such limitations. This mapping can be easily extended beyond the ULL boundaries at the same spatial scale.

Transferability

By using existing LC products to integrate and extract classification sample points, we solved the problem of their difficult acquisition which was depicted in previous studies. As a novelty, we propose an algorithm for automatic sample points' acquisition. This method of classification feature screening can now be applied to other studies. By evaluating and screening the relative importance of multiple feature variables on model evaluation, we obtained a balance of good classification accuracy as well as a high classification efficiency.

We achieved this discerning classification scheme at the intercontinental level. Our methodology ideally exploits all the spatial LC information, and therefore we were able to design a well-developed mapping procedure. With our elaborated GEE workflow, no additional infrastructure is needed. Our processing is easily reproducible in other cities contrasting other approaches.

Comparability and consistency

Our approach was designed for and applied to all the 6 ULLs in Europe and China. All mappings consist of the same categories. For this reason, all mappings are comparable at the same scale and consistent over time. The different scales allow for understanding land-cover dynamics at different levels of detail.

Trade-off between detail and resources

The land-cover products were processed by using publicly available open data and a cloud computing platform, which is efficient and low-cost. Meanwhile, the 30m land-cover data product has a high temporal resolution and can be used to explore land-cover dynamics and the corresponding ecological impacts over a long time series (Landsat TM/ ETM+). The 10m land cover can provide more spatial detail at one point in time because of a newly developed sensor system (Sentinel-1&2).

From maps and models to ecosystem service assessment

So far, Urban land-use/land-cover (LULC) products have been applied for:

- Analysis of urban dynamics
- Ecosystem service assessment based on look-up values
- Ecosystem service assessment using spatial or process-based model
- Economic assessment of benefit

Current applications in REGREEN

In our recent study, based on the proposed 30m land-cover products, we assess the quantity and equity of ES for the past two decades and prospected developments in 2030 under different scenarios for all 6 ULLs. Specifically, we used the Conversion of Land Use and its Effects at Small regional extent (CLUE-S) model to simulate future land cover under three scenarios in 2030 (Wu et al. 2022b): business-as-usual (BAU), a market-liberal scenario (MLS), and an ecological protection scenario (EPS). Then using ecosystem service model approaches and the landscape analysis, the dynamics of green infrastructure (GI) fraction and connectivity, carbon sequestration, and $PM_{2.5}$ removal were further evaluated for all 6 ULLs from 2000 to 2030.

Outputs

Publications

The land cover mapping development, and its application are described in two papers:

- Banzhaf, E., Wu, W. B., Luo, X., Knopp, J. (2021) Integrated Mapping of Spatial Urban Dynamics—A European-Chinese Exploration. Part 1—Methodology for Automatic Land Cover Classification Tailored towards Spatial Allocation of Ecosystem Services Features. Remote Sensing, 2021, 13(9), 1744, https://doi.org/10.3390/rs13091744
- Wu, W., Luo, X., Knopp, J., Jones, L., Banzhaf, E. (2022b) A European-Chinese Exploration: Part 2—Urban Ecosystem Service Patterns, Processes, and Contributions to Environmental Equity under Different Scenarios. Remote Sens. 2022, 14, 3488. https://doi.org/10.3390/rs14143488

Datasets

- Banzhaf, E., Wu, W., Luo, X., Knopp, J. (2021) Europe and China Refined Land cover (ECRLC) [Data set]. https://doi.org/10.5281/zenodo.5502635
- Wu, W., Luo, X., Knopp, J., Jones, L., Banzhaf, E. (2022a) Refined Land cover for Beijing, Shanghai, Ningbo in China and Paris Region, Velika Gorica, Aarhus in Europe under different scenarios in 2030 [Data set]. https://doi.org/10.5281/zenodo.6997232
- Wu, W. (2022) Europe and China Refined Land cover (ECRLC) (10m) (Version V2) [Data set]. https://doi.org/10.5281/zenodo.5846090

This factsheet was updated: November 22, 2023

1.2 High resolution land cover mapping

Main contact, (and other people involved) Julius Knopp (UFZ), (Ellen Banzhaf (UFZ))

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Short description of output

High-resolution land-cover mapping (HRLC) products of the European ULLs are elaborated. The approach is object based. Land-cover classes/ categories include mineral surfaces, buildings, bare soil, artificial grass, deciduous and evergreen trees, shrub, grass and water. The mapping is supposed to:

- Get the highest possible resolution of land cover for the ULL
- Provide a basis for local decision making
- Be used to link other WPs joining quantitative and qualitative research and applications
- Enhance knowledge on socio-demographic and socio-economic implications of residents for various pressures at allocated hotspots
- Work as an overlay of information over walkable floor maps to visualize land cover and land use

Figure 4: Map showing the distribution of aggregated vegetation classes per parcel in a residential area of Aarhus ULL, alongside the number of residents per building.

Method

Object-based image analysis (OBIA): By aggregating individual pixels in remotely sensed datasets, objects can be derived, which better resemble real-world objects (e.g., roads instead of impervious surface). This method was applied to both, the ULL Aarhus and ULL Velika Gorica. The ULL Paris Region was mapped using existing datasets which were reclassified and merged to produce an equivalent LC product.

Approach for REGREEN

- Input data were provided by each ULL or through external sources (ESA Third party mission program)
- Strong reliance on test sites and ground truthing, which were mapped by fieldwork or assisted by Google Maps Street View
- Provide detailed information on land cover for the whole ULL regardless of property status (accessibility)
- Serve as an input for models on environmental pressures (e.g., noise, flooding, water pollution)

Table 3: Basic information on map outputs from high-resolution land-cover mapping.

ULL	Spatial resolution	Years	Categories
Aarhus	20 cm	2014	9 classes: mineral surfaces, buildings, bare soil, artificial grass, deciduous trees, evergreen trees, shrub, grass and water
Paris Region	NA, vector based	2017	7 classes: mineral surfaces, buildings, bare soil, trees, shrub, grass and water
Velika Gorica	30 cm	2016	9 classes: mineral surfaces, buildings, bare soil, artificial grass, deciduous trees, evergreen trees, shrub, grass and water

Table 4: Data input requirements for high-resolution land-cover mapping

ULL	Data name	Data type	Data format	Spatial resolution	Time points, year(s)	Data detail
Aarhus	Digital orthophoto	RS data, raw	Raster	12.5 – 20 cm	2014, 2015, 2018, 2019	8 Bit, RGB+NIR
	Digital surface model	RS data, raw	Raster	40 cm	2015	LiDAR derived, 32Bit float
	Digital terrain model	RS data, raw	Raster	40 cm	2015	LiDAR derived, 32Bit float
Paris Region	MOS+ 2017, mode d'occupation du sol	Thematic land cover/ land use product	Vector	NA	2017	81 thematic classes, land cover and land use
	Hauteur vegetation	Thematic land cover product	Raster	1 m	2015	Classified vegetation height in 1cm increments
	Cadastre vert Hauts- de- Seine	Thematic land cover product	Vector	NA	2012	Areas covered by vegetation
	Copernicus Small and Woody features	Thematic land cover product	Vector	NA	2015	Thematic classification of shrubs
	Copernicus Street tree layer	Thematic land cover product	Raster	2 m	2018	Street tree canopy extent
Velika Gorica	WorldView3	RS data, raw	Raster	30 cm	2016, 2017	12 bit, 8 bands, visible range, red edge, NIR
	Digital surface model	RS data, raw	Raster	40 cm	2021	Orthophoto – derived by photogrammetry
	Digital terrain model	RS data, raw	Raster	20 cm	2018	LiDAR derived, 32Bit float

How NBS are incorporated

Not applicable

Upscaling/Downscaling

The maps are produced for each European ULL at the highest possible resolution and can be resampled to a coarser thematic or spatial resolution. So, upscaling is feasible. Extraction of mapped data for various urban extents is simple and easy to undertake within the same spatial scale.

Transferability

The choice of mapping approach for the three different European ULLs was based on data availability. While this was a constraint, the mapping approaches chosen are still very much applicable to areas outside of the ULL, within the same country or even covering Europe.

The domestic digital orthophotos and digital terrain and surface models, which were applied for the Aarhus ULL, cover all of Denmark and are updated on a regular schedule. It is thus feasible for other cities in Denmark to adapt this approach.

For the ULL Paris Region, a mix of available land-cover and land-use products was used. This is not necessarily transferable to other regions of France, as the underlying and mainly used dataset MOS+ 2017 is only available for the Île-de-France region. However, using similar products such as the Urban Atlas or the incorporated STL and SWF datasets from Copernicus, this methodology is potentially transferable to other areas inside and outside of France.

The satellite data acquired for Velika Gorica ULL covers the entire globe. The two major constraints however are the availability of high-resolution terrain and surface data, and the costs, as the WorldView3 satellite is operated commercially.

Processing the data requires partial utilisation of commercial software. This could potentially be replaced with the use of open-source software, thus ensuring further transferability to other future projects while keeping costs to a minimum.

Comparability and consistency

Throughout the different mapping campaigns in the European ULLs, a major focus was on the comparability of the products across ULLs in terms of thematic and spatial resolution. The thematic categories focus on the built and natural environment alike, and try to represent categories, which are of interest to further modelling and scenario application within the project. The spatial resolution was, depending on the ULLs, not consistent, but was transferred to a level, which still retains the shares of the different thematic classes in a balanced way, while giving the highest possible spatial resolution which can still feed into further modelling. This was mainly limited by computational time in the related task in the mapping and modelling work packages.

From maps and models for ecosystem service assessment

So far, the HRLC mapping has been applied for:

- Mapping (e.g., of green-blue infrastructure, built-up areas, potential for green roofs)
- Ecosystem service assessment using spatial or process-based model (as input to afforestation modelling)
- Economic assessment of benefit as input to traffic noise mitigation modelling

Current applications in REGREEN

HRLC mapping has been applied for all 3 European ULLs.

Outputs

Publications

- Knopp, J., Levin, G., Banzhaf, E. (2023) Aerial data analysis for integration into a green cadastre – an example from Aarhus, Denmark. IEEE Journal of Selected Topics in Applied Earth

Observations and Remote Sensing (J-STARS) 16, 6545 – 6555 https://doi.org/10.1109/JSTARS.2023.3289218
- Paper on Velika Gorica ULL is planned

Datasets
- Not publicly available yet

This factsheet was updated: November 22, 2023

1.3 Urban footprint mapping for ULLs

Main contact, (and other people involved) Julius Knopp (UFZ), (Ellen Banzhaf (UFZ))

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Short description of output

The urban footprint is a measure for the functional urban area, which describes the extent of the physical area occupied by an urban area, including built-up areas, infrastructure, and other man-made features as well as green and blue spaces. It may include commuting zones and other urban-rural interlinkages. Maps for the urban footprint within the administrative boundaries of all six ULLs to better capture the human-induced urban environment. The same approach is applied for all ULLs, except for specific areas, which are excluded or included based on information from ULL representatives.

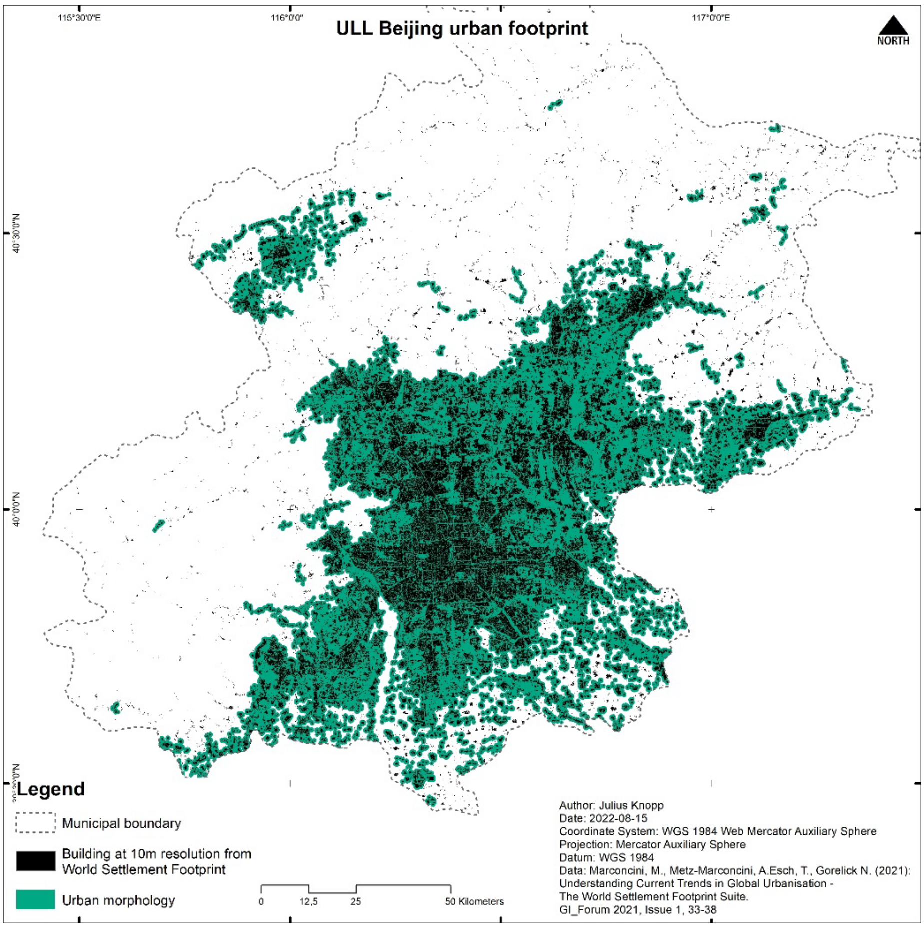

Figure 5: Urban footprint for Beijing ULL

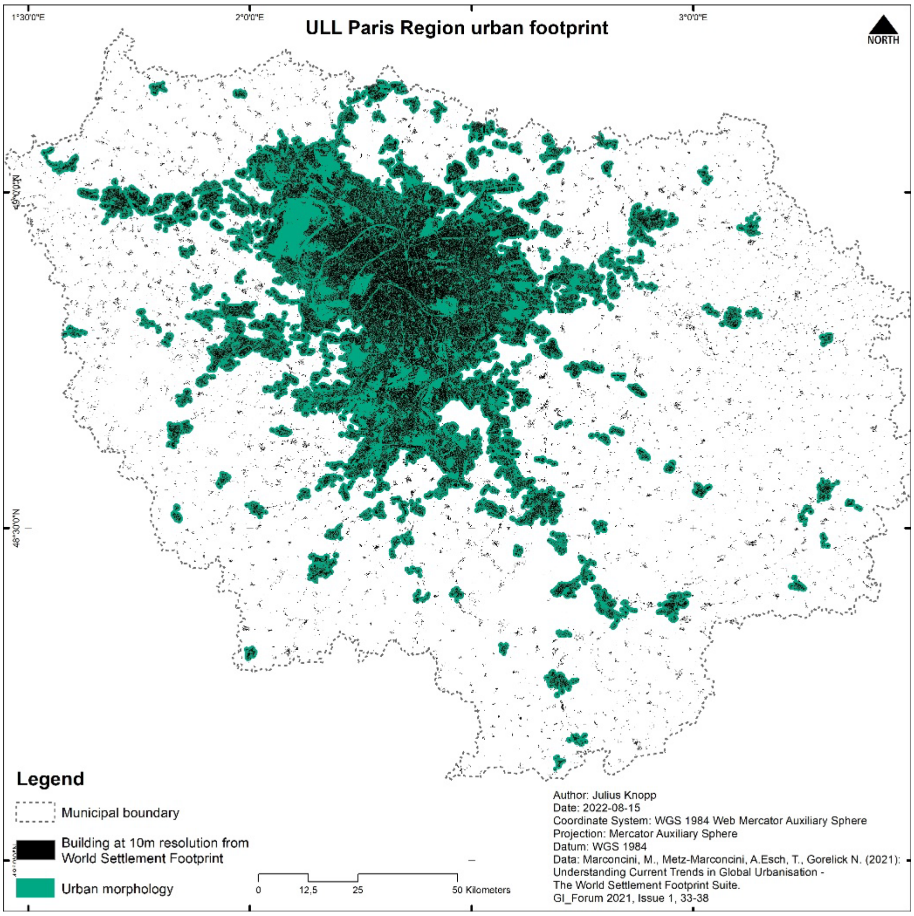

Figure 6: Urban footprint for Paris region ULL

Method

The method used is based on a binary settlement map. The world settlement footprint by the ESA provides such a dataset. Using this, focal statistics are applied to detect higher densities of urban structures, based on a defined threshold. Here, we used a threshold of 0.2 and a radius of 25 pixels, equating to 250m. These areas were then transferred into vector data to be buffered with an additional 300m. This is consistent with most access to green space recommendations, and to not exclude green spaces at the boundaries of urban areas. To define smaller settlements in a certain distance as rural, an exclusion was applied to polygons smaller than 10km². Afterwards, areas specific to the ULLs were included, and the resulting extent was clipped with the administrative boundaries of the respective ULL to ensure matching coverage.

Approach for REGREEN

As described in the methods section, areas specific to the ULLs were included or excluded in the urban footprint. This covers either large green areas outside of the urban areas or sites where the municipality has no influence over its development, such as airport facilities. For Aarhus ULL, areas such as Risskov, Lake Brabrand, Årslev Engsø and the forests south of Aarhus down to Moesgaard were included, while Ajstrup Strand was excluded. For Velika Gorica ULL, the airport to the North and North-West of the city was excluded.

Table 5: Basic information on map outputs for urban footprints

ULL	Spatial resolution	Year	Categories	Data availability
• Aarhus • Paris Region • Velika Gorica • Beijing • Ningbo • Shanghai	10 m	2019	• Urban • Non-urban	Internally

Table 6: Data requirements for urban footprint mapping

Data type	Resolution	Data format	Time points, year(s)
Administrative boundaries	NA	Vector polygons	As recent as possible
Settlement data such as the World settlement footprint (WSF) 2019 by ESA Settlement data	At least 10 m	Vector polygons or raster	2019
Additional areas excluded or included, based on local knowledge	NA	Vector polygons	As recent as possible

How NBS are incorporated

We cannot map NBS as such, but urban footprints are important base maps to identify existing NBS and allow for positioning additional NBS within the urban area.

Upscaling/Downscaling

Downscaling of urban footprints is not feasible but can be easily extended beyond the ULL boundaries.

Transferability

Since the mapping of urban footprints is based on globally available data, the approach can be applied to any city or region. This has also been tested in the cities of Birmingham and Oslo.

Comparability and consistency

Our approach was designed for and applied to all the six ULLs in Europe and China. Therefore, the elaborated urban footprints are comparable and consistent across ULLs.

Trade-off between detail and resources

The approach is relatively easily applied, and resource use is limited. Use of local knowledge can, however, entail extra time.

From maps and models to ecosystem service assessment

So far, the urban footprint mapping has been applied for:

- Refined analysis of urban structures;
- Ecosystem service assessment based on look-up values;
- Ecosystem service assessment using spatial or process-based model; and
- Economic assessment of benefit.

Current applications in REGREEN

Urban footprints have been mapped for all six ULLs. Furthermore, urban footprints have been applied in the three European ULLs, to calculate base indicators for populations' access to urban green spaces.

Outputs

Publications

- No publications yet

Datasets

- No publicly available datasets yet

This document was updated: January 30, 2023

1.4 Mapping of land characteristics from cadastral data

Main contact, (and other people involved) Gregor Levin (AU), (Julius Knopp (UFZ))

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Short description of output

Maps for different land characteristics based on available cadastral data. Maps are spatially explicit and include different characteristics, such as building types, ownership categories or public accessibility.

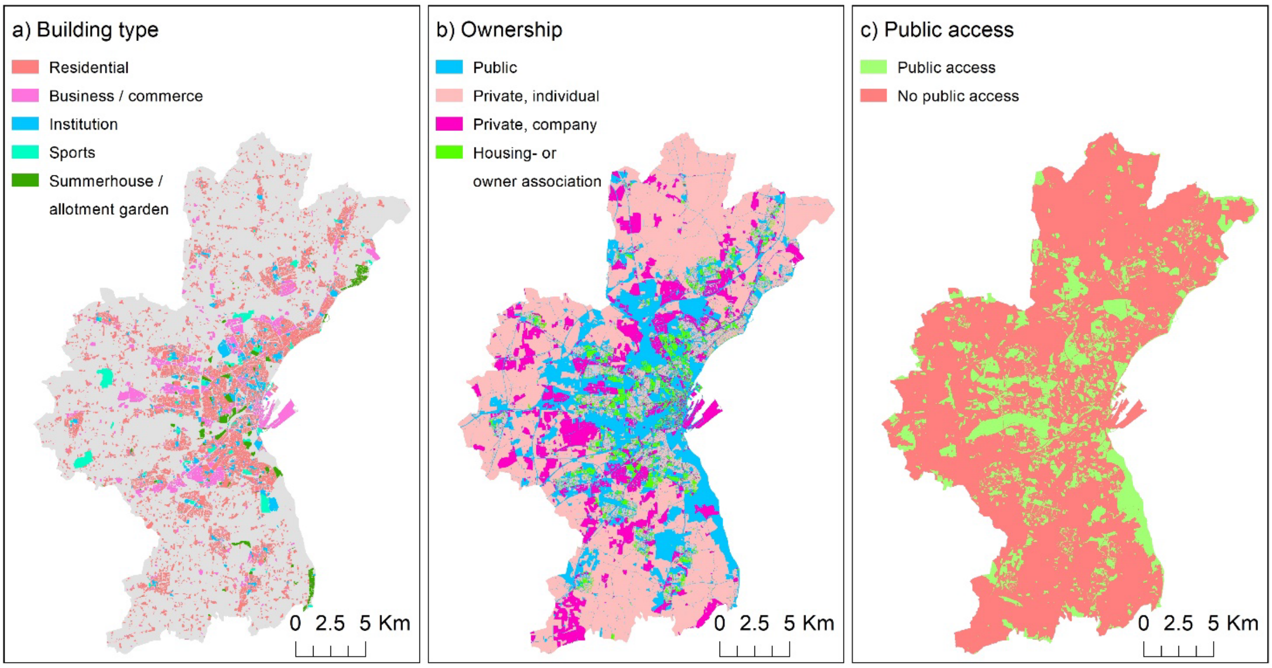

Figure 7: Different land use characteristics based on cadastral data from 2018 for Aarhus ULL

Method

Cadastre parcels are administrative units, which contain, or can be linked to parcel-specific information, such as building types or ownership. Furthermore, cadastre maps can be combined with other spatially explicit information, such as land cover and land use maps, to derive other thematic maps, such as public accessibility of green-blue spaces.

Approach for REGREEN

- Compiling of relevant cadastral datasets for European ULLs;
- Linking of cadastral information from relevant databases;
- Spatial combination of cadastral datasets with other relevant spatially explicit information; and
- Elaboration of derived thematic maps for e.g., building type, ownership, and public accessibility

Table 7: Basic information on map outputs from cadastral data.

ULL	Spatial resolution	Year	Categories
Aarhus	Cadastre parcels (~81,500 parcels)	2018	• Building type • Ownership • Public accessibility
Paris region	Cadastre parcels (~403,000 parcels)	2017	• Land cover • Land use • Building type • Public accessibility
Velica Gorica	Land use/ zoning plan parcels (~1000)	2012	• Land use • Building type • Public accessibility

Table 8: Data requirements for mapping of urban land use characteristics from cadastral data.

Data type	Spatial unit	Format	Time points, year(s)
Cadastre or parcel map	Cadastre parcel	Vector map	Most recent available
Building register or map of building footprint	Building	Tabular data or vector/point map	Best agreement with applied cadastre map
Ownership register	Cadastre parcel	Tabular data or vector map	Best agreement with applied cadastre map
Additional land use / land cover datasets	NA	Vector or raster map	Best agreement with applied cadastre map

How NBS are incorporated

Cadastral information does not include NBS as such. However, maps derived from cadastral information can be applied to analyse NBS interventions in relation to different ownership categories, building types and/or public accessibility and thus be used to evaluate the effectiveness of NBS.

Upscaling/Downscaling

Up- and downscaling of cadastral data is not feasible. However, cadastral information can be aggregated to larger administration units.

Transferability

Transferability of this mapping approach depends on availability of cadastre maps and relatable cadastre specific or spatially explicit information. Since cadastral information differs between countries and cities, the methodology developed in REGREEN cannot be directly transferred to any city or region but needs to be adjusted to available datasets.

Comparability and consistency

While spatial resolution is comparable across ULLs, cadastral and other spatially explicit data vary with respect to categorisations of e.g., land use or ownership. However, derived thematic maps e.g., superior building types or distinctions between public and private ownership and between public access and no public access are comparable across ULLs.

Trade-off between detail and resources

Cadastral data are spatially explicit and highly detailed. The main workload in processing of these datasets is related to interpretation and translation of categories in the different available datasets into meaningful and comparable classes. There is a trade-off between applied resources for interpretation and the detail, which is required for ecosystem service assessment. While many resources were used to compile a very detailed dataset for Aarhus ULL, fewer resources can be used for Paris region and Velica Gorica, resulting in datasets with less detail, but still comparable to Aarhus ULL.

From maps and models to ecosystem service assessment

So far, mapping of land characteristics from cadastral data has been applied for Aarhus ULL for:

- Mapping (of e.g., green-blue infrastructure, land use characteristics, ownership, public accessibility);
- Ecosystem service assessment based on look-up values (e.g., baseline indicators for green-blue infrastructure); and
- Ecosystem service assessment using spatial or process-based model (e.g., access of different population groups to green-blue spaces).

Current applications in REGREEN

So far, a full cadastral map with information on building type, ownership and public accessibility has been compiled for Aarhus ULL for the year 2018. This dataset has been applied for delineation of green-blue spaces and for analyses access to green-blue spaces in relation to different socio-economic and demographic variables.

Outputs

Publications

- No publication yet.

Datasets

- Aarhus ULL: Levin, G (2023). Processed cadastre map for Aarhus municipality 2018 [Data set] https://doi.org/10.5281/zenodo.7561205
- Paris Region ULL: Under preparation.
- Velica Gorica ULL: Under preparation.

This factsheet was updated: January 30, 2023

1.5 Water quality assessment model

Main contact, (and other people involved): Mike Hutchins (UKCEH), (Yueming Qu (UKCEH), James Miller (UKCEH))

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Short description of output

The river model QUESTOR (Pathak et al., 2021; Pathak et al., 2022) produces time series (daily or hourly) of flow, temperature, nutrient and sediment concentrations, chlorophyll (algal biomass) and dissolved oxygen. When run in hourly mode it can also be used to estimate the ecosystem metabolism, which represents the balance between photosynthesis and respiration and how this might change under different scenarios. In this way it provides an integrated measure of the health of the ecosystem; as well as information about pollutant concentrations which can be related directly to regulatory standards. A simpler version of the model, QUESTOR-YS has been developed for rapid assessment in urban situations (Hutchins et al. Paper in revision). QUESTOR-YS has been applied in Aarhus ULL to investigate the likely impact of a tree planting programme (Figure 8).

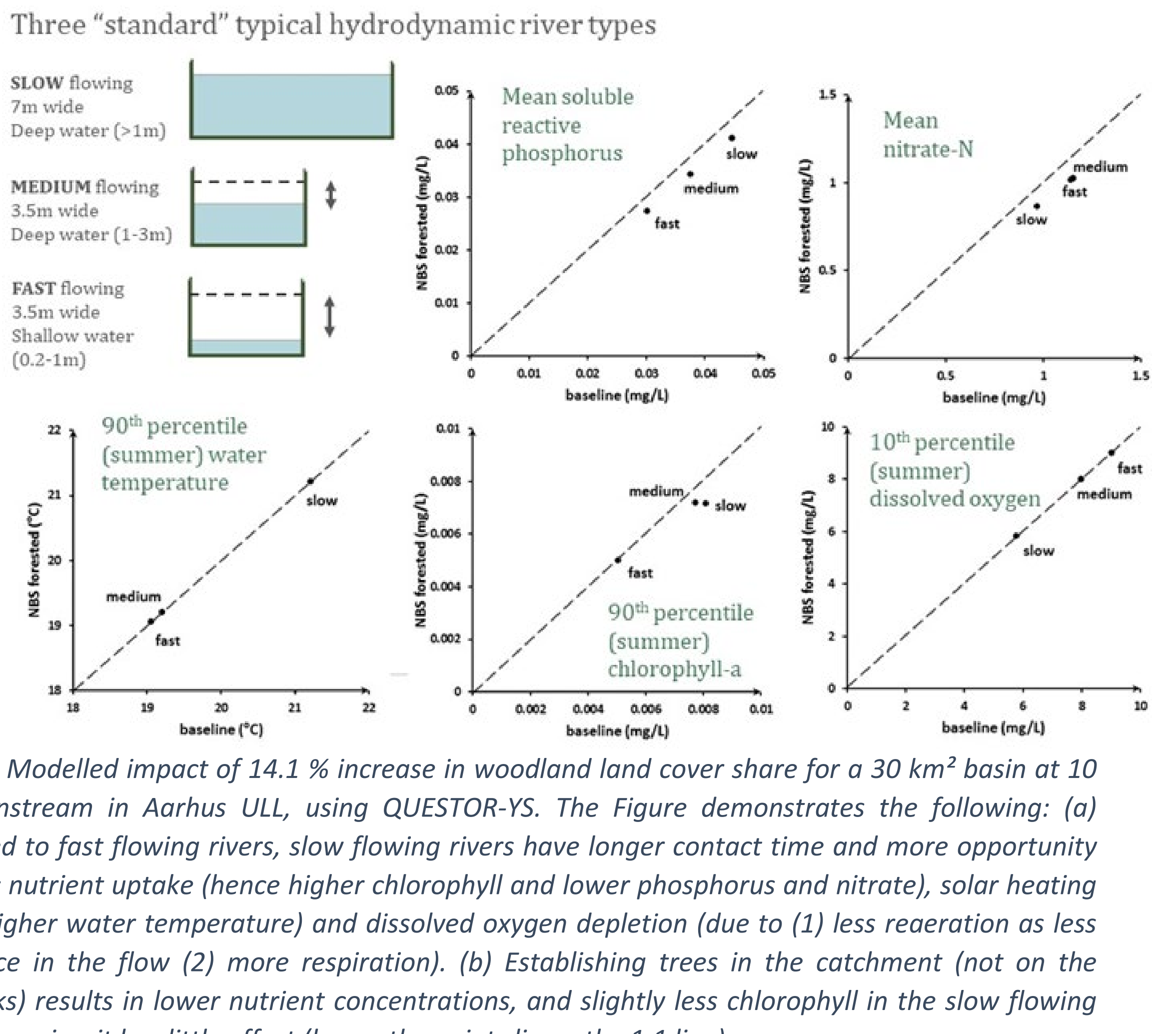

Figure 8: Modelled impact of 14.1 % increase in woodland land cover share for a 30 km² basin at 10 km downstream in Aarhus ULL, using QUESTOR-YS. The Figure demonstrates the following: (a) Compared to fast flowing rivers, slow flowing rivers have longer contact time and more opportunity for biotic nutrient uptake (hence higher chlorophyll and lower phosphorus and nitrate), solar heating (hence higher water temperature) and dissolved oxygen depletion (due to (1) less reaeration as less turbulence in the flow (2) more respiration). (b) Establishing trees in the catchment (not on the riverbanks) results in lower nutrient concentrations, and slightly less chlorophyll in the slow flowing case. Otherwise, it has little effect (hence the points lie on the 1:1 line).

Method

QUESTOR is a 1-D model of river networks used for simulating flow and eutrophication. It consists of a set of reaches bounded by influences (weirs, abstractions, effluents, tributary rivers). To determine flow routing, the reaches are defined by constant-width and variable-depth with travel time, water depth and discharge related using non-linear equations and information on riverbed condition. By linking flow routing to biochemical processes (as continuously stirred tank reactors) the reach structure represents advection and dispersion. Biologically QUESTOR represents primary producers: phytoplankton transported along the system (and also plants and benthic algae). The model has been used to assess water quality in river catchments of sizes ranging from <50 km^2 to ~10,000 km^2. Diffuse inputs can be represented by observations, process-based rainfall-runoff/diffuse pollution models or simple statistical models. Solar radiation inputs control water temperature and primary production.

Approach for REGREEN

The key variables and approach for the QUESTOR model are briefly described, followed by the approach to implement QUESTOR-YS.

Table 9: Basic information on output from water quality assessment model using QUESTOR

Scale of extent	Approximate spatial resolution of output	Temporal resolution
"Part of city" and larger scales (but can represent drivers at smaller scales)	Reaches (river stretches of hundreds of metres in length)	Hourly or daily

Table 10: Data input requirements for water quality assessment model using QUESTOR

Data type	Other information	Spatial resolution	Temporal resolution
Solar radiation	Either global radiation or sunshine hours/cloud cover	One nearby site	Hourly. At least 2 years
Riparian canopy cover	Derived from LiDAR or other photogrammetric data	Individual trees	Snapshot
River flows	Spot observations of water depth also very useful	Network of sites in a catchment	Daily resolution. At least two years duration
River water quality	Temperature, nutrients, oxygen, biochemical oxygen demand, chlorophyll	Network of sites in a catchment	~fortnightly/monthly or better. At least 2 years duration.
Abstractions and effluents	Flow volumes and water quality (can assume defaults)	Location and size	Minimum information is constant flow volume
River morphology	Width, riverbed condition, weir locations	Some within-catchment variability desirable	Snapshot

How NBS are incorporated

- NBS that influence rainfall-runoff response (e.g., green roofs, de-paving) will influence flow rate in the channel which then has an effect on water quality. For these a link to a hydrological model is necessary, which will be provided by linking to the water flooding model (see factsheet section 2.6).
- NBS that influence the channel directly (e.g., riparian shade establishment) only need the QUESTOR model.

Upscaling/Downscaling

- Test model for small sub-catchments (including NBS effect).
- Assume these are representative of neighbouring sub-catchments in the same river network and apply in those too.
- If necessary, add in other point sources (e.g., sewage treatment works) for a whole-city assessment. Some larger-scale responses such as regional groundwater are hard to include.
- Downscaling could involve splitting reaches up into smaller sub-reaches (but not really advisable below 100m resolution).

Standardised rivers approach using QUESTOR-YS

We have specified a standard urban catchment/river morphology which can be applied in all ULLs. This quantifies the differing relative benefits achievable with various types of NBS establishment in different cities. Approach as follows:

- The catchment size, river width and hydrodynamics will remain constant between cities which then allows identification of how sensitive river water quality is to local conditions.
- Local data characterising hydrology, climate and pollution. These do not need to be from specific rivers but just reflect typical summer conditions in the city: (1) river flow data from a typical urban river (2) some solar radiation (or sunshine hours) data. (3) Water temperature (or air temperature if problematic) (4) some water quality data from a typical urban river.
- Compare relative potential between ULLs for restoration benefits of various types: (1) daylighting, (2) riparian shade, (3) restoring meanders (4) catchment tree planting in headwaters or nearby. Evaluating other catchment NBS may be possible (e.g., grass swales, wetlands). The downstream spatial evolution of beneficial effects will be quantified.

Transferability

The methodology can be readily and easily transferred to any other cities (not just in REGREEN) provided basic data are available (as described for method 2 above).

Trade-off between detail and resources

Of the approaches described above we are now adopting method 2 in preference to method 1. This is a simple approach which makes it easy to apply in each city because the data demands are relatively small. The trade-off is that the river water quality we are simulating in each city has not been tested against data in specific situations. But that can be built in later by adapting the approach if desired (i.e., more similar to method 1).

From maps and models to ecosystem service assessment

The model has been applied for Aarhus ULL as part of a scenario-based ecosystem service assessment.

Current applications in REGREEN

The water quality assessment model has been applied for Aarhus ULL.

Outputs

Publications

The QUESTOR-YS model is described in the following paper:

- Hutchins, M., Qu, Y., Seifert-Dähnn, I., Levin, G. (in review). Comparing likely effectiveness of urban Nature-based Solutions worldwide: the example of riparian tree planting and water quality.

Datasets

- Not publicly available yet.

References

- Pathak, D., Hutchins, M.G., Brown, L., Loewenthal, M., Scarlett, P., Armstrong, L., Nichols, D., Bowes, M.J., Edwards, F. (2021) Hourly prediction of phytoplankton biomass and its environmental controls in lowland rivers. Water Resources Research, 57. https://doi.org/10.1029/2020WR028773
- Pathak, D., Hutchins, M.G., Brown, L., Loewenthal, M., Scarlett, P., Armstrong, L., Nichols, D., Bowes, M.J., Edwards, F., Old, G. (2022) High-resolution water-quality and ecosystem-metabolism modelling in lowland rivers. Limnology and Oceanography, 67, 1313-1327. https://doi.org/10.1002/lno.12079

This factsheet was updated: November 22, 2023

1.6 Hydrological modelling

Main contact, (and other people involved): James Miller (UKCEH), (Gianni Vesuviano (UKCEH))

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Short description of output

The hydrological model will produce time series of flow in either storm drains or open channels. The main model developed for REGREEN ANaRM (Adapted Nature-based Rational Method) is distributed and produces gridded outputs. We also employed the SWMM stormwater model that produces lumped catchment outlet location flows (Huber et al., 2005). Note, the outputs can also feed into the water quality QUESTOR model (see factsheet in section 2.5) input nodes as well as providing understanding on how NBS affect river flows in test catchments. Figure 9 shows an output of the ANaRM model for a catchment in Aarhus ULL. NBS scenarios that change urban land cover to Sustainable Drainage Systems (SuDS) and greenspace, alongside open areas to large attenuation ponds, are superimposed on the existing urban map and these alter runoff in these changed areas, which is then routed downstream, lowering flows in the river network.

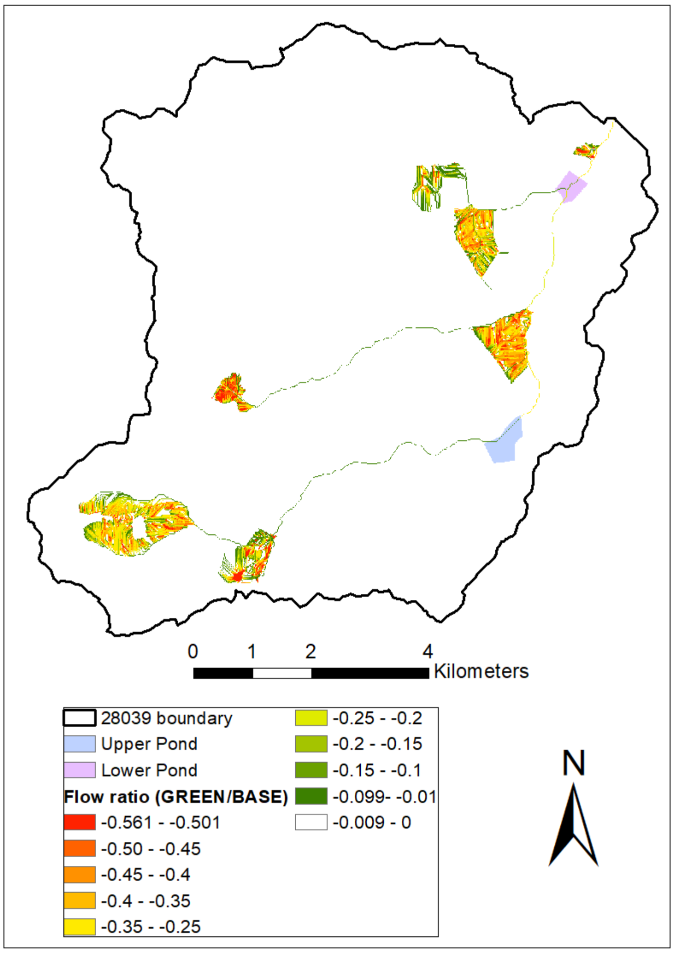

Figure 9: Map showing flow ratios between a base scenario and a NBS scenario in Aarhus ULL.

Method

Combination of using new ANaRM model with some validation using SWMM model Aarhus.

Approach for REGREEN

- Discussion with each ULL to find out what coverage of river data (flow, quality) is like (density of monitoring sites, variables measured).
- Choose one or two small river catchments to set up model in one ULL: ideally two with one containing NBS features the other not (control site) for testing the model in both situations. Alternatively, testing of a set up with just one catchment will be less rigorous unless historic (pre-NBS) data available. ULL to provide basic mapped information showing land use, river network and monitoring sites.
- Access data with help from ULLs.
- Define model and source code/model.
- Calibrate model using observed data.
- Validate model against observed data in chosen catchments.
- Analyse suitability for capturing NBS effects.
- Model various NBS scenarios – defined in project – such as varying share of green land cover (e.g., amount of green roofs or green space within catchment for NBS)
- As far as feasible, identify specific impact of NBS on hydrological processes.
- Explore ULL scenarios of implementing NBS and effect of location of NBS. In Paris, likely NBS to consider: De-paving and green roofs. Aarhus: green roofs, urban forest and local SuDS.

Table 11: Basic information on output from hydrological modelling

Scale of extent	Approximate spatial resolution of output	Temporal resolution
"Part of city" including areas with NBS and within a hydrological catchment	Catchments with land cover at minimum 50m and catchment from 1km^2	Hourly

Table 12: Data input requirements for hydrological modelling

Data type	Other information	Spatial resolution	Temporal resolution
Land cover	Gridded land cover map – showing greenspace and other NBS	10 m	2020 (or most recent available)
Digital elevation model		Horizontal 5m, Vertical 0.01m	As available
City hydrology	City river and storm drain mapping – including all surface water features (rivers, ponds, canals -essential) and sub-surface features (drains, major storage - if possible	Line/point	2020 (or most recent available)
NBS (location/type)	Location, type, details on installed NBS that are in agreed NBS list	5m / location (point)	When installed
River flows	Gauged flows (storm drain/open channel) across ULL – ideally some sites will be downstream of NBS, ideally	Network of sites in a catchment (point)	Sub-daily (15min - hourly resolution). At least two years duration
Channel morphology	Width, height, material – of gauged locations	1m	snapshot
Meteorological data	Rainfall and potential evapotranspiration	Ideally gridded - at least point from gauges	15 minutes

How NBS are incorporated

The model can be specifically set up to cover the agreed NBS – with a focus on green roofs and green space, and water retention basins – and how these affect runoff quantity and timing at a wider scale. This may require revision of how some LULC classes are mapped to best represent NBS.

Upscaling/Downscaling

The model can be set-up for multiple catchments in each ULL. It is possible to upscale from some model outputs, but this will have limits for scaling to larger catchments. What might be more suitable is to use outputs to develop a meta-model that can be used as a geographically based decision support tool. The model will be not suitable for the scale of e.g., a single park.

Transferability

The applied method will be easy to transfer if basic DEM and land cover data are available.

Comparability and consistency

The ANaRM outputs should be comparable to other ESS model outputs if they use the same consistent land cover and scenarios data. For example, if we assess the effects on water flows or NBS scenarios involving SuDS and trees using ANaRM, this might show changes in runoff and flows, while for a model looking at noise the effects from the same changes and NBS would relate only to sound.

Trade-off between detail and resources

Our approach was to develop a model that required a minimum of data and detail to ensure the model was useable in ESS toolkits and not require complex data. Despite its simplicity the model outputs (peak flows) were validated in the associated research and paper.

From maps and models to ecosystem service assessment

So far, the hydrological model has been applied for:

-
- Ecosystem service assessment using spatial or process-based model.

Current applications in REGREEN

The model has been applied for Aarhus ULL.

Outputs

Publications

The model is described in the following manuscript:

- Miller, J.D., Vesuviano, G., Wallbank, J.R., Fletcher, D.H. and Jones, L., (2023). Hydrological assessment of urban Nature-Based Solutions for urban planning using Ecosystem Service toolkit applications. Landscape and Urban Planning, 234, p.104737. https://doi.org/10.1016/j.landurbplan.2023.104737

Datasets

- Not publicly available yet.

References

- Huber, W.C., Rossman, L.A. and Dickinson, R.E. (2005) EPA storm water management model, SWMM5. In: Singh, V.P., Frevert, D.K. (Eds) Watershed models. Taylor and Francis. 359.

This factsheet was updated: January 30, 2023

1.7 Traffic noise mitigation

Main contact, (and other people involved): David Fletcher (UKCEH), (Laurence Jones (UKCEH))

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Short description of output

The output is a raster depiction of noise attenuation due to trees, with units in dBA[1], typically with a horizontal resolution of 10m. This can be interrogated, using shape files of residential buildings, to quantify the mitigation received.

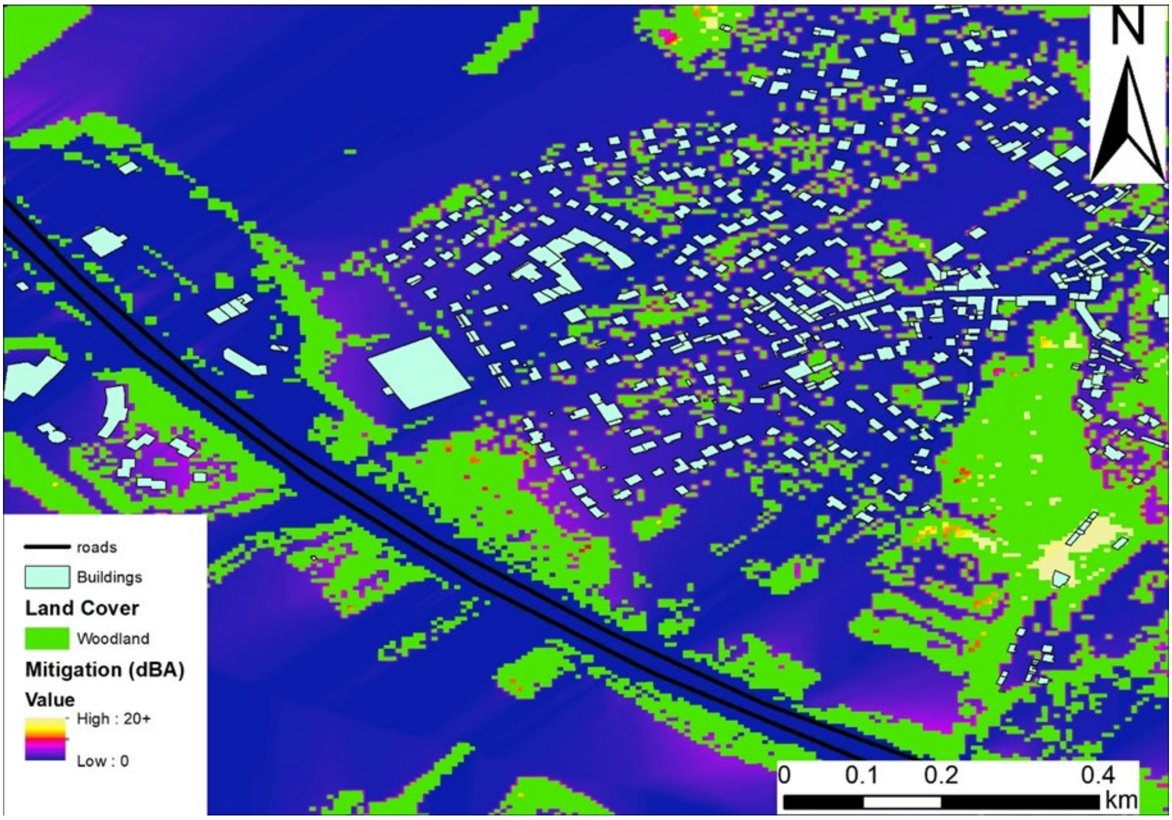

Figure 10: Mapped noise mitigation model output, displayed for a locale within Paris Region (1.958, 48.94 decimal degrees). Mitigation is depicted as A-weighted decibels, Lden (day, evening, night). This output can be subtracted from the European Noise Directive (END) statutory noise mapping data to provide a "with trees" exposure scenario for residential buildings.

Method

Statutory noise modelling, performed to satisfy the EU Noise Directive (Directive 2002/49/EC) does not currently account for the mitigating effects of vegetation, namely trees. Trees can have potentially substantial mitigating impact on the level of traffic noise experienced by residential properties (e.g., Van Renterghem, 2014). Quantifying the mitigating effect of trees is an important aspect of valuing natural capital. However, there is presently no freely available noise-modelling software that easily accounts for the effect of trees. Furthermore, traditional noise modelling approaches are very

[1] Noise level is measured in decibels (dB) and can be adjusted to account for human perception of different frequencies; termed A-weighted decibels (dbA).

processor intensive (hence, the EU statutory noise modelling is only carried out for major roads and does not account for vegetation).

Approach for REGREEN

Our approach uses the EU modelled traffic noise data (i.e., that which is produced to satisfy the EU Noise Directive 2002/49/EC) as a basis for calculating the mitigation due to woodland. In this newly developed approach, we exploit the concept of cost-distance, across a resistance-surface, to model the propagation of sound across a landscape. By modifying the resistance of specific regions, we imitate the attenuating effect of woodland on traffic noise. We base our approach on calculating the minimum anisotropic accumulated cost surface from defined origin points (points coincident with the major roads – the source of traffic noise), for a given resistance surface. The accumulated cost calculations are based on a transition matrix, representing the costs for traversing between adjacent cells of a raster dataset (the extent of the study area). These matrices are directional, so contain values for all, i.e. A→B & B→A, 8-directional adjacent cell transitions. The methodological sequence is as follows:

- Create Matrix 1, where the cost for moving is 100 units per metre, for all transitions.
- Create matrix 2, where the costs are calculated from the raw noise data, using a non-commutative function (NCF) that returns very small values (typically of the 0.001 magnitude), with lower values for reductions and high values for increases. The NCF takes the form:

  $$\max(x) - x[1] + x[2]$$

  Where x is comprised of two values: [1] value of origin cell; [2] value of the destination cell.
- Combine the costs in matrices 1 & 2, by addition, to create a transition Matrix 3, which we use as the basis to calculate the minimum anisotropic accumulated cost surface from the origin points. This output gives estimates of the distance from source that the sounds has travelled, for each grid cell.
- Copy Matrix 3 and then modify the values of this Matrix 4, by adding a cost of 100 units per metre to all grid cells coincident with the trees shape file.
- Calculate the minimum anisotropic accumulated cost surface from the origin points. This output allows us to calculate, for each cell coincident with the trees shape file the distance travelled through woodland, by subtracting the values of the initial accumulated cost surface (the cost for travelling through woodland was double that of the other cells).
- Copy Matrix 3 again and then modify the values of this Matrix 5 by adding a cost, calculated according to an attenuation-distance relationship for traffic noise travelling through woodland, taken from the literature (Van Renterghem, 2014). We use the distance travelled through woodland (from step 5) to calculate this additional cost.
- Calculate the minimum anisotropic accumulated cost surface from the origin points, based on Matrix 5, with the modified cost values corresponding to distance travelled through woodland. This output allows us to calculate the equivalent attenuation for each grid cell but applying the standard inverse-distance relationship of sound from a linear source. The shape of this relationship is curvilinear and follows the principle of a 3 dB drop in noise level every time the distance travelled doubles.

Table 13: Basic information on output from noise modelling

Scale of extent	Approximate spatial resolution of output	Temporal resolution
Whole city	10 m horizontal resolution	NA

Table 14: Data input requirements for noise modelling

Data type	Other information	Spatial resolution	Temporal resolution
Modelled Traffic Noise, raster Note, different noise metrics are available: Lden, LNight, are preferred, but others available (LA1018, etc.). Other noise sources: Rail might also be useful	Unclassified (i.e raw)	10 m horizontal	Most recent available
Trees, polygons shape file, or raster	Maybe useful to disaggregate trees by deciduous/evergreen	10 m horizontal (if raster format)	Most recent available
(If above trees dataset is not available) Land cover classification, including a trees class (or classes)	Maybe useful to disaggregate trees by deciduous/evergreen	10 m horizontal	Most recent available
Major roads, line shape file	To include those roads used in the traffic noise modelling	These should be accurate and match the trees data, spatially	Most recent available

How NBS are incorporated

NBS are represented in this analysis by the woodland shape file, used to modify the costs of traversing the landscape. Any NBS that contains woodland is incorporated in the modelling and could potentially, depending on the context, provide some degree of service of noise mitigation.

Upscaling/Downscaling

Any aggregation would be carried out on tabular data, calculated from extracting values for dwellings/buildings.

Transferability

The noise mitigation model can currently be directly transferred to any city for which the underlying statutory END noise mapping data are available. The other essential input data are a shapefile of the road network (widely available for all major cities) and raster data depicting woodland, which is commonly available for urban areas, either via the local administrative/planning office, or can be derived from satellite data (e.g., Sentinel-2 data, at 10m horizontal resolution).

Comparability and consistency

The noise mitigation modelling methods are currently being developed further, in order to allow the model to be applied in cities where there are no underlying END noise map data. However, it may not be possible to calculate monetary valuations of the service provided when using this version of the model, as the valuation of mitigation is contingent on knowing the exposure levels, both before and after accounting for the effects of woodland. Relatively detailed social data are also necessary for the valuation procedure, and these are not always available. Absence of spatial data depicting the locations of the population, or of some form of underlying noise-level data, would make it harder to run an inter-city comparison of the benefits provided by woodland. However, this can still be done in principle, by reducing the model outputs to a series of summary statistics on number of properties mitigated per hectare of trees, or number of people receiving noise mitigation, or health outcome, per hectare of trees.

Trade-off between detail and resources

Because the impacts of noise are directionally dependent, the noise modelling requires relatively highly detailed spatial data on underlying noise and woodland (minimum 10m resolution). Undertaking this sort of modelling at more coarse resolution would potentially introduce very large errors, as, for example, the mitigation provided by a belt of woodland may be dependent on which side of a two-lane highway it is located. We consider that 10m resolution is the minimum possible to be able to discern such details.

From maps and models to ecosystem service assessment

So far, the traffic noise mitigation model has been applied for:

- Mapping (uses high resolution mapping data of woodland for Paris);
- Ecosystem service assessment using spatial or process-based model (this approach runs a spatial model to calculate noise mitigation by trees);
- Assessment incorporates number/type of people benefiting from service (uses fine-scale population data, allocated to residential buildings); and
- Economic assessment of benefit (uses economic values for health impacts of noise).

Current applications in REGREEN

- Paris Region – all the way to full economic assessment of benefit.
- Paris city – all the way to full economic assessment of benefit.

Outputs

Publications

The model is described in the following paper:

- Fletcher, D.H., Garrett, J.K., Thomas, A., Fitch, A., Cryle, P., Shilton, S., Jones, L. (2022) Location, Location, Location: Modelling of Noise Mitigation by Urban Woodland Shows the Benefit of Targeted Tree Planting in Cities. Sustainability, 14, 7079. https://doi.org/10.3390/su14127079

Datasets

- Not yet publicly available

References

- Van Renterghem, T. (2014) Guidelines for optimizing road traffic noise shielding by non-deep tree belts. Ecological Engineering, 69, 276. https://doi.org/10.1016/j.ecoleng.2014.04.029

This factsheet was updated: January 30, 2023

1.8 Heat mitigation

Main contact, (and other people involved): David Neil Bird (JR), (Hannes Schwaiger (JR))

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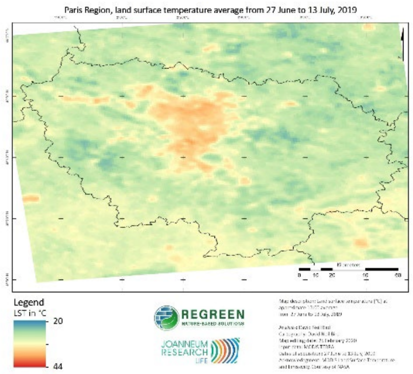
Short description of output

Maps of Urban Heat Island (UHI) at relevant scale and an estimation of the value of NBS to reduce UHI. There are three possible outputs:

- Maps of historical urban heat island at the relevant scale.
- Estimates of the value and impacts of NBS on the urban heat island based on historical data.
- Modelled urban heat island changes due to a specific action by the ULL to introduce or increase NBS.

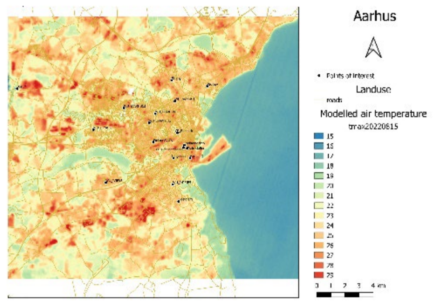
The scale will depend on the needs of the ULL. Examples are shown in Figure 11.

Regional-scale



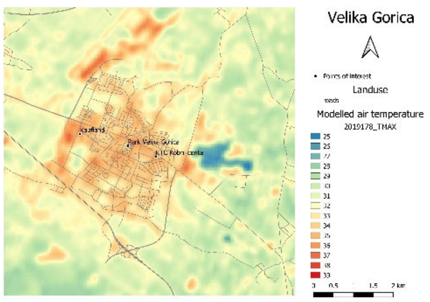
Example: Ile de France, July 12 2019, 14:00

City scale



Example: Aarhus, August 14 2022, 12:27. The maximum air temperature on this day was 26.8 °C. The city core, located around the harbour (center of image) has hot spot with up to 29.5 °C temperature. The sea (right) and large park south of the city centre along the coast appear as cooler areas

Local scale



Example: Velika Gorica, June 27, 2019, 13:44. The maximum air temperature on day was 35.6 °C in Zagreb. No weather stations in Velika Gorica are available. At the local scale, one can distinguish to how spots; Zagreb airport north of the town and a large shopping centre parking lot on the west edge of the town. The cool spot east of the town is a lake in an abandoned gravel pit.

Figure 11: Examples of Urban Heat Island mapping at different scales.

Method

Historical mapping of the UHI and the estimation of value and impacts of NBS is based on land surface temperature (LST) from satellite data (MODIS and / or LANDSAT 8/9). The LST is corrected to air temperature using historical ground-based temperature measurements.

<u>Modelling urban heat island changes</u> due to ULL specified actions to increase NBS can be done using a new method developed during the REGREEN project, in which the normalised differential vegetation index (NDVI) measured from satellite data (MODIS and / or LANDSAT 8/9) is modified due to ULL specified actions assuming analogies to existing urban landscapes. A modelled LST is calculated from the modified NDVI.

Model background

<u>Historical mapping of the UHI and the estimation of value and impacts of NBS</u>: MODIS and LANDSAT are used in most studies of UHI from remote sensing. LANDSAT has high spatial resolution (30m x 30m) but low temporal coverage (prior to 2022: 16-day repeat). Since the beginning of 2022, a second LANDSAT sensor has been in operation. This allows for LANDSAT images approximately every 8 days. MODIS, in contrast, has high temporal coverage (4 images per day) but low spatial resolution (1,000m x 1,000m). Which data one uses for the analysis depends on one‘s needs. Cloud cover influences the estimated LST and the high temporal resolution of MODIS allows one to overcome losses due to cloudy days. However, the air temperature effects of an NBS can be very localised and the high spatial resolution of LANDSAT can capture these effects.

Approach for REGREEN

- Historical UHI and valuation of NBS:
    - Collection of and processing of satellite based LST.
    - Correlation of LST to various indicators of NBS (such as vegetation index, percentage vegetation, vegetation metabolism rates, imperviousness).
    - Correction of LST to air temperature using ground-based temperature data.
- Modelling urban heat island changes
    - Identification of a specific NBS projects by the ULL, and/or creation of scenarios.
    - Modelled through changes in NDVI as specified by NBS project.
    - Collection of data and modelling.

Table 15: Basic information on output from heat mitigation modelling

Output type	Method	Scale of extent	Spatial resolution	Temporal resolution
Satellite based LST	MODIS	City or district scale	1,000m x 1,000m	2 times daily
	LANDSAT	All scales (city, district, local)	30m x 30m	Prior to 2022, once every 16 days. Since January 2022, once every 8-days

Table 16: Data input requirements for heat mitigation modelling

Data type	Other information	Horisontal and vertical resolution	Temporal resolution
MODIS satellite images	• NBS indicators • Ground temperature	1,000m x 1,000m	2 times daily
LANDSAT satellite images	• NBS indicators	30m x 30m	Prior to 2022, once every 16 days. Since

	• Ground temperature	January 2022, once every 8-days
•	•	
•	•	

How NBS are incorporated

The goal is to estimate and map the impacts of NBS on the urban heat island. This will be accomplished by:

- Deriving relationships of changes in historical UHI to one (or more) indicators of NBS; and/or
- Modelling the changes in UHI that result from a scenario for NBS interventions.

Upscaling/Downscaling

Historical UHI and valuation of NHS may potentially be usable over a wide area and possible to downscale. Modelled urban heat island changes due to a specific action by the ULL will not be able to be up scaled.

Transferability

The methodology has been successfully applied in all three European ULLs (Aarhus, Paris Region, and Velika Gorica). As MODIS and LANDSAT data are available globally, the remote sensing-based approaches can in principle be applied to any city or regions. Transferability of the model-based approaches depends on availability of required input data.

Comparability and consistency

Since the methodology uses the same data sources for all ULLs the results should be relatively comparable and consistent between all ULLs.

Trade-off between detail and resources

The methodology developed was chosen because it is not very resource and data demanding. All satellite data are freely available and simple to download. The processing flow and algorithms developed in “R” have been standardized for rapid processing.

The shortcomings of the method are, however, that it provides temperature estimates at a 30 m x 30 m resolution. Hence, it is only appropriate for some NBS. For example, the impacts of individual trees or microparks cannot be adequately modelled. In addition, the methodology focuses on vegetation and does not include water bodies.

From maps and models to ecosystem service assessment

So far, the heat mitigation model has been applied for:

- Mapping;
- Ecosystem service assessment using spatial or process-based model; and
- Economic assessment of benefit.

Current applications in REGREEN

So far, the model has been applied to:

- Paris Region – NDVI, LST and average and maximum air temperature in map form at 30m x 30m resolution for approximately every 25th day in 2019;
- Paris city – NDVI, LST and average and maximum air temperature in map form at 30m x 30m resolution for approximately every 25th day in 2019;
- Aarhus – NDVI, LST and average and maximum air temperature in map form at 30 m x 30 m resolution for 14 days in 2022 (to October 15); and
- Velica Gorica – NDVI, LST and average and maximum air temperature in map form at 30 m x 30 m resolution for approximately every 25th day in 2019.

Outputs

Publications

The model development is described in the following paper:

- Bird, D.N., Banzhaf, E., Knopp, J., Wu, W., Jones, L. (2022) Combining Spatial and Temporal Data to Create a Fine-Resolution Daily Urban Air Temperature Product from Remote Sensing Land Surface Temperature (LST) Data. Atmosphere 13 (7), 1152. https://doi.org/10.3390/atmos13071152

Datasets

Datasets internally available:

- Paris – NDVI, LST, Tmin, Tmax for every 25th day in 2019.
- Velika Gorica – NDVI, LST, Tmin, Tmax for every 25th day in 2019.
- Aarhus – NDVI, LST, Tmax for 14 days in 2022.

References

- None

This factsheet was updated: January 30, 2023

1.9 Air pollution modelling

Main contact, (and other people involved): Janice Scheffler (UKCEH), Massimo Vieno (UKCEH), (Laurence Jones (UKCEH), Alice Fitch (UKCEH))

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Short description of output

The European Monitoring and Evaluation Programme Meteorological Synthesizing Centre - West (MSC-W) model (EMEP MSC-W – www.emep.int) coupled with the Weather and Forecast Research (WRF) model (https://www.mmm.ucar.edu/models/wrf), named EMEP-WRF hereafter, is used in Regreen to calculates the 3D+time atmospheric composition. The WRF model calculates the required 3D+time meteorological variables; such as temperature, wind speed and precipitation. The EMEP-WRF horizontal and vertical resolution varies depending on the specific application. For the Regreen project domain a resolution of 3 km x 3 km was used that includes all the cities in the project (see Figure 12). An additional 27 km x 27 km domain (not shown here) covering Europe was used as boundary conditions for the Regreen domain.

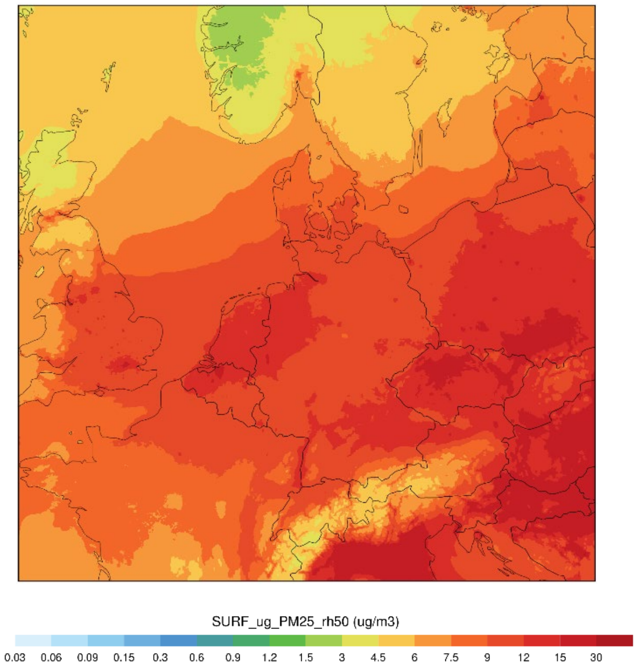

Figure 12 Surface concentration of $PM_{2.5}$ [µg/m^3] for 2018.

Method

The EMEP-WRF is a photochemistry model capable of representing the hourly atmospheric composition at a horizontal scale ranging from 100 km to 1 km. The Weather Research Forecast (WRF) model is used as the (3D) meteorological input. The EMEP-WRF model simulates hourly to annual average atmospheric composition and deposition of various pollutants; including $PM_{2.5}$, secondary organic aerosols (SOA), elemental carbon (EC), secondary inorganic aerosols (SIA), sulphur dioxide (SO_2), ammonia (NH_3), nitrogen oxides (NO_x), and ozone (O_3). EMEP-WRF includes dry and wet deposition of pollutants. Model outputs are validated against measured concentrations at official air quality monitoring sites. See example in Figure 13.

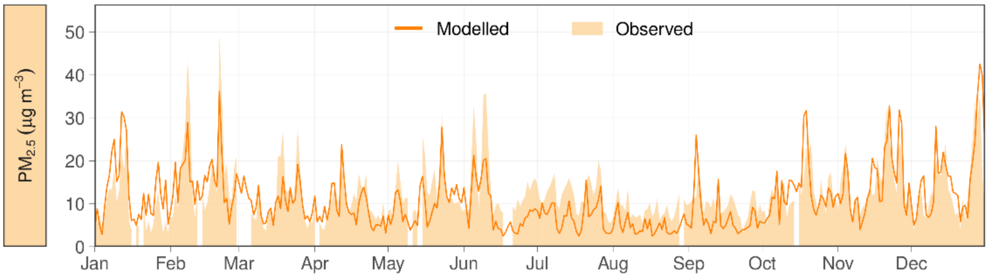

Figure 13 Modelled (line) and observed (shading) surface concentration of PM2.5 [µg/m^3] for 2018 for Gonesse, Paris Region.

Approach for REGREEN

For Europe, the EMEP-WRF model domain includes the three European ULLs at a horizontal resolution of 3 km x 3 km, nested within a wider European domain run at 27 km x 27 km. The WRF meteorology is calculated for the REGREEN domains and thereafter the chemistry EMEP model is used to evaluate the changes in air quality and atmospheric compositions and changes due to current and perturbated green areas.

Since EMEP-WRF runs at a coarser resolution than other ecosystem service models, for REGREEN runs, specific scenarios were created to test questions about the benefits of pollution removal by vegetation (trees, grass, crops, etc.) which operate at city scale and in the peri-urban surroundings. These scenarios explored, for example, how much $PM_{2.5}$ pollution trees remove when they are located within the urban footprint, compared with the same area of trees located outside the urban footprint but within the peri-urban areas of the municipal boundary.

Basic information on map/model output

Scale of extent (e.g. single park, city centre or part of city, whole city, small area but up-scale to whole city)	Entire Europe, including the REGREEN ULLs
Approximate spatial resolution of output (e.g. metres, city block)	~27 km x 27 km for Europe down to 3 km x 3 km for the cities included here
Temporal resolution (time points) of output (if relevant)	Hourly – meteorology and chemistry

Data table for input requirements

Data type	**Other information (e.g. requirements; thematic classes or features needed)**	**Spatial resolution (& vertical if important)**	**Time points, year(s)**
Gridded emissions	NO_x, SO_x, $PM_{2.5}$, VOCs, PM_{co}, CO, NH_3	0.1° x 0.1°	Hourly to Annual

How NBS are incorporated

The EMEP-WRF calculates the removal of pollutants by the vegetation. The model is used to quantify how much pollution is removed (or emitted) by current and additional vegetation, and the resulting change in pollutant concentration as a result of that removal. This can be used to estimate change in exposure of urban populations to air pollution, and the consequent health benefits.

Upscaling/Downscaling

Model results can be transferred to other areas by creating a meta-model from the outputs of the larger scale runs. Some results can be downscaled/ disaggregated.

For example, the quantity of pollution removed by woodland can be attributed spatially to the locations in the city where woodland occurs. However, some aspects cannot easily be disaggregated to a finer resolution below the grid cell resolution of the model (3 km x 3 km for European ULLs). This is because the benefits in terms of reduced pollution concentrations, and the pollution concentrations themselves cannot easily be disaggregated. It may be possible to do some limited disaggregation if finer resolution pollution concentration maps are available, but this also needs to consider other factors such as air mass transport.

Transferability

The outputs from the EMEP-WRF model can be used to derive meta-models which allow transferability to different contexts around Europe. These will likely use information on relative proportion of tree cover, background concentrations of $PM_{2.5}$, and deposition (removal) rates of $PM_{2.5}$ to assess the ecosystem service provided.

Comparability and consistency

Raw EMEP-WRF model outputs on pollutant concentrations are validated against fixed monitoring stations around Europe. Processed model outputs are checked for comparability against previous model runs and calculations made in assessing the pollutant removal service. Previous analytical results are shown to be comparable to I-Tree assessments for some pollutants, and where they differ, the reasons for this are known (e.g. the more comprehensive treatment of NO emissions in the EMEP-WRF model compared with I-Tree).

Trade-off between detail and resources

In the case of EMEP-WRF, the strengths of this modelling approach are that it incorporates the detailed atmospheric interactions that occur between pollutants and with meteorological parameters, in combination with the atmospheric transport component. This realistically represents the context-dependency of pollutant removal on weather and atmospheric chemistry. The trade-off is that this sort of computer model can only be run on high-power computing clusters due to the very high data and processing demands. A further trade-off is that there is less scope (currently) to differentiate a large number of vegetation classes in the model. This is likely to change in the future however, as approaches to expand the forms and types of vegetation that can be represented in the model.

One last consideration is the spatial scale at which the model runs. The atmospheric chemistry interactions are modelled at a relatively coarse scale compared with the scale of typical urban fabric (3 km x 3 km in this application, although finer applications to 1 km x 1 km are currently possible). However, this scale is appropriate to capture most of the transport and chemistry mechanisms, since vegetation cover upwind will influence pollutant concentrations and pollutant capture downwind. Finer-scale scenarios operating at within-city scales can still be represented in the model as varying proportions of land cover which is used as input to the model. However, the fine-scale spatial variation in change in pollutant concentrations cannot easily be represented. To achieve fine-scale accuracy in concentrations requires a different type of model to reflect dispersion and barrier effects at fine-scale

(CFD – computational fluid dynamics models), as well as detailed information on the location of emission sources. At present there is no robust approach to bridge these two modelling scales. For REGREEN calculations, we use the outputs from EMEP-WRF to derive meta-models which are city-specific, and so allow predictions of changes from other scenarios in a manner that takes into account local city context (see factsheet on “Air pollution meta-model - PM2.5 air pollution removal by trees”).

From maps and models to ecosystem service assessment

So far, the air pollution removal model has been applied for:

- Mapping the change in pollutant concentration and deposition for all European ULLs,
- Ecosystem service assessment using spatial or process-based model; and
- Economic assessment of benefit.

Current applications in REGREEN

The model calculations are being run for all three European ULLs, nested within a domain covering the whole of Europe. Model results will be extracted for each city and summarised to create meta-models. Several runs will be conducted, following different vegetation management scenarios for urban and for peri-urban vegetation. The model runs therefore cover all cities below:

- Paris Region
- Paris city
- Aarhus
- Velika Gorica

Outputs

- Datasets - Not publicly available yet.

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1.10 Air pollution meta-model - $PM_{2.5}$ air pollution removal by trees

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Short description of output

The model output is a raster grid, containing estimates of $PM_{2.5}$ [2] (kg ha^{-1}) removed per annum. Numerical values only occur in grid cells containing woodland/trees, as this is where $PM_{2.5}$ deposition happens. Additionally, a reduction in concentration is calculated, with a single estimate given for the entire extent of the city (i.e., not mapped over a raster grid – see below for explanation. This approach may be refined in subsequent work to allow some spatial differentiation across the city).

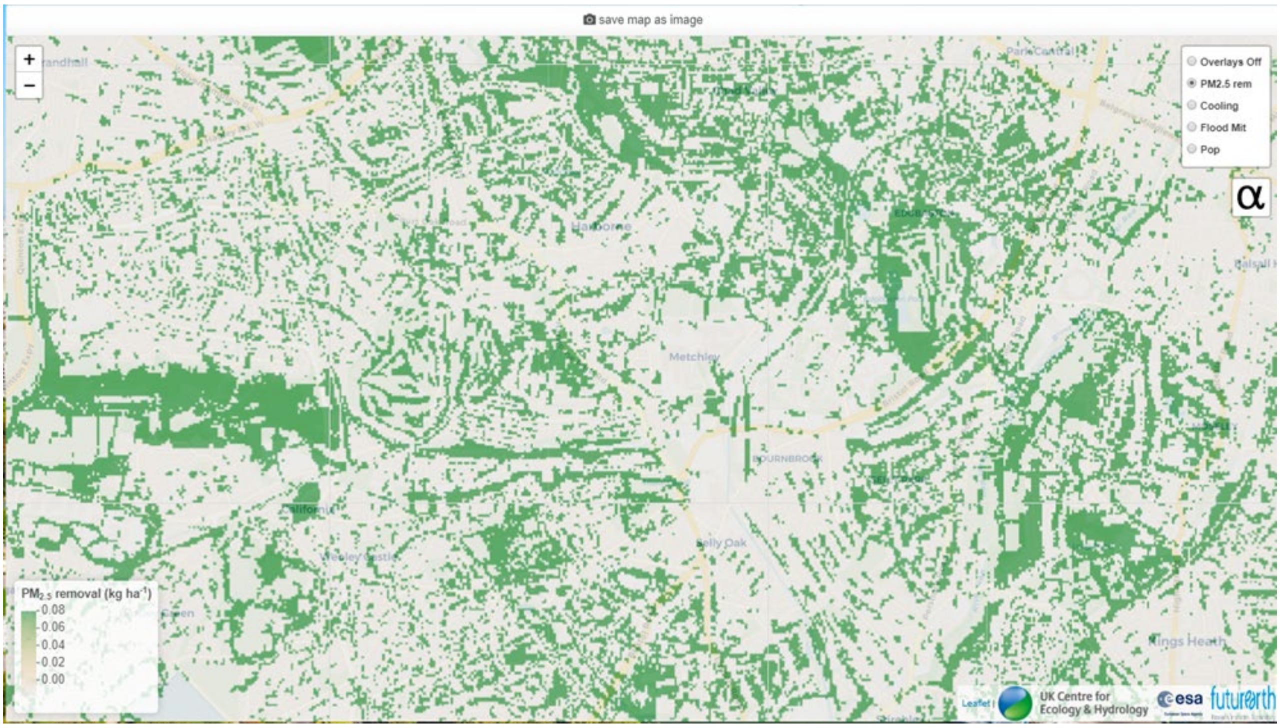

Figure 14: Example of $PM_{2.5}$ removal model output, displayed in City Explorer Toolkit web-app.

[2] Particulate Matter of diameter 2.5 micrometres or less.

Method

Air pollution removed ($PM_{2.5}$) by woodland is calculated using methods derived by re-analysis of data from Jones et al. (2017) and Jones et al. (2019). A meta-model was created in the form of two regression equations to calculate quantity of $PM_{2.5}$ pollution removed by woodland, and the resulting change in $PM_{2.5}$ concentration. For the first equation, analysis showed that pollution removal was linearly related to amount of woodland, but efficiency varied according to $PM_{2.5}$ concentration. Therefore, we simplified the response variable to pollution removed per hectare of woodland, resulting in the following equation in which $PM_{2.5}$ concentration is the only predictor variable. This calculation can be used to calculate $PM_{2.5}$ removal rate of any sized area of woodland:

*PM_removal_rate = 1.1664 * PM_conc + 0.4837*

where PM_removal_rate is quantity of $PM_{2.5}$ removed per unit area of woodland per year (kg ha^{-1} yr^{-1}), and PM_conc is the concentration of $PM_{2.5}$ (µg/ m^3). This equation can then be used to calculate the quantity of pollution removed by factoring in the total area of woodland in the area of interest.

The second equation calculates the change in $PM_{2.5}$ concentration that occurs as a result of pollution removal through dry deposition processes and is a function of the proportion of woodland in an area, the initial concentration of $PM_{2.5}$, and an interaction term between those two factors. Since a realistic change in pollutant concentration can only be achieved with vegetation over a large area, this equation is designed to be used at a city scale using average $PM_{2.5}$ concentration and overall proportion of woodland:

*Change_PM_conc = -0.0318 * PM_conc –0.1112 * Log10WoodPC – 0.054*

** PMxLogWood + 0.0832*

where Change_PM_conc is the change in $PM_{2.5}$5 concentration (µg/ m^3), PM_conc is the initial $PM_{2.5}$ concentration (µg/ m^3), Log10WoodPC is the Log10 of the percentage of woodland (percentage +1%, to avoid very low values) in the relevant area, and PMxLogWood is PM_conc multiplied by Log10WoodPC. Taking account of spatial location of beneficiaries and pollutant exposure within a city could be achieved by calculating a population weighted average $PM_{2.5}$ concentration as an input to the equation.

Approach for REGREEN

Ongoing work in REGREEN is adapting this approach based on the outputs from the EMEP runs, to create new REGREEN-focused meta-model equations, one for each city, derived from bespoke scenarios created to run EMEP across the European domain.

Table 17: Basic information on output from $PM_{2.5}$ removal modelling.

Scale of extent	Approximate spatial resolution of output	Temporal resolution
Whole city region (e.g., Paris Region)	Matches the land cover data, used as the input.	Inputs should be annual average $PM_{2.5}$ concentrations and outputs are also annual (total removed and average reduction in concentration).

Table 18: Data input requirements for $PM_{2.5}$ removal modelling.

Data type	Spatial resolution	Temporal resolution
$PM_{2.5}$ concentration (raster)	Highest resolution available	Annual mean
Trees/woodland	10m	NA

How NBS are incorporated

The meta-model calculates the removal of pollutants by the trees. The model is used to quantify how much pollution is actually removed by adding or by current trees. Different NBS configurations may be tested, and the effect quantified. The meta-model only models the effects of trees. Land cover data are used as the input, with the trees/woodland class isolated from all other classes.

Upscaling/Downscaling

The equation for quantity of pollutant ($PM_{2.5}$) removed can be applied at any scale, and any location. It has already been used in global applications but will be refined using new REGREEN outputs. The equation for city-scale change in pollutant concentration should only be applied at city-scale.

Transferability

The principal inputs for the model are tree canopy/woodland coverage and annual-averaged ground-level atmospheric $PM_{2.5}$ concentration spatial data. Providing these datasets are available for the full extent of the city in question, then the model can provide estimates of $PM_{2.5}$ removed and reduction in mean concentration.

Comparability and consistency

Spatial resolution of both $PM_{2.5}$ concentration and woodland data are likely to impact comparability of outputs, where these vary across between studies. Sentinel-2-derived land cover classification can provide a universal source of tree/woodland extent (canopy cover) data, at 10m horizontal resolution, which supports comparability between cities/regions. Near-global annual mean $PM_{2.5}$ concentration datasets are available (e.g., van Donkelaar et al., 2018), however, such datasets tend to be at relatively coarse spatial resolution. Higher resolution local/regional model outputs can be available for some (e.g., from Airparif, for Paris city region), but not all, cities. Comparisons between cites, using different $PM_{2.5}$ concentration datasets should be carried out with caution (and particular attention should be paid to quantified errors of the methods used to create the dataset).

Trade-off between detail and resources

The meta-model for quantity of pollution removed is very simple, so can be used at high resolution without any significant issues. However, model outputs at spatial resolutions beyond (i.e., greater than) 5-10 m are unlikely to provide additional meaningful information.

The meta-model approach for change in PM2.5 concentration can be applied at the resolution of the EMEP-WRF run (i.e. 3x3km), but can be disaggregated to finer scales of underlying pollutant concentration data, with some assumptions.

From maps and models to ecosystem service assessment

So far, the air pollution removal model has been applied for:

- Mapping (uses REGREEN mapping as input);

- Ecosystem service assessment using spatial or process-based model (uses a meta-model to calculate service provided);
- Assessment incorporates number/type of people benefitting from service; and
- Economic assessment of benefit.

Current applications in REGREEN

The meta-model has been applied in Paris region, Aarhus and Velika Gorica ULLs.

Outputs

Publications

The meta-model approach described here is outlined in the following paper:

- Fletcher, D.H., Likongwe, P.J., Chiotha, S.S., Nduwayezu, G., Mallick, D., Md, N.U., Rahman, A., Golovátina-Mora, P., Lotero, L., Bricker, S., Tsirizeni, M. (2021) Using demand mapping to assess the benefits of urban green and blue space in cities from four continents. Science of The Total Environment, 785, 147238. https://doi.org/10.1016/j.scitotenv.2021.147238

Datasets

- Not publicly available yet.

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This factsheet was updated: November 22, 2023

1.11 Biodiversity - habitat quality potential of urban green spaces

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Short description of output

The outputs include radar charts and maps showing the habitat quality of green space patches. The habitat value is a unitless number ranging between 0 and 1, which indicates the potential of a green space patch to support urban biodiversity compared to other green space patches in the studied area.

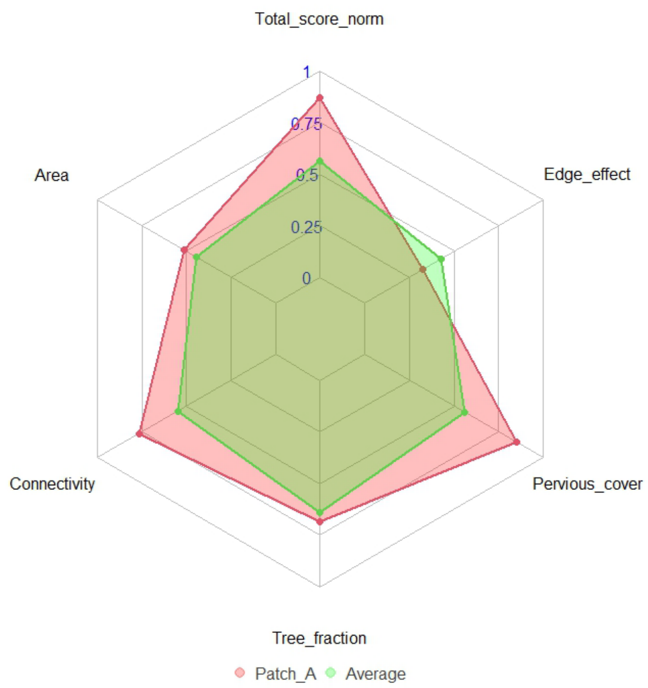

Figure 15: A radar chart showing the comparative potential of an urban green space to support urban biodiversity. A patch (patches) with the lowest habitat value will be assigned a value of zero, while the patch (patches) with the highest habitat value will be given a value of one of the total scores. The average values of each indicator and the total score are shown for comparative purposes. In this example, the patch has an above-average habitat value. In the five metrics used to construct the habitat value, the patch only performs poorer than average in terms of edge effect.

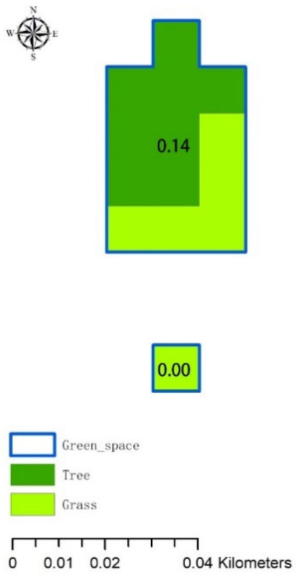

Figure 16: A simulated data showing the habitat values of five green space patches. Green space consists of trees and grasses.

Method

To map the biodiversity of a park, a city district, or a city mainly takes two ways: directly or indirectly. The direct way is to put the occurrence of flora and fauna on the map. This way requires detailed field data, which is rarely available. Most studies use the indirect method, which measures the habitat quality of a place instead of biodiversity. It assumes that areas with high habitat quality can support higher biodiversity. The InVEST Habitat Quality model (Hamel et al., 2021; Terrado et al., 2016) and the Singapore Index (City biodiversity index) (Chan et al., 2021) are the two representative methods. The InVEST Habitat Quality model combines maps of land use land cover (LULC) with data on threats to habitats and habitat response. The threat levels and the sensitivity of different land use are key parameters. However, those parameters are difficult to estimate, so they are often arbitrarily assigned. The Singapore index is suitable for comparing urban biodiversity at the district or city level as it has a governance component. Therefore, a mapping method that primarily depends on objective data and can be scaled up is needed.

Approach for REGREEN

- Our approach uses the land cover data to calculate the habitat quality of urban green space patches. Based on existing knowledge of the relationship between urban landscape and biodiversity, we construct a composite index from five landscape metrics at the patch level to indicate the habitat quality of the patches. The detailed process is shown below.
- Create urban green space patches. First, the urban boundary map will be used to delineate urban areas. The tree and grass classes were extracted from land cover data and merged as urban green space patches. For cities where land use maps were available, urban green spaces can be directly extracted from the maps and used as masks to extract land cover from land cover products.
- The following landscape metrics (Table 1) at the patch level will be calculated for each urban green space patch. Values of all metrics will be normalized to a range of zero and one using a Min-Max transformation.

- A composite index will be calculated by aggregating the metrics values. Equal weights are used.
- The composite index value can be used to plot radar charts for each green space or generate maps. The mean values of each landscape metric and the composite index can be calculated for any geography unit.

Table 19: Landscape metrics used to calculate a composite indicator.

Name	Acronym	Description	Value
Patch area (ha)	AREA	The area of the patch. In general, large patches can support higher diversity than small patches.	AREA>0, without limit
Edge contrast index	ECON	The sum of the patch perimeter segment lengths (m) is multiplied by their corresponding contrast weights divided by the total patch perimeter (m). The metric indicates the potential magnitude of the edge effect. A higher edge effect in urban areas often means more disturbance.	0⩽ECON≤100
Euclidian nearest neighbour index (meter)	ENN	The distance (m) to the nearest neighbouring patch of the same type is based on the shortest edge-to-edge distance. The metric indicates the connectivity of the patch. Patches with higher connectivity are less isolated and are beneficial to biodiversity in general.	ENN>0, without limit
Percentage of tree cover in the patch	TREE	The percentage of tree cover inside a green space patch. Many studies in cities in temperate biome found that a high percentage of tree cover supports more wildlife.	TREE≥0, up to 100
Percentage of pervious surface areas in the 500m buffer around the patch	PERV	The percentage of pervious surface inside the buffer zone (500m) of a green space patch. It can be calculated as 100-% of impervious surface. Impervious areas around the patch can hinder the dispersal of plant and animal species.	PERV⩾0, up to 100

Table 20: Basic information on output from mapping the habitat quality of urban green spaces.

Scale of extent	Approximate spatial resolution of output	Temporal resolution
From a single site to a whole city	10 m horizontal resolution	NA

Table 21: Data input requirements for mapping the habitat quality of urban green spaces.

Data type	Other information	Spatial resolution	Time points, year(s)
Land cover map	Include following classes 1. Tree/Shrub 2. Grass 3. Impervious area 4. Water	10 m horizontal (ESA or ESRI 10m)	Most recent available
Urban boundary data	Contain urban boundaries of cities	10m-30m (GHS built-up surface grid)	Most recent available
Land use map (optional)	Contain the class of urban green spaces or classes that form urban green spaces, e.g., parks, green belt	10-100m Raster map and vector map	Most recent available
Major roads, line shapefile	To the level of residential access roads	To the class of residential access roads	Most recent available

How NBS are incorporated

NBS are represented in this analysis by the green spaces.

Upscaling/Downscaling

Upscaling is possible. Habitat quality at the block, district, and city levels can be calculated by averaging the composite index of green spaces inside these places. The selected patch metrics allow averaging at the class level.

Transferability

The habitat quality mapping method can be transferred/applied to any city and region. The primary data source is land cover maps, which are freely available (e.g., ESRI 10 m Global land cover products). Other required data, such as road networks (e.g., Open Street map), are also freely available.

Comparability and consistency

The habitat quality mapping method currently only considers the landscape features of urban green spaces. The simplification enables the use of the method in places where biodiversity monitoring data is scarce. A more complicated approach is incorporating biodiversity monitoring data into the mapping process. For example, some cities have citizen science data like eBird data for large urban green space patches. They may be added as an indicator or used to calibrate the results of the current method. However, data availability will restrict this option.

Trade-off between detail and resources

The field survey data of flora and fauna in each green space patch will give the most accurate and detailed estimate of the biodiversity value of urban green spaces. Nevertheless, this type of data is only available in some cities. Assessing the habitat quality of the urban green space is a commonly adopted alternative. Landscape metrics that have a proven relationship with biodiversity can provide a good indication of the habitat quality of urban green spaces. These landscape metrics can be derived from land cover maps or remote sensing data that are freely available for all cities worldwide.

From maps and models to ecosystem service assessment

So far, the habitat quality mapping has not yet been applied for ecosystem service assessment

Current applications in REGREEN

- The method is currently being developed for Beijing ULL.

Outputs

Publications

- No publications yet.

Datasets

- Not publicly available yet.

References

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This factsheet was updated: January 30, 2023

1.12 Biodiversity – threshold indices for urban green spaces

Main contact, (and other people involved): Julius Knopp (TU), Marie Spanier (MNHN), Gregor Levin (AU)

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Short description of output

The outputs include maps and statistics for thresholds for size, proportion of canopy cover and proportion of grass cover for urban green space. Thresholds are derived from literature and reflect urban green spaces' potential as habitat for specific key species.

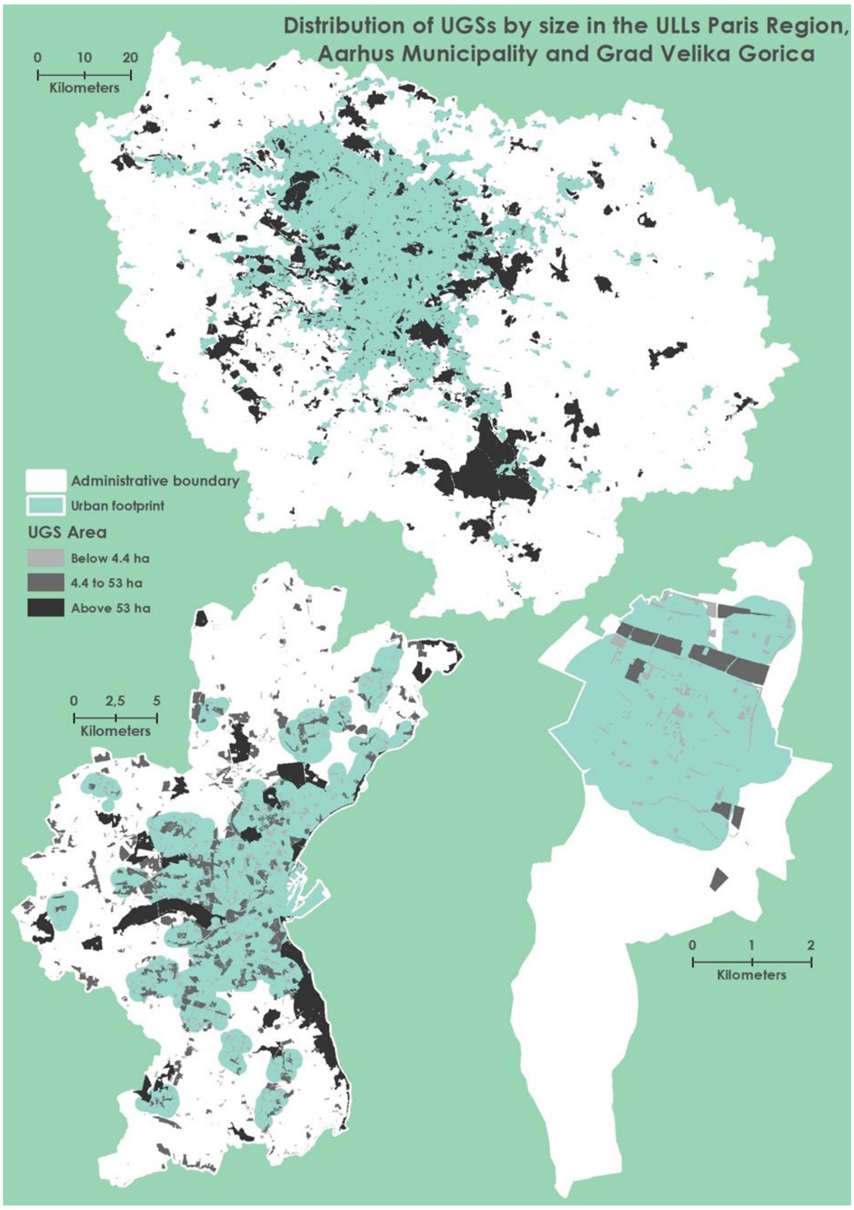

Figure 17: Distribution of urban green spaces by size for Paris Region, Aarhus municipality and Grad Velika Gorica

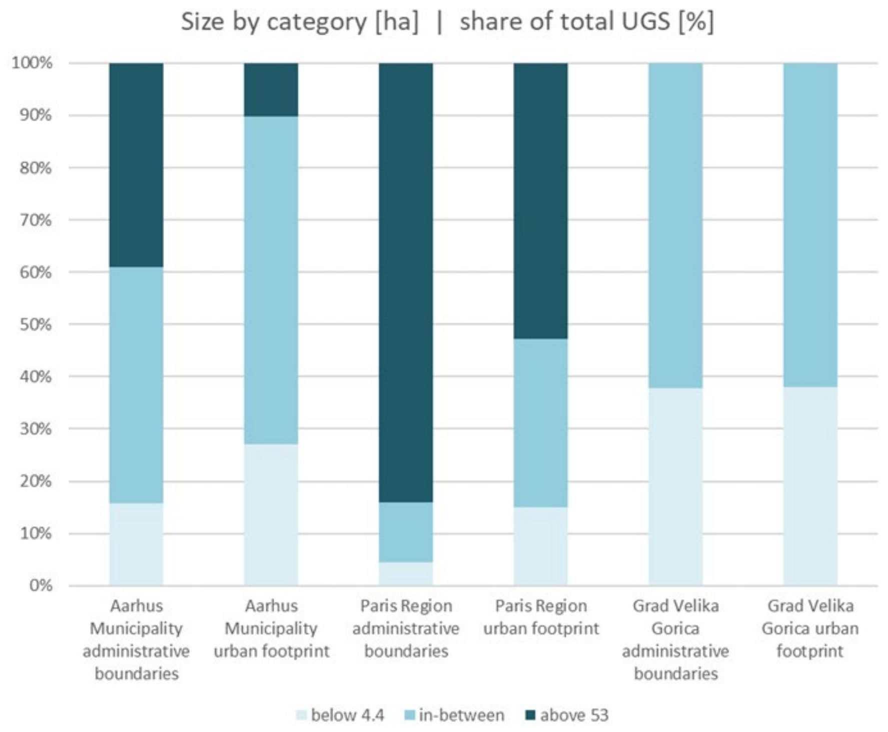

Figure 18: Distribution of urban green spaces by size within the ULLs, both within their LAU (local administrative unit) and their urban footprints

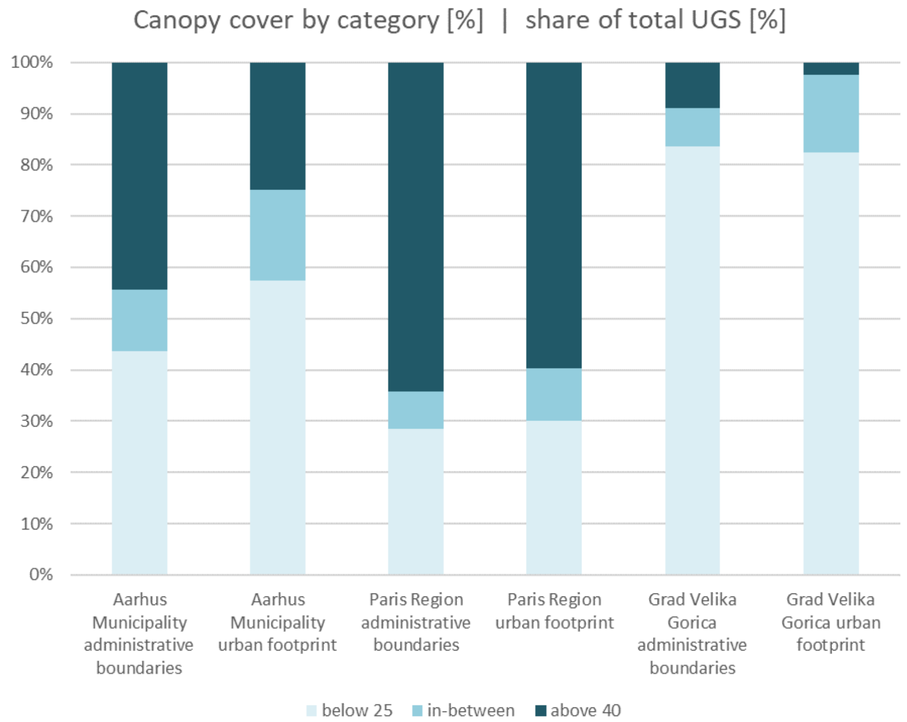

Figure 19: Distribution of urban green spaces by canopy cover within the ULLs, both within their LAU and their urban footprints

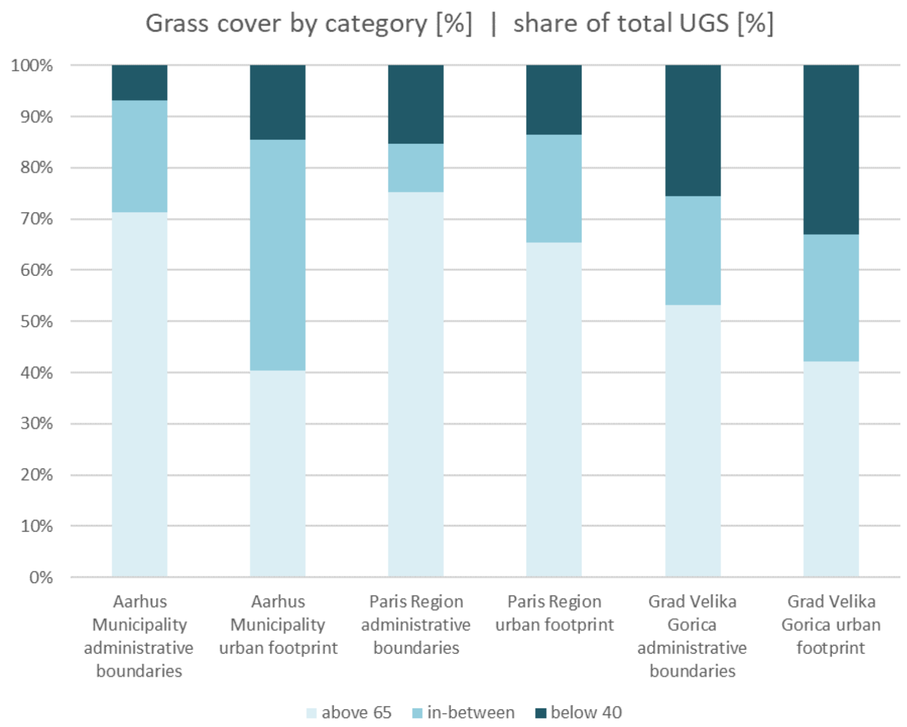

Figure 20: Distribution of urban green spaces by grass coverage within the ULLs, both within their LAU and their urban footprints

Method

Applied thresholds for size and for canopy and grass cover are derived from existing literature (Beninde et al., 2015; Spotswood et al., 2019; Vega & Küffer, 2001). To assess size and proportions canopy and grass cover for urban green spaces, vector layers of the delineation of green spaces are overlaid with high resolution raster or vector layers of land cover. Subsequently, the area and proportion of size, canopy cover and grass cover are calculated for each urban green space and summarised at city level. Since the applied thresholds are specifically relevant for urban spaces, indices are also calculated within the functional urban area, reflected by the urban footprint (see fact sheet 1.3).

Approach for REGREEN

- Layers of green space delineation were provided by ULLs
- High resolution land cover data were produced for all European ULLs (see fact sheet 1.2)

Table 22: Basic information on outputs from threshold indices for urban green spaces

ULL	Spatial resolution	Years	Categories
Aarhus	20 cm	2014	Size, canopy coverage, grass coverage for public green spaces
Paris Region	NA, vector based	2017	Size, canopy coverage, grass coverage for public green spaces
Velika Gorica	30 cm	2016	Size, canopy coverage, grass coverage for public green spaces

Table 23: Data input requirements threshold indices for urban green spaces

Data name	Data format	Spatial resolution	Data detail
High resolution land cover maps	Raster or vector	<= 10 meters	Described in fact sheet 1.2
Delineation of public green spaces	Raster or vector	<= 10 meters	Derived from ULL
Urban footprint	Vector	<= 10 meters	See fact sheet 1.3

How NBS are incorporated

Not applicable

Upscaling/Downscaling

Applied maps are at the highest possible resolution (<= 10 meters) and upscaling is therefore not feasible.

Transferability

Depending on data availability, the applied method can principally be transferred to any city.

Comparability and consistency

As applied input datasets have comparable resolutions and categorisation, outputs are comparable and consistent across the ULLs.

From maps and models for ecosystem service assessment

So far, the threshold indices have only been applied for assessments at ULL scale

Current applications in REGREEN

The threshold indices have been applied for all 3 European ULLs.

Outputs

Publications

- No publications yet.

Datasets

- Not publicly available yet.

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- Spotswood, E.N., Grossinger, R.M., Hagerty, S., Bazo, M., Benjamin, M., Beller, E.E., Grenier, L., & Askevold, R.A. (2019). Making Nature's City
- Szulczewska, B., Giedych, R., Borowski, J., Kuchcik, M., Sikorski, P., Mazurkiewicz, A., & Stańczyk, T. (2014). How much green is needed for a vital neighbourhood? In search for empirical evidence. Land Use Policy, 38, 330-345.

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- Vega, K. A., & Küffer, C. (2021). Promoting wildflower biodiversity in dense and green cities: the important role of small vegetation patches. Urban Forestry & Urban Greening, 127165

This factsheet was updated: November 22, 2023

1.13 Vital statistics for European ULLs

Main contact, (and other people involved) Julius Knopp (UFZ), (Gregor Levin (AU), Ellen Banzhaf (UFZ))

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Short description of output

Collected datasets on demographic, social and economic variables for the three European ULLs. The datasets were provided, and their categories translated into English by the ULLs. Spatial assignment of statistical values varies from spatially explicit address or building scale to information aggregated to administrative units or a reference grid.

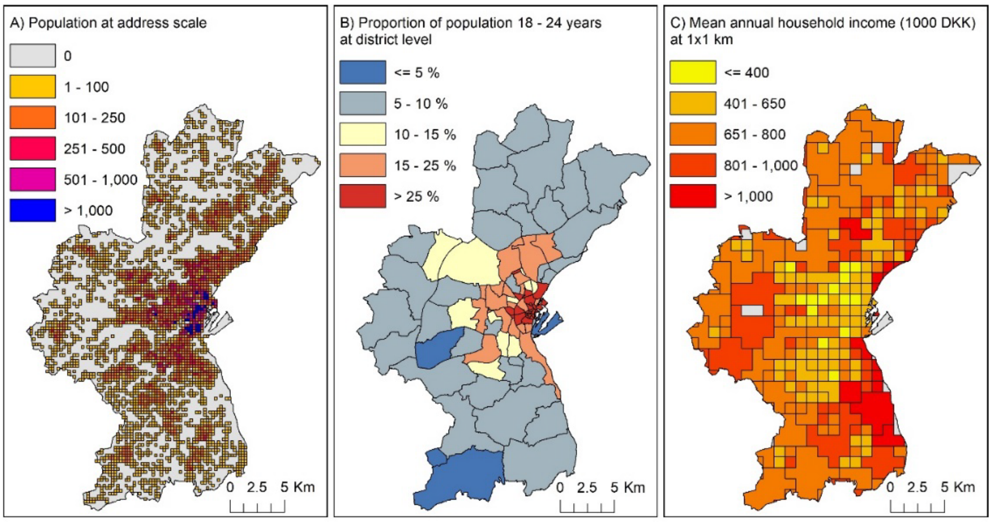

Figure 21: Examples of maps based on vital statistics for Aarhus ULL.

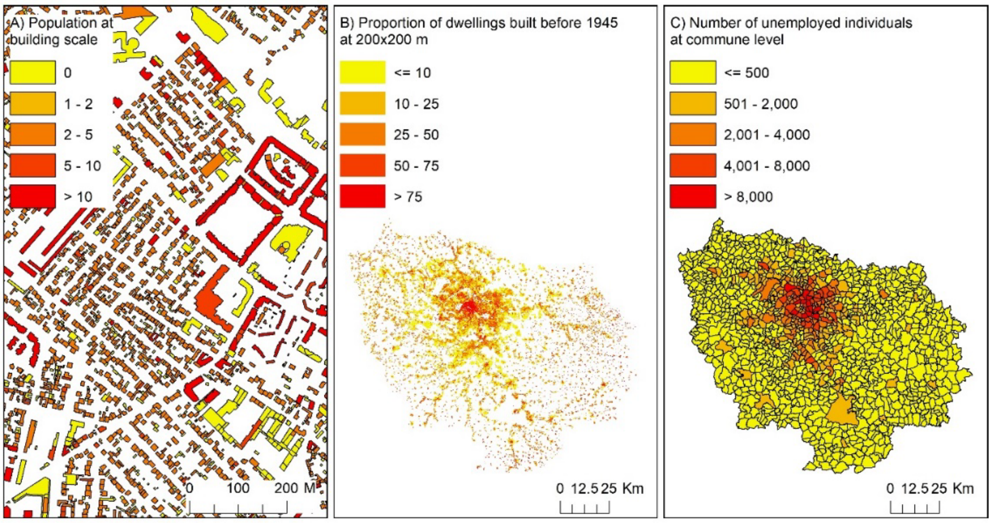

Figure 22: Examples of maps based on vital statistics for Paris region ULL.

Table 24: Available vital statistics for European ULLs.

ULL	Dataset	Variables (selected based on relevance)	Data format	Spatial resolution / unit	Year(s)
Aarhus	Population at address level	• Population by number of individuals	Point	89,966 addresses	2022
	Data at district level	• Population by age • Population by nationality • Population by civil status • Population by family type • Type of dwelling • Size of dwelling • Mean size of dwelling pr. person		89 districts	2021
Denmark	Household income at 1x1 raster	• Number of households • Mean annual household income • Number of households with annual income in bands of 100,000 DKK	Raster	1km (cells with < 300 households merged with neighbour cell)	2020
Paris region	Data at commune level	• Population • Population by employment and age • School-age population (18-25 years) • Number of households • Number of poor households • Number of dwellings	Polygons	1,288 communes	
	Population at building scale	• Population by number of individuals	Polygons	~3 Mio buildings	2016
France	Data at 200x200 m cells	• Population by age • Number of poor households • Number of single person households • Owner households • Single parent households	Raster	200x200 m	2015
Velica Gorica	Data at 1km cells	• Population by gender • Population by age group • Population by education • Employment status	Raster	1x1 km	2010
Global	Gridded Population of the World	• Population by number of individuals	Raster	1x1 km	2000, 2005 2010, 2015 2020

This document was updated: January 30, 2023

1.14 Disaggregation of vital statistics

Main contact, (and other people involved) Gregor Levin (AU) and Julius Knopp (UFZ)

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Short description of output

Elaboration of spatially explicit information based on vital statistics for European ULLs, such as socio-demographic and socio-economic information for exploration of relationships between population and NBS, e.g., access for different population groups to green-blue spaces. Note: for Chinese cities, we did not apply this approach because we have a limitation of data source for refined spatial scales. While intensively discussed, the district level for e.g., Shanghai is still very coarse, and it would still cover huge areas with a couple of millions urban dwellers each, while refined demographic information is rare to get. Consequently, the goal to picture inner urban differentiation would be rather limited.

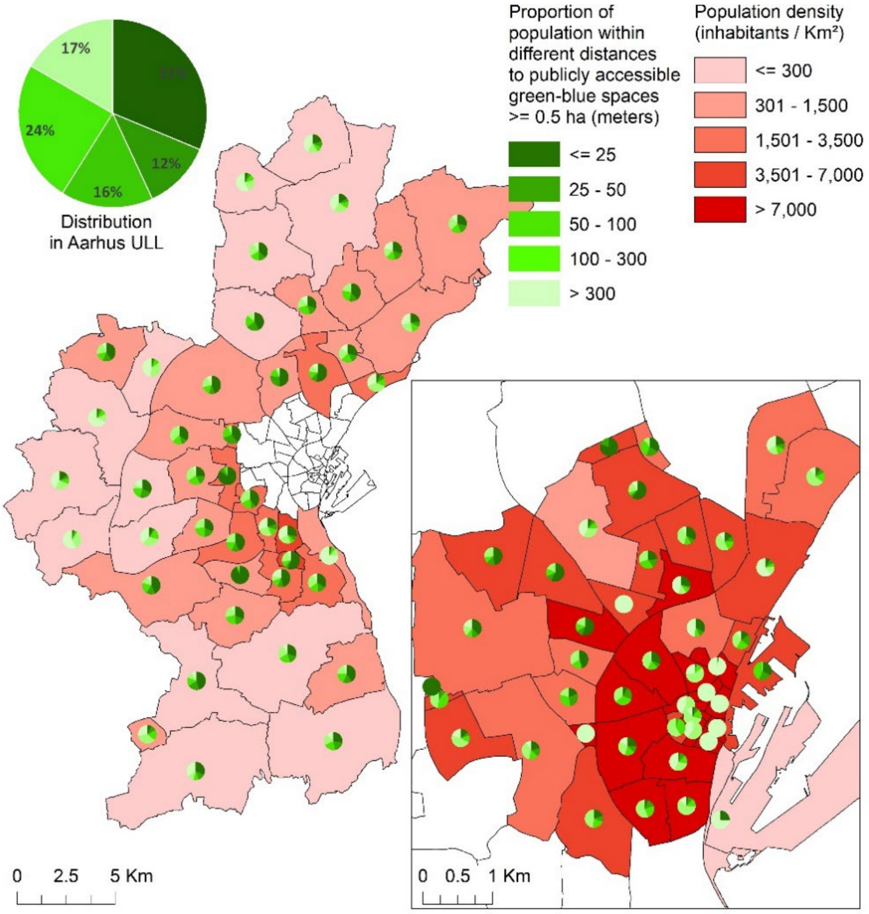

Figure 23: Proportion of population within different distances to publicly accessible green-blue spaces for districts in Aarhus ULL in 2021.

Method

Disaggregation of vital statistics variables to parcel level using spatial statistics. The concept is to find a viable spatial unit to link different data at different levels of spatial explicitness. The parcels of the ULLs cadastre are used for this purpose. A distribution of the socio-economic variables is then achieved by the separately developed dasymetric mapping, where the citizens of the ULLs are allocated to residential buildings to get more insight into the spatial explicitness of their distribution.

Approach for REGREEN

Based on the collection of vital statistics variables (see factsheet in section 2.11), a transferable workflow for the ULLs was developed. As shown in Figure 24, the process is based on four main elements: The number of inhabitants per statistical zone, the vital statistics variable, the access to green areas and the land use/land cover data.

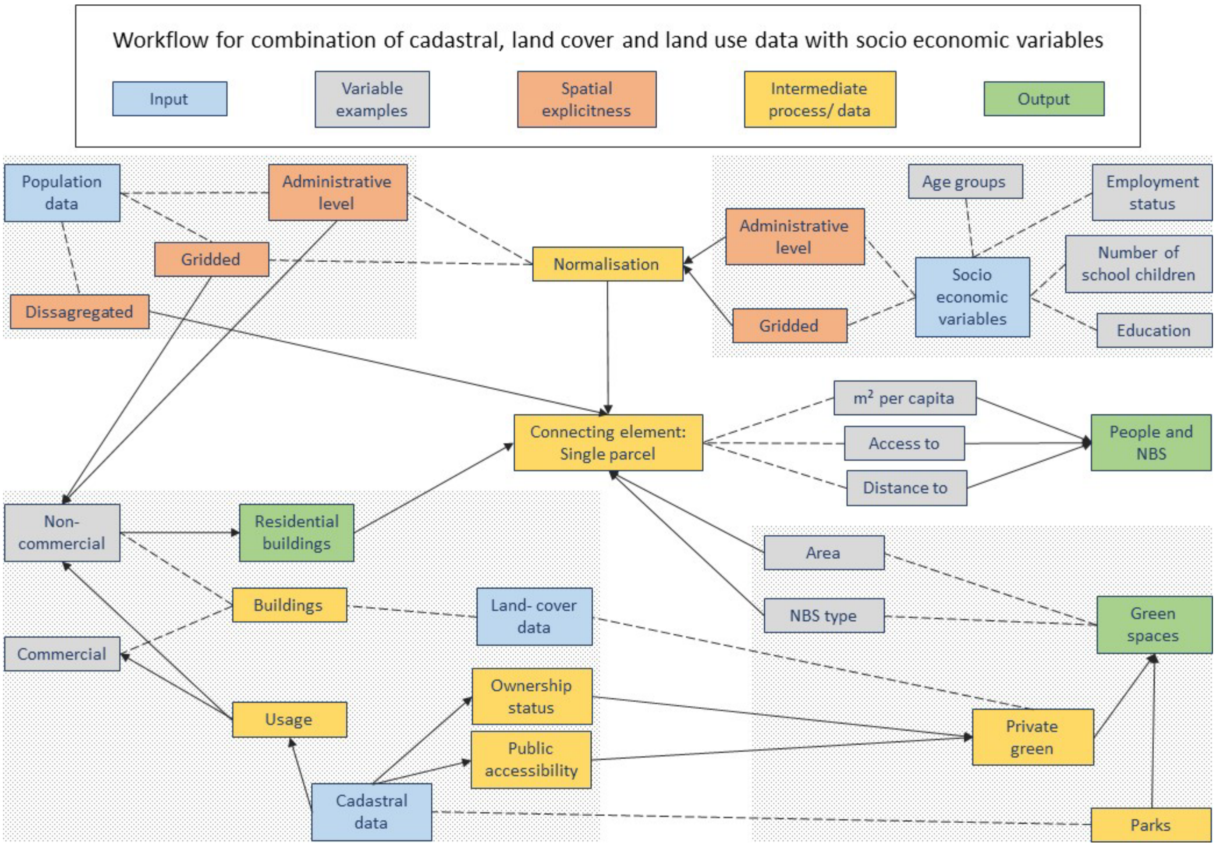

Figure 24: Flow chart describing the combination of vital statistics with other spatial information.

First, population data is distributed to individual dwellings based on the dasymetric mapping approach. Where necessary, data on residential areas are obtained from cadastral data or zoning plans. This intermediate product is then used to redistribute the various socio-economic variables. These are either on an administrative spatial level or on a grid and are linked to these according to the number of inhabitants per building.

The other two main elements at the bottom containing information on urban green spaces and land-use/ land- cover are more spatially explicit and can be linked directly. Where land-cover information on private land is limited, land-cover categories can add more information. Publicly owned land is already mapped and is also assigned a land-use category. The link between the four data sources is the individual parcel in the centre of the figure. This can be used to calculate e.g., accessibility, green space per capita and access to the nearest public green space.

To assess impacts of Nature Based Solutions (NBS) on different aspects of the population, NBS need to be spatially related to social, demographic, and economic information. To assess the impact of e.g., a new urban green space, its spatial extent needs to be linked to spatially explicit population information. For Aarhus ULL, only population numbers are available at spatially explicit address level, while socio-demographic and socio-economic information is only available at aggregated levels. However, disaggregating socio-demographic and socio-economic information to address level, a spatial explicitness of this information can be approximated. An example for disaggregation of socio-demographic information is described in Figure 25.

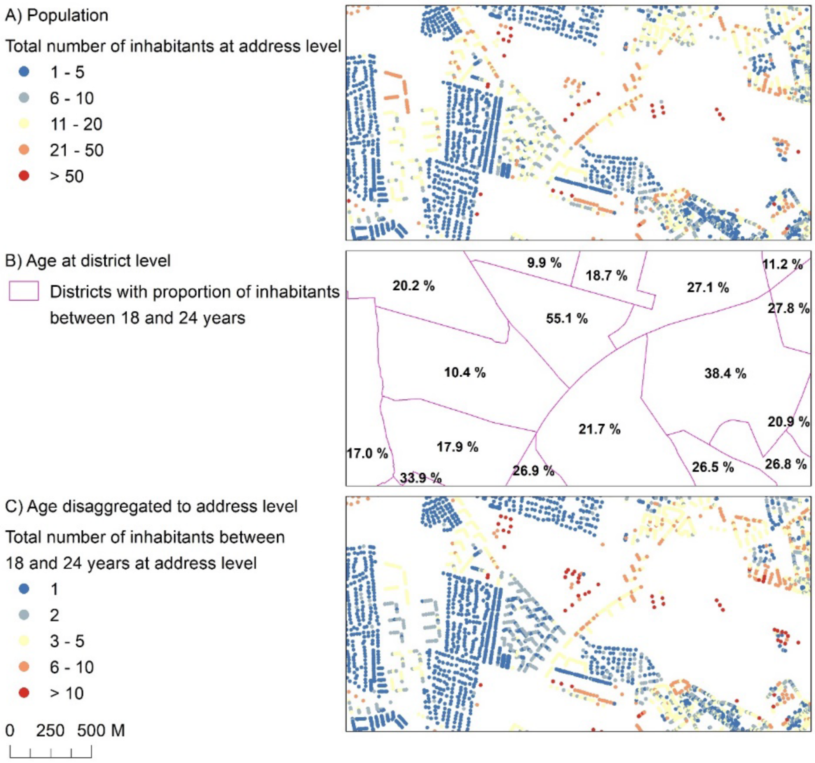

Figure 25: Disaggregation of socio-demographic data to address level exemplified for inhabitants between 18 and 24 years for an extract of Aarhus ULL. Population at address level (A) is overlaid with the proportion of inhabitant between 18 and 24 years at district level (B). The number of inhabitants between 18 and 24 years.

Table 25: Data requirements for disaggregation of vital statistics.

Data type	Spatial unit	Format	Time points, year(s)
Population data	Address or building footprint	Vector or point	Most recent available
Vital statistics at administrative level	District, municipality, commune	Vector	Best agreement with population data
Vital statistics at raster level	Raster of various cell sizes	Raster	Best agreement with population data
Additional land use / land cover datasets	NA	Vector or raster map	Best agreement with population data

How NBS are incorporated

Disaggregation of vital statistics to spatially explicit scales can be applied to explore impacts of NBS on the population, e.g., in terms of different population groups’ access to green-blue spaces.

Upscaling/Downscaling

Spatially explicit information at address or building scale represents the highest level of resolution. Information can be upscaled to any higher, e.g., administrative level.

Transferability

Transferability of this mapping approach depends on availability of spatially explicit population data and of access to vital statistics. Since type and availability of information differs between countries and cities, the methodology developed in REGREEN cannot be directly transferred to any city or region but needs to be adjusted to available datasets.

Comparability and consistency

While spatial resolution is comparable across ULLs, vital statistics vary with respect to available information. Comparability thus depends on availability of comparable information across ULLs.

Trade-off between detail and resources

Disaggregation of vital statistics to spatially explicit scales or units entails a spatial approximation. I.e., applied statistics do not get more precise, but can be spatially linked to other spatially explicit data. A large range of vital statistics is available for the different ULLs. To use resources efficiently, it is important to point at information, which is critical for further assessment of links between population and ES.

From maps and models to ecosystem service assessment

So far, disaggregated information from vital statistics has been applied for Aarhus ULL for:

- Mapping;
- Ecosystem service assessment based on look-up values; and
- Ecosystem service assessment using spatial or process-based model.

Current applications in REGREEN

So far, disaggregated population data have been used to calculate base indicators for access to urban parks for the three European ULLs. For Aarhus ULL, vital statistics have been disaggregated to address level for an analysis of different population groups' access to green-blue spaces.

Outputs

Publications

- No publication yet.

Datasets

- No publicly available datasets yet.

This factsheet was updated: January 30, 2023