REGREEN
NATURE-BASED SOLUTIONS

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

Deliverable **N°3.4**

WP N°3 Mapping and modelling ecosystem services

TOOLS AND GUIDELINES FOR MAPPING AND MODELLING PROCEDURES

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EXECUTIVE SUMMARY

In this report we provide an overview of mapping and modelling procedures, which are developed and applied during the first three years of the REGREEN project. The different mapping and modelling approaches are described in short and comprehensible factsheets, supplemented by illustrations such as maps or process flows. The project is at the time of publication still ongoing. Consequently, the status and completeness of the different described mapping and modelling approaches range from some approaches, which have been finalised and already been applied in e.g., ecosystem service assessment and scenario analyses to other approaches, which are still under development and so far, only applied in pilot studies.

In the REGREEN project, we aim at assessing Ecosystem Services (ES) and explore scenarios for Nature Based Solution (NBS) interventions by applying mapping and model outputs in final wellbeing assessments and valuation of benefits of NBS. For some ES, this has been completed, at least in pilot set ups, while for others, this will be accomplished within the final year of the project.

All applied approaches to mapping and modelling ES are sophisticated and intensively elaborated. For this reason, we can discuss the transferability of the approaches presented and show examples of such transfer work. This helps to transfer the mapping and modelling approaches applied in the REGREEN project to other study areas and to use them in further environment-related research questions. When working with study areas across Europe or other continents, it becomes valuable to have comparable mapping and modelling approaches and results. That brings us to the issue of data consistency, which we reflect upon in detail. Research work must also be feasible. Therefore, it is necessary to weigh up between attention to detail and available resources. As our project focusses on different urban areas in Europe and China, it becomes obvious to pay attention to the people living in this environment. Most people live in cities, where they may be exposed to (or are the cause of) environmental pressures. Human health and equity are important aspects in this research. Therefore, the links between urban population and ES and the corresponding demands are highlighted. To do so, maps and models in ecosystem service assessment are applied, and scenarios developed. All mapping and modelling activities in the REGREEN project are well-exemplified to serve as illustrative guidelines and tools for further research in Europe and China.

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1 INTRODUCTION

1.1 Purpose of the document

This report is part of the deliverables of the EC funded REGREEN project. The overall aim of REGREEN is to promote urban liveability, by systematically modelling and combining ecosystem services (ES) and biodiversity as the basis for NBS that can be widely deployed by public and private actors. To do so, we will develop an integrated approach for mapping and modelling multiple socio-ecological functions and services, and, as innovation, we will then aim at providing multiple ES provided by one NBS. This is done for 6 Urban Living Labs (ULLs). In Europe these are: Aarhus, Denmark; Paris Region, France; and Velika Gorica, Croatia. In China these are: Beijing, Ningbo and Shanghai.

In this report we compile and discuss mapping and modelling procedures, which have been conducted over the first 3 years of the REGREEN project. In June 2022 deliverable 3.1 "Synthesis report on current datasets and their applicability of ecosystem services mapping and modelling" (Banzhaf et al., 2020) was published. This synthesis report evaluated scale dependent data and models by exploiting existing frameworks and collating data at various scales to quantify ES and formed the basis for developing and applying specific mapping and modelling procedures in REGREEN.

At present, all mapping procedures have been completed while most models have either been developed and tested for pilot studies or are already readily available as tools, which can be applied in further scenario analyses. The purpose of this report is 1) to document mapping and modelling procedures and outputs developed in REGREEN so far, and 2) to give guidance to stakeholders (e.g., city planners, organisations, companies) and researchers on critical issues when applying mapping and modelling approaches developed in the REGREEN project.

1.2 Structure of the document

This report is structured as follows:

After the introducing chapter 1, chapter 2 contains factsheets with short and simple descriptions of the different mapping and modelling procedures, which are developed and applied in the REGREEN project. For each mapping and modelling approach, we describe the mapping/modelling outputs, explain applied methods, and describe data requirements. Furthermore, we include reflections on issues such as transferability, comparability and consistency, and trade-offs between detail and resources. Finally, we provide references to any related publications and to any published datasets.

In chapter 3, we give specific guidance to working with mapping and modelling ecosystem services. Based on the work conducted in the REGREEN project so far, we reflect on and discuss the following themes:

- Transferability of applied mapping and modelling procedures to other cities or regions;
- Comparability and consistency between different alternative mapping and modelling procedures;
- Trade-offs between detail and resources when choosing mapping and modelling approaches;
- Exploring linkages between people and ecosystem services;
- Getting from maps and models to ecosystem service assessment; and
- Applying maps and models in scenario analyses.

Under each theme, we provide relevant cases from mapping and / or modelling work in the REGREEN project so far.

In chapter 4 we give some general conclusions and recommendations for applications of mapping and modelling procedures.

2 FACTSHEETS

The following sections contain so called factsheets for the different mapping and modelling approaches, which are developed and applied in the REGREEN project so far. The purpose of the factsheets is to describe applied methods and outputs in a short and comprehensible way. More exhaustive documentations are or will be included in other documents or scientific articles. Also, the factsheets should be understood as living documents, representing the status of the specific mapping and modelling approaches in early 2023. While some of the approaches have been fully developed and applied within all ULLs, others are still in a pilot phase or have not yet been applied within all ULLs.

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

  Short description of if and 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.

2.1 Urban land-use / land-cover mapping

Main contact, (and other people involved) Wanben Wu (FU), (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, i.e., densely built-up, dispersed built-up, cropland, deciduous forest, coniferous forest, grassland, water bodies and bare land.

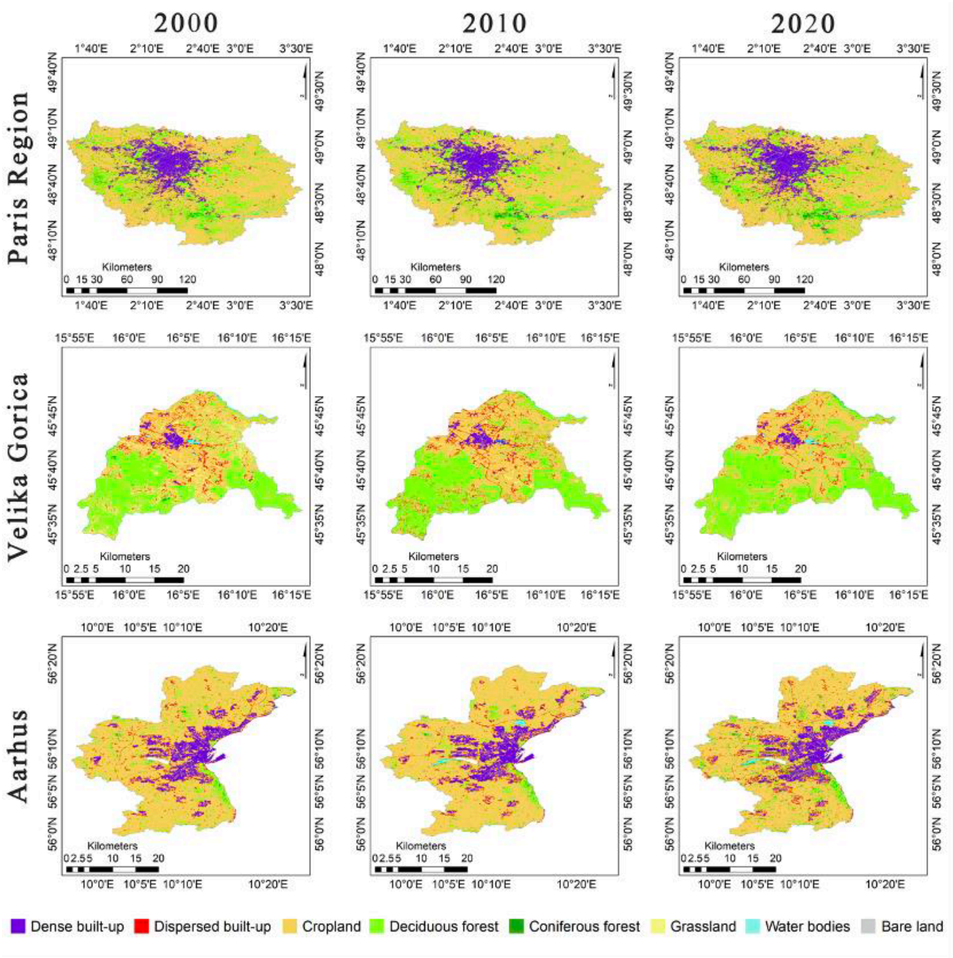

Figure 1: Land cover maps with 30m spatial resolution of the three European ULLs for 2000, 2010, and 2020

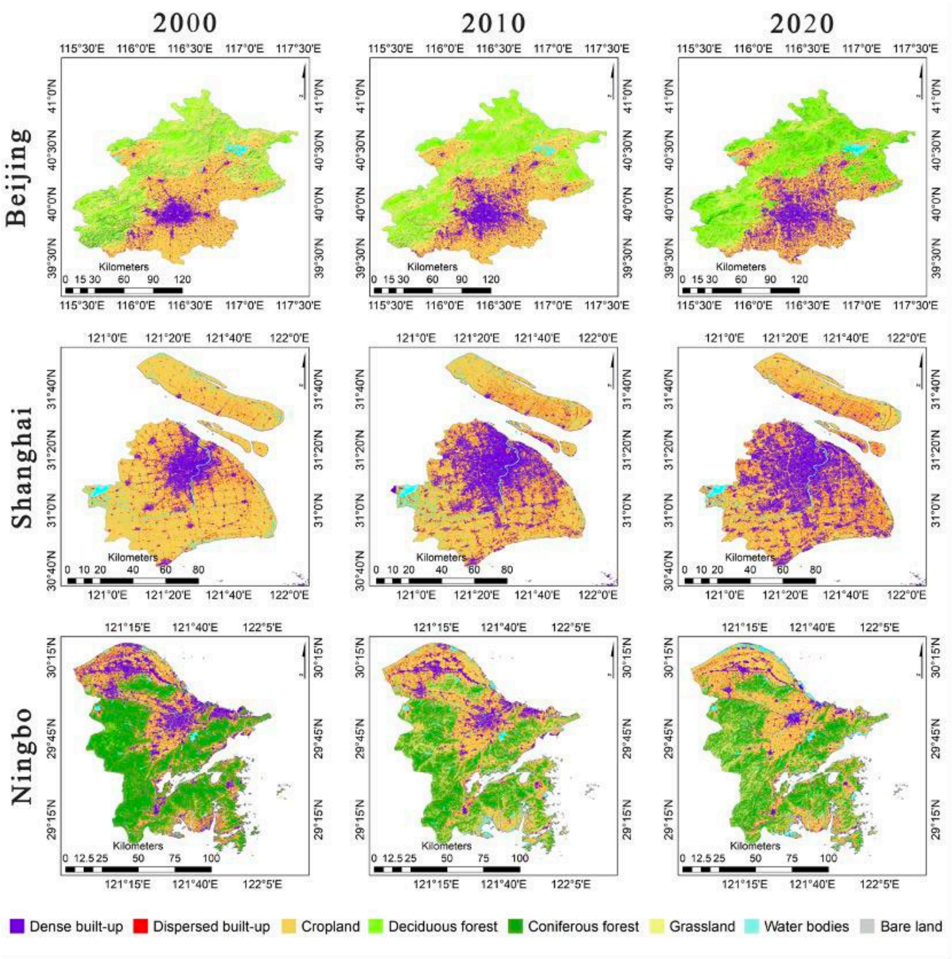

Figure 2: Land cover maps with 30m spatial resolution of the three Chinese ULLs for 2000, 2010, and 2020

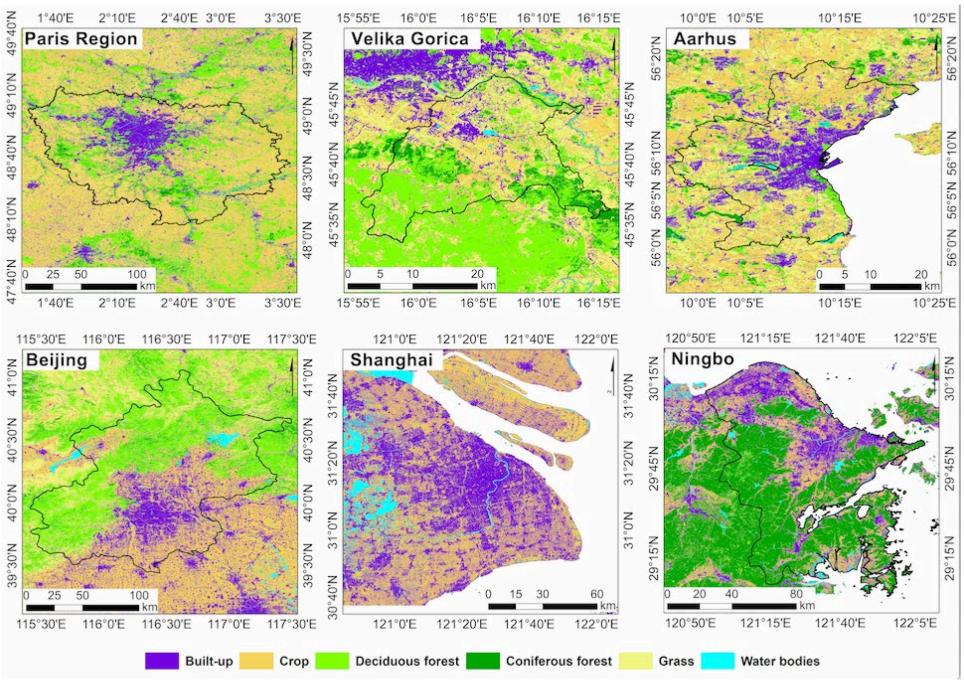

Figure 3: Land cover maps with 10m spatial resolution of the six ULLs for 2020

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.

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	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	densely built-up, dispersed built-up, cropland, deciduous forest, coniferous forest, grassland, water	https://zenodo.org/record/5846090#.Yv9LauxBz0o
3	60 m	2030	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) (Wu et al. 2022b) model to simulate future land cover under three scenarios in 2030: 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

- 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: January 30, 2023

2.2 High resolution land cover mapping

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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	mineral surfaces, buildings, bare soil, artificial grass, deciduous trees, evergreen trees, shrub, grass and water
Paris Region	NA, vector based	2017	mineral surfaces, buildings, bare soil, trees, shrub, grass and water
Velika Gorica	30 cm	2016	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

- Paper on Aarhus ULL in preparation
- Paper on Velika Gorica ULL is planned

Datasets

- Not publicly available yet

This factsheet was updated: January 30, 2023

2.3 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. 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.

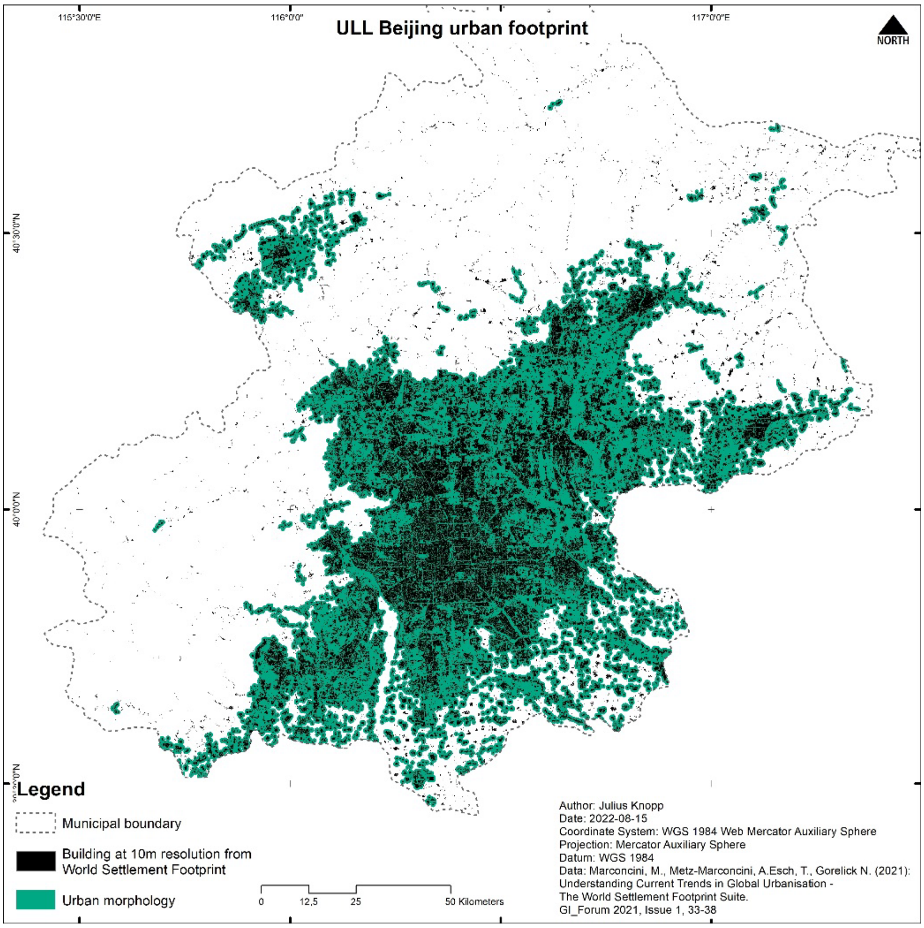

Figure 5: Urban footprint for Beijing ULL

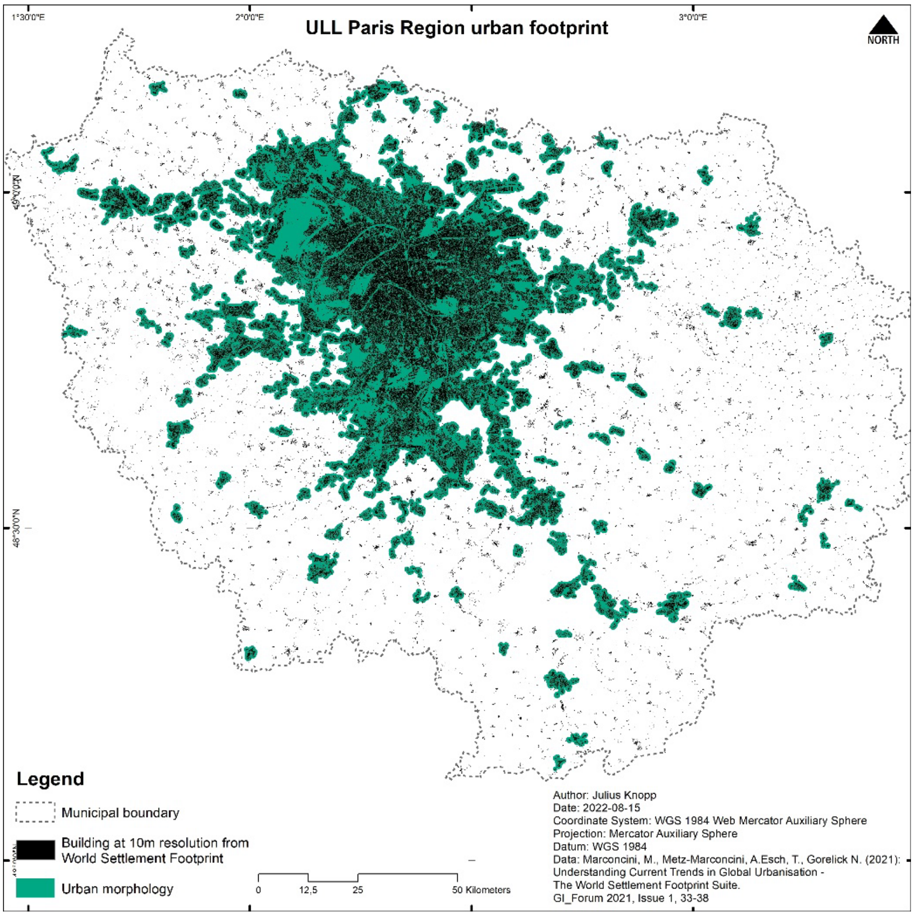

Figure 6: Urban footprint for Paris region ULL

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

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2.4 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.

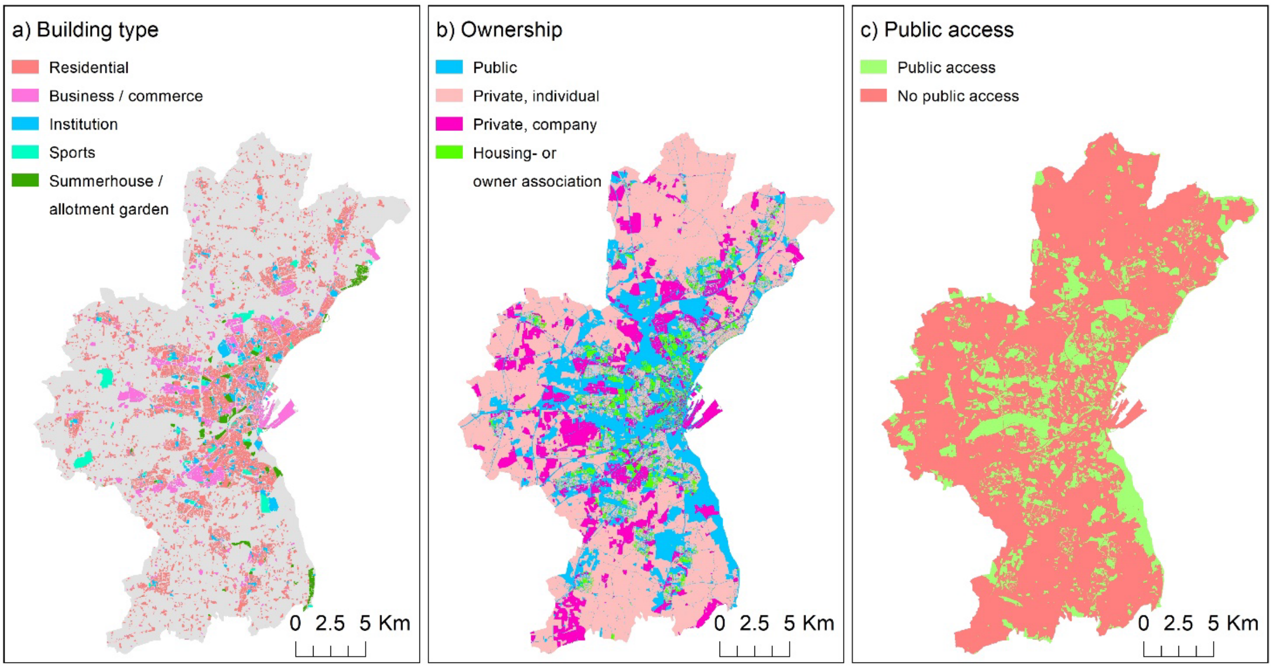

Figure 7: Different land use characteristics based on cadastral data from 2018 for Aarhus ULL

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 accessibiliy
Paris region	Cadastre parcels (~403,000 parcels)	2017	• Land cover • Land use • Building type • Public accessibiliy
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 there were used quite many resources to compile a very detailed dataset for Aarhus ULL, less resources will be used for Paris region and Velica Gorica, resulting in datasets with lesser 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

2.5 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. The model has been applied in Aarhus ULL to investigate the likely impact of a tree planting programme (Figure 8).

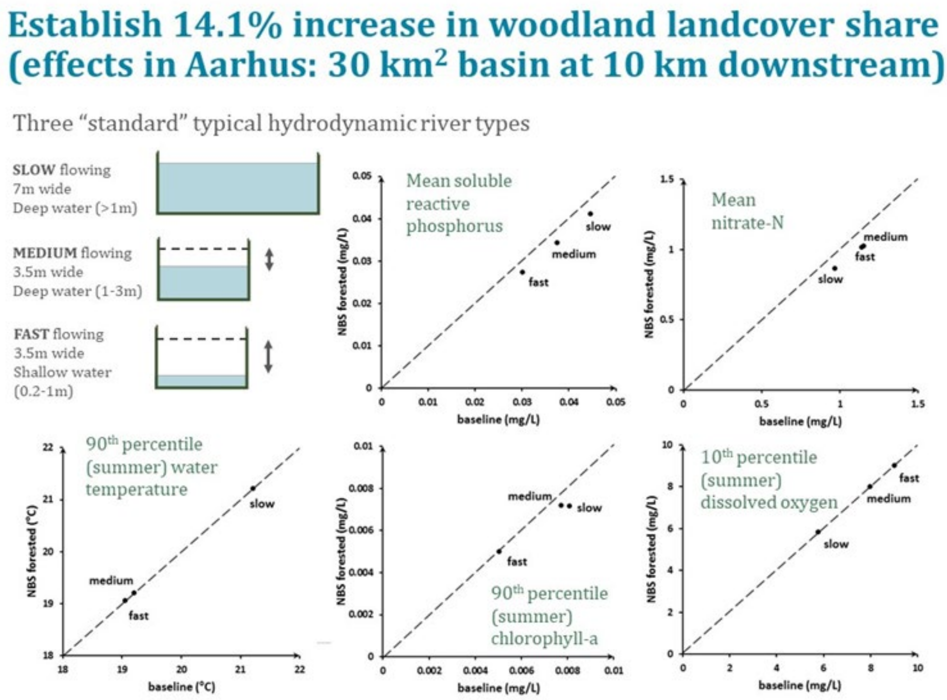

Figure 8: Modelled impact of 14.1 % increase in woodland land cover share for a 30 km² basin at 10 km downstream in Aarhus ULL. The Figure demonstrates the following: (a) Compared to fast flowing rivers, slow flowing rivers have longer contact time and more opportunity for biotic nutrient uptake (hence 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 km² to ~10,000 km². 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 focus will now be on Method 2 below. We will also apply the model as originally intended (Method 1) in specific cases if time permits and if this is feasible/desirable.

Method 1: Specific rivers/catchments/NBS measures

- Brief discussion with local representatives (ULLs) to identify likely coverage and accessibility of river flow and quality data (i.e., density of monitoring sites, variables measured).
- Choose one or two small river catchments to set up model in a 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 are available.
- ULLs to provide basic mapped information showing land use, river network and monitoring sites.
- Access data with help from ULLs.
- Test model against observed data in chosen catchments.
- As far as feasible, identify specific impact of NBS on hydrological/hydrochemical processes.
- Explore scenarios of implementing NBS and effect of location of NBS.
- To aid comparability, apply similar processes across each ULL.

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

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

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).

Method 2 Standardised rivers approach

We have specified a standard urban catchment/river morphology which can be applied in all ULLs. This will quantify 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 until now only been applied for a pilot study in Aarhus ULL and not yet been applied for ecosystem service assessment.

Current applications in REGREEN

The water quality assessment model has been applied for a pilot study in Aarhus ULL.

Outputs

Publications

- None yet.

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

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2.6 Hydrological modelling

Main contact, (and other people involved): James Miller (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 will 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 this alter runoff in these changed areas, which is then routed downstream, lowering flows in the river network.

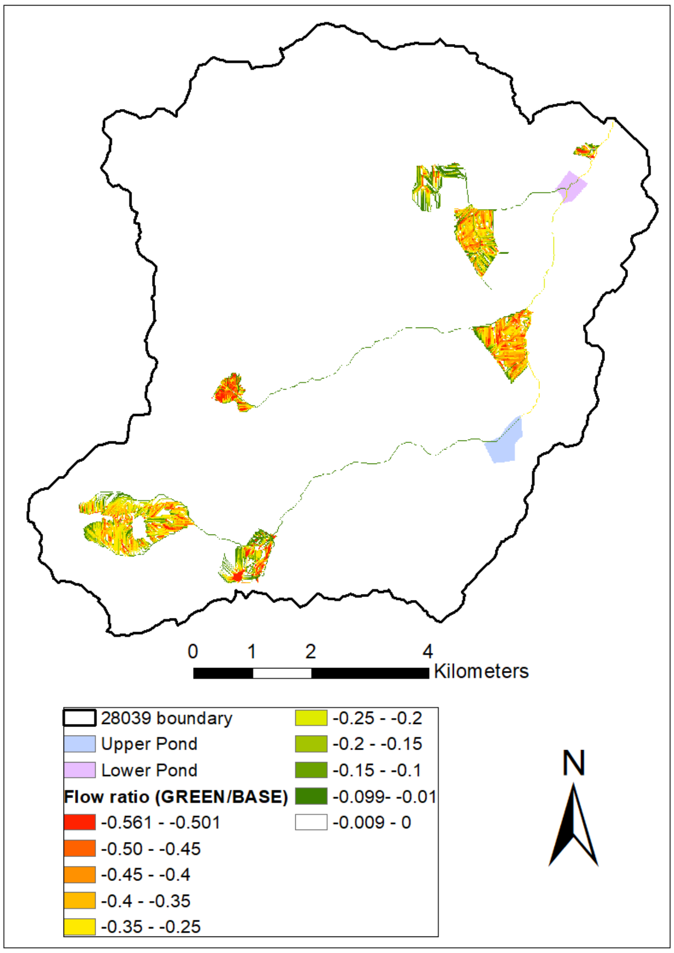

Figure 9: Map showing flow ratios between a base scenario and a NBS scenario in Aarhus ULL.

Method

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

Approach for REGREEN

- Brief 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. Probably start with Aarhus - most likely to have clear data access. Then Paris will be modelled next.
- 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.
- Apply similar process in other ULLs.
- Scale up results to city level using meta-model.

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 will be specifically set up to cover the agreed NBS – with a focus on green roofs and green space – and how these affect runoff quantity and timing at a wider scale. The question however is uncertain regarding how the NBS are mapped. This depends on ULL data and also whether NBS scenario maps are to be developed.

Upscaling/Downscaling

The model will be set-up for two small catchments in each ULL – with the model then able to be up-scaled as needed. However, it is foreseen this will have limits for scaling. 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:

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

Current applications in REGREEN

The model has been applied for a pilot case in Aarhus ULL.

Outputs

Publications

- Paper submitted and under review: Manuscript Number: LANDUP-D-22-01210 "Hydrological assessment of urban Nature-Based Solutions for urban planning using Ecosystem Service toolkit applications".

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.

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2.7 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[3], typically with a horizontal resolution of 10m. This can be interrogated, using shape files of residential buildings, to quantify the mitigation received.

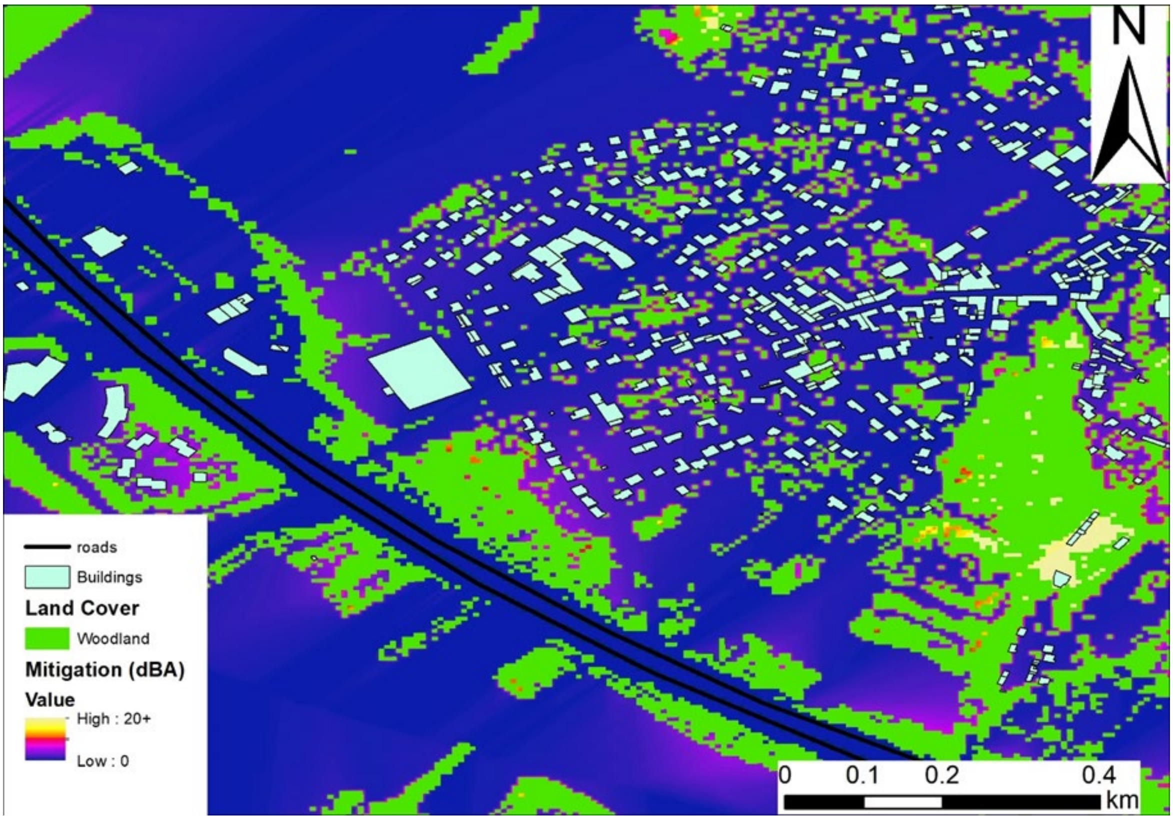

Figure 10: Mapped noise mitigation model output, displayed for a locale within Paris Region (1.958, 48.94 decimal degrees). Mitigation is depicted as A-weighted decibels, Lden (day, evening, night). This output can be subtracted from the European Noise Directive (END) statutory noise mapping data to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

[3] 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.

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 can be contingent upon 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

- 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

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2.8 Heat mitigation

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

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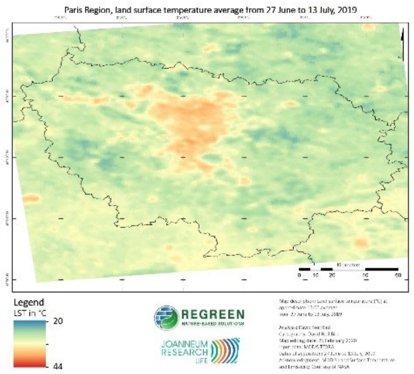
Short description of output

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.

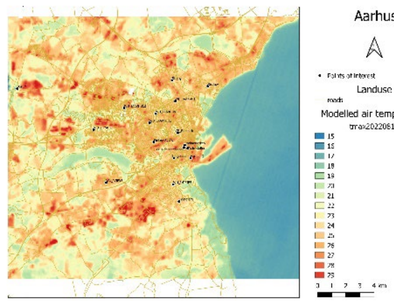
The scale will depend on the needs of the ULL. Examples are shown in Figure 11.

Regional-scale



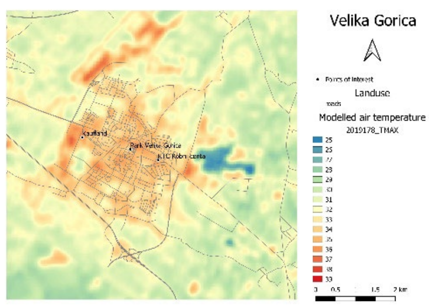
Example: Ile de France, July 12 2019, 14:00

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 will be based on land surface temperature (LST) from satellite data (MODIS and / or LANDSAT 8/9). The LST will be corrected to air temperature using historical ground-based temperature measurements.

Modelling urban heat island changes due to ULL specified actions to increase NBS will be done using either MUKLIMO-3 (Sievers, 1990; Sievers, 1995), or ENVI-met (Bruse, 1999; Bruse and Fleer, 1998) depending on the scale of the action.

During the project a new method will be attempted, in which the normalised differential vegetation index (NDVI) measured from satellite data (MODIS and / or LANDSAT 8/9) will be modified due to ULL specified actions assuming analogies to existing urban landscapes. A modelled LST will be calculated from the modified NDVI.

Model background

Historical mapping of the UHI and the estimation of value and impacts of NBS: 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.

Modelled urban heat island changes due to proposed NBS project by the ULL is accomplished using one of two programs: MUKLIMO-3 and ENVI-met.

- MUKLIMO-3 is useful for modelling the UHI of small cities (20km x 20km) or city districts. It is specifically useful for modelling the impacts of a planned NBS intervention (e.g., tree planting or green roofs). Spatially, the models are quite detailed (100m x 100m grid or finer), and the data requirements (land cover plus building and vegetation descriptors) are more onerous than satellite based UHI estimates. The outputs, that we have used, are limited to an annual estimate of summer-days (days with T_{max} > 25°C) or hot-days (das with T_{max} > 30°C).
- ENVI-met is ideal for modelling the very local impacts of interventions. It may be suitable for Velika Gorica who in our first meeting indicated that they were interested in the impacts of greening the roof of a municipal building. Models have quite small extents (300m x 300m) with very fine grid spacing of 3m x 3m and is for a single day.

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 project by the ULL.
  - Modelled through changes in NDVI as specified by NBS project.
  - Model selection (MUKLIMO-3 or ENVI-met) depending on the scale and extent of the 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
Modelling	MUKLIMO-3	All scales (city, district, local)	Model defined (30 – 100m grid)	Annual averages
	ENVI-met	Local	3m x 3m	A single day

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 • Ground temperature	30m x 30m	Prior to 2022, once every 16 days. Since January 2022, once every 8-days
MUKLIMO-3 • Building heights and materials (by land cover class) • Roof pitch (by land-cover class) • Pavement (as class) • Tree heights and density (by land cover class) • Low vegetation density by land cover class) • Albedo	• Surface-based weather measurements • Land-cover classes	Vertical resolution from 10-50m	Daily meteorological measurements
ENVI-met • Building heights and materials • Tree heights and density • Low vegetation density • Pavement • Albedo	• Surface-based weather measurements • Detailed building maps	Vertical resolution from 10-50m	Daily meteorological measurements

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 ULL specified NBS intervention.

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 short comings 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

- 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.

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

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

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Short description of output

The model output is a raster grid, containing estimates of $PM_{2.5}$ [4] (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).

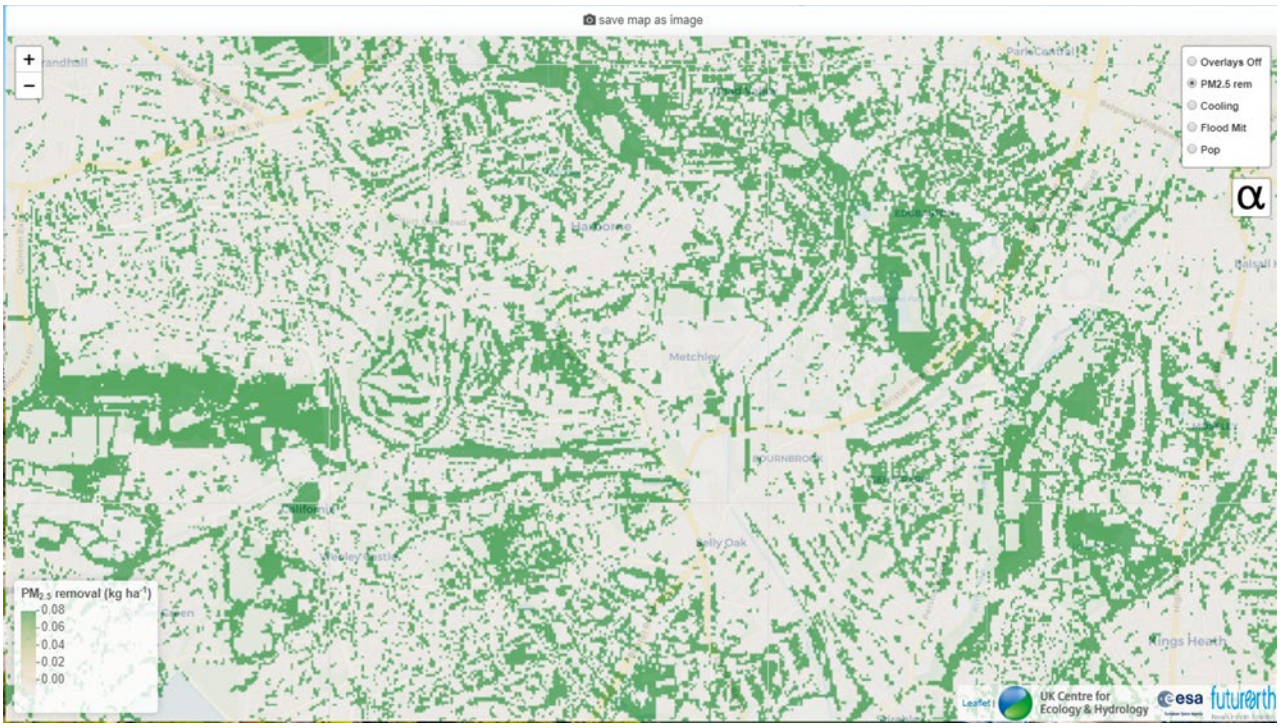

Figure 12: Example of $PM_{2.5}$ removal model output, displayed in City Explorer Toolkit web-app.

[4] 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

This approach will be adapted for REGREEN, based on the outputs from the EMEP runs, which will be used to create new REGREEN-focused meta-model equations.

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 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.

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 (not yet applied, but is possible); and

- Economic assessment of benefit (not yet applied, but is possible).

Current applications in REGREEN

The meta-model has been applied in Paris region and in Aarhus ULLs so far. Once updated with new REGREEN-focused models, versions will be applicable to all ULLs.

Outputs

Publications

- 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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2.10 Biodiversity - habitat quality mapping 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.

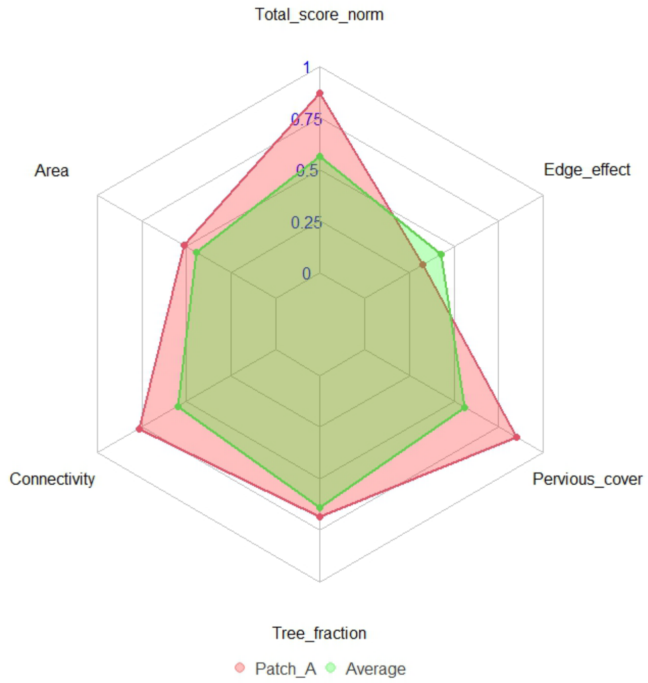

Figure 13: A radar chart showing the comparative potential of an urban green space to support urban biodiversity. A patch (patches) with the lowest habitat value will be assigned a value of zero, while the patch (patches) with the highest habitat value will be given a value of one of the total scores. 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.

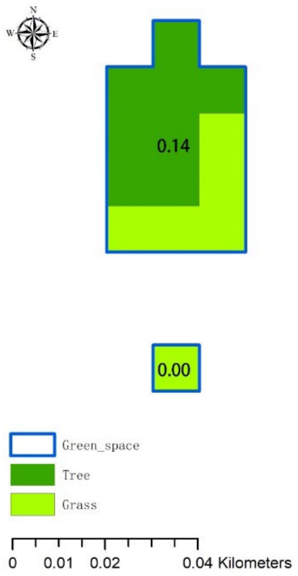

Figure 14: A simulated data showing the habitat values of five green space patches. Green space consists of trees and grasses.

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.

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2.11 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.

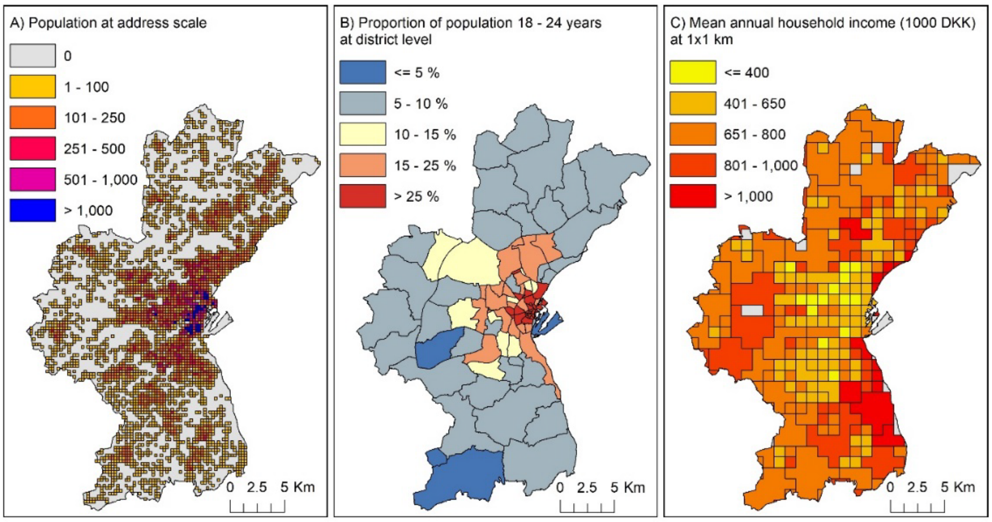

Figure 15: Examples of maps based on vital statistics for Aarhus ULL.

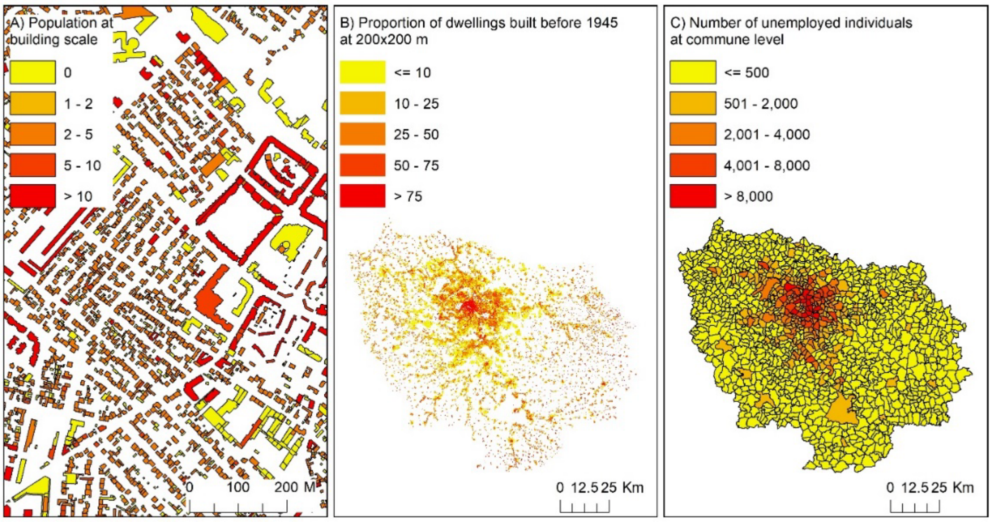

Figure 16: Examples of maps based on vital statistics for Paris region ULL.

Table 22: 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

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2.12 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.

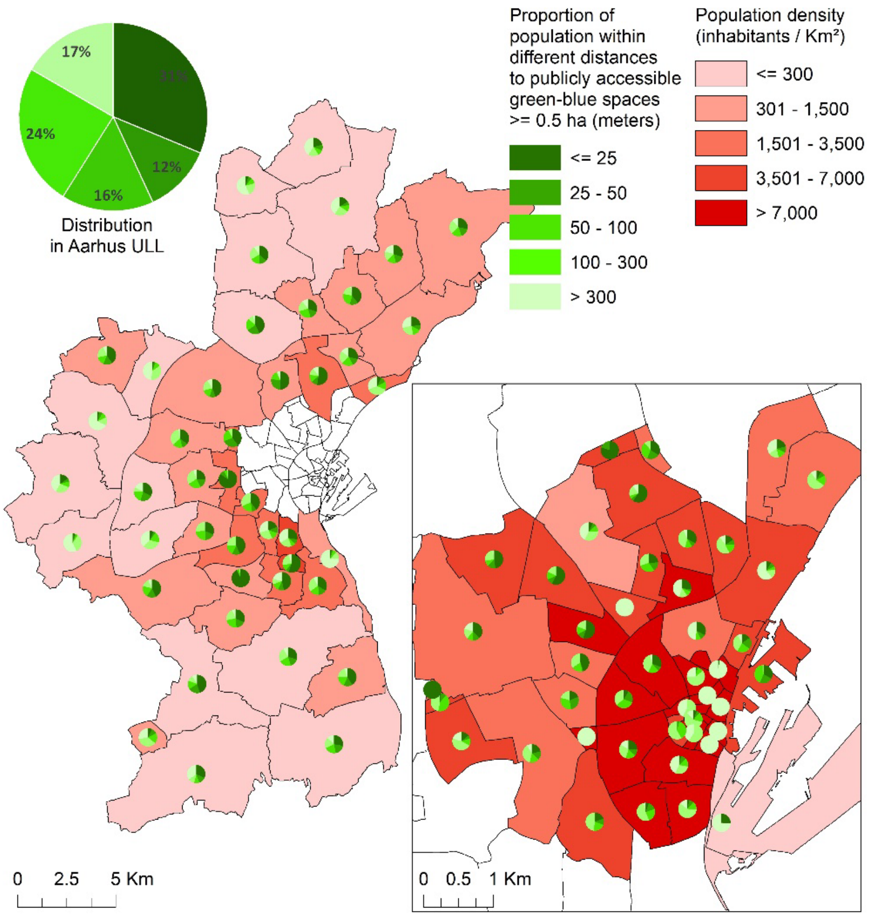


Figure 17: Proportion of population within different distances to publicly accessible green-blue spaces for districts in Aarhus ULL in 2021.

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 18, 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.

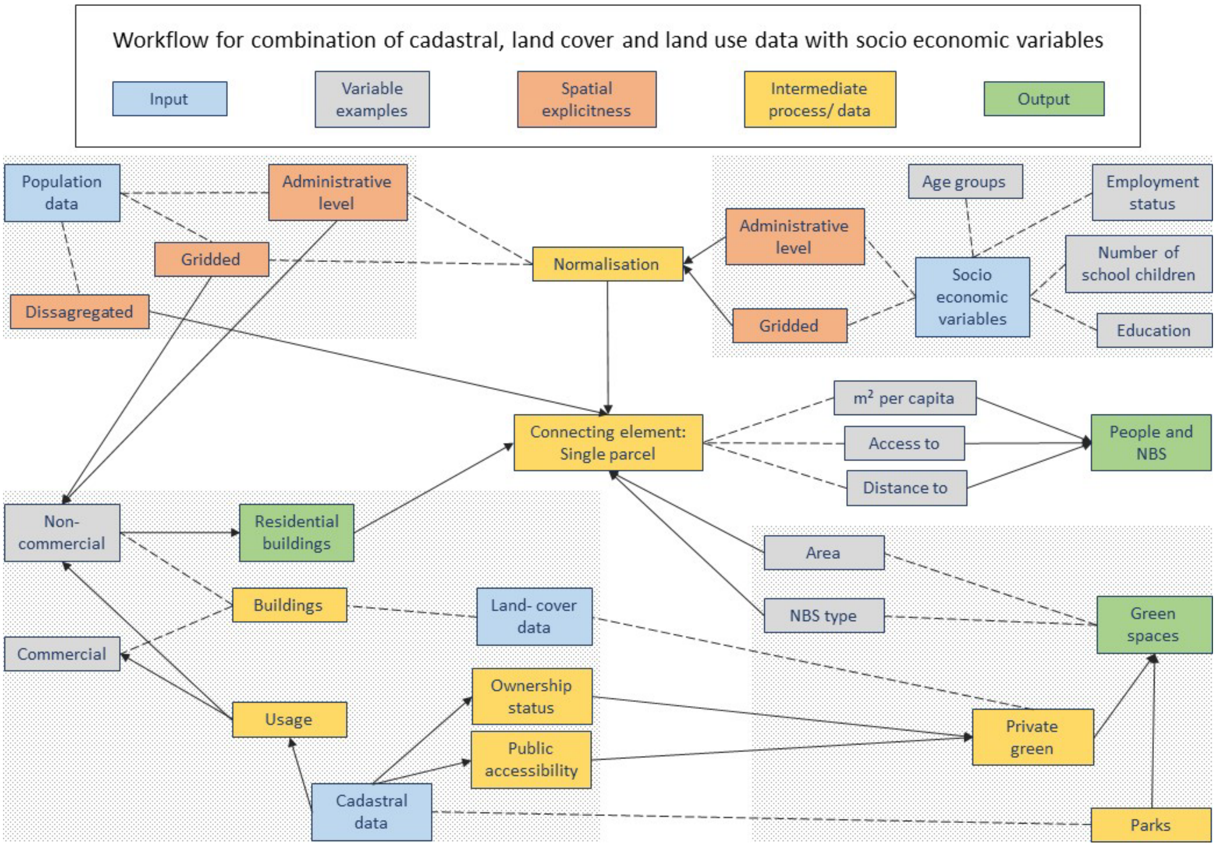


Figure 18: Flow chart describing the combination of vital statistics with other spatial information.

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 19.

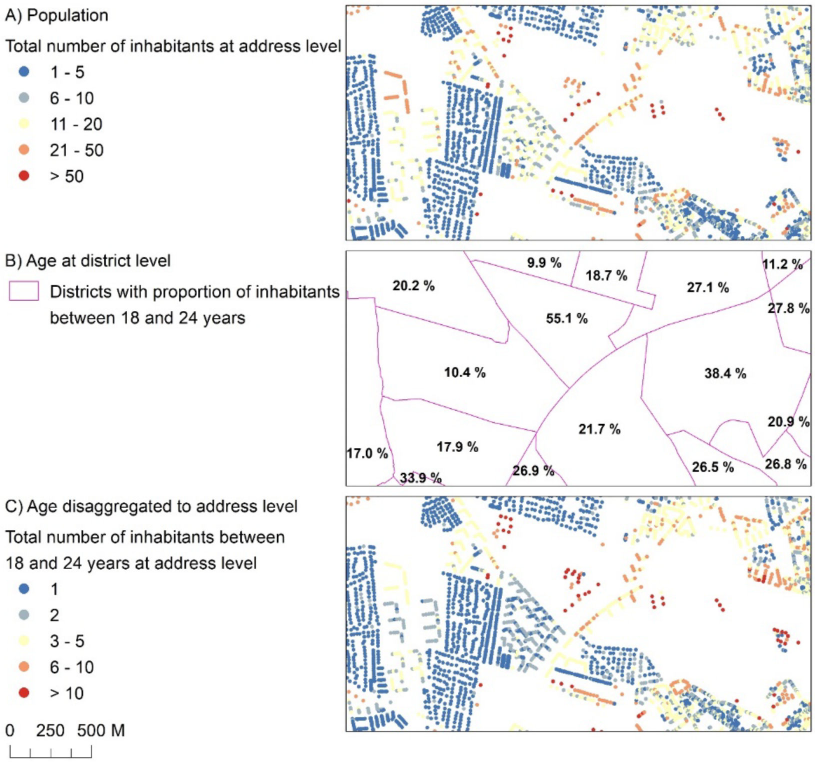


Figure 19: Disaggregation of socio-demographic data to address level exemplified for inhabitants between 18 and 24 years for an extract of Aarhus ULL. Population at address level (A) is overlaid with the proportion of inhabitant between 18 and 24 years at district level (B). The number of inhabitants between 18 and 24 years.

Table 23: 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

3 GUIDANCE ON WORKING WITH MAPPING AND MODELLING ECOSYSTEM SERVICES

In this chapter, we give specific guidance to working with mapping and modelling ecosystem services. Based on the work conducted in REGREEN so far, we reflect on and discuss following themes:

- Transferability of applied mapping and modelling procedures to other cities or regions;
- Comparability and consistency between different alternative mapping and modelling procedures;
- Trade-offs between detail and resources when choosing mapping and modelling approaches;
- Exploring linkages between people and ecosystem services;
- Getting from maps and models to ecosystem service assessment; and
- Applying maps and models in scenario analyses.

Under each theme, we give relevant cases from mapping and / or modelling work in the REGREEN project so far.

3.1 Transferability

In this section we provide reflections on how mapping and modelling procedures can be transferred to other cities or regions. While e.g., mapping approaches, which are based on global remotely sensed datasets, are relatively straightforward to apply to other cities or regions, others are dependent on availability of detailed local data and can therefore not be easily transferred.

3.1.1 Land cover mapping based on publicly available remotetely sensed data

We propose a new algorithm for automatic sample point acquisition from existing Land Cover (LC) products. This method can be used to evaluate and filter multiple feature variables for LC classification. Furthermore, we used GINI coefficients on model evaluation to achieve a balance of good classification accuracy and high classification efficiency. We applied this method at the intercontinental level and found that our methodology exploited all spatial LC information, allowing us to design an effective mapping procedure. Our automatic workflow based on Google Earth Engine requires no additional infrastructure and is easily reproducible in other cities.

Table 24: Publicly available remotely sensed data and respective classification approaches.

Data source	Spatial resolution	Years	Mapped categories	Classification approach
Landsat Series	30m	2000 2010 2030	• Dense built-up • Dispersed built-up • Cropland • Deciduous forest • Coniferous forest • Grassland • Water • Bare land	• Random forest classification model • Google Earth Engine
Sentinel 1&2	10m	2020	• Dense built-up • Dispersed built-up • Cropland • Deciduous forest • Coniferous forest • Grassland • Water	• Random forest classification model • Google Earth Engine
Existing land cover products	60m	2030	• Built-up • Cropland • Green space • Water	• CLUE-S Model

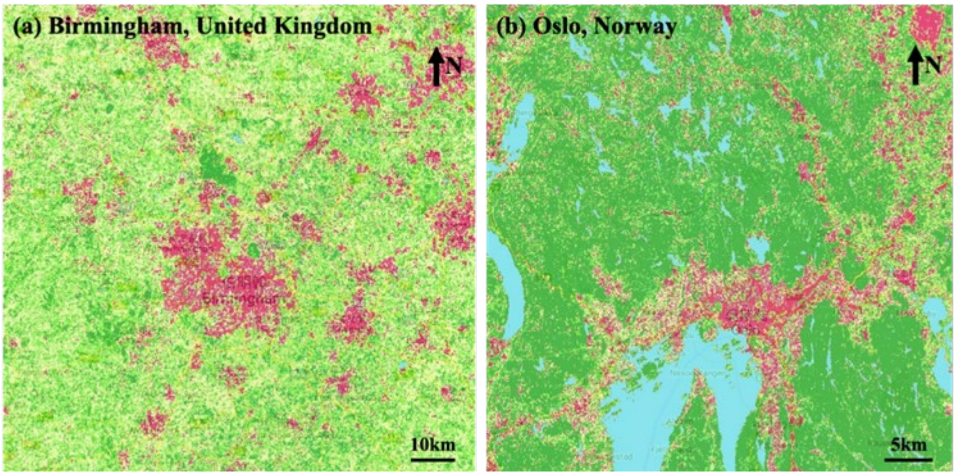


Figure 20: Examples of LC mapping at 10 m ground resolution for in 2020.

3.1.2 Urban footprint delineation

The urban footprint serves to better capture the actual urban environment within the ULLs. This translates into a subset of the area of the ULL, located within the administrative boundaries, where the density of buildings is above a certain threshold per area, thus indicating a high population count. In this way, rural areas within the ULLs which are not connected can be excluded. Furthermore, this shifts the focus on NBS which are either within the city boundaries or directly adjacent.

To acquire this additional area of interest for each ULL, we used the administrative boundaries of the ULLs as provided by the partner and the world settlement footprint as maintained by the ESA. This choice in datasets also provides a high level of transferability, as it is possible to apply this approach to all 6 ULLs as well as urban areas outside of this project's scope.

The workflow itself uses focal statistics to identify high density areas of buildings and uses buffers as well as additional area thresholds to compute the final urban footprint product. However, some input by ULLs is required, as the actual usage, acceptance, and attractiveness of areas within the ULL can vary and include for instance forests at the edge of a city and exclude airports where the ULL might not have sufficient potential for intervention. This approach has already been transferred to other cities outside of the project (See e.g., Figure 21 and 22).

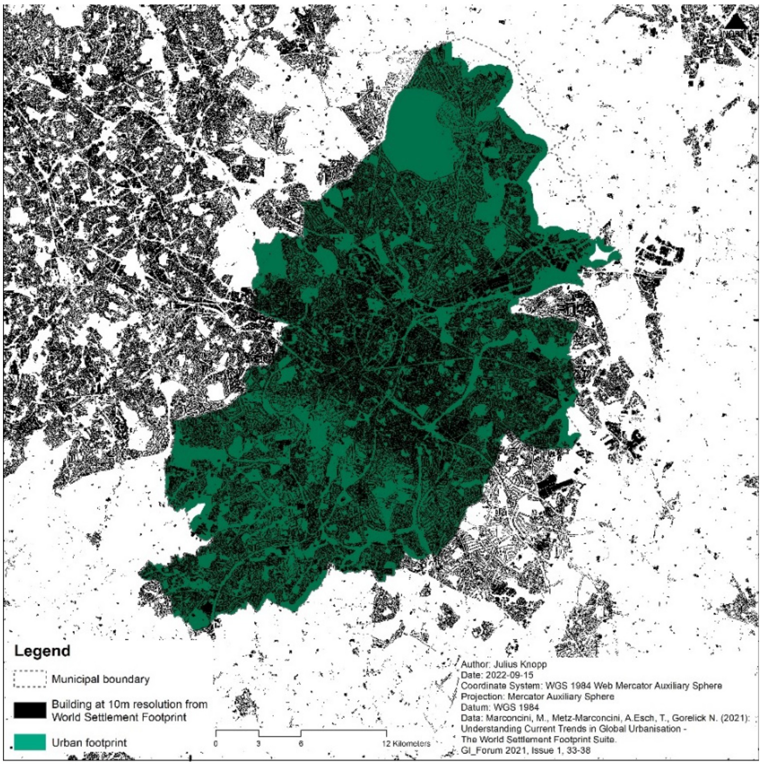


Figure 21: Urban footprint for Birmingham, UK.

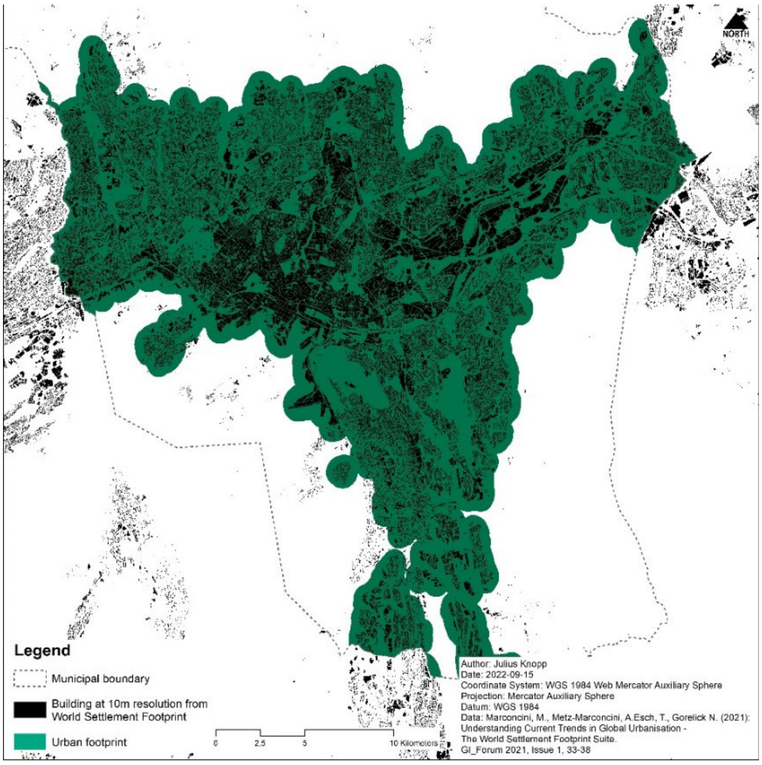


Figure 22: Urban footprint for Oslo.

3.1.3 Sources and usage of population data for socio-spatial analysis towards NBS

With respect to transferrable methods across Europe, one can neither just use local / regional nor merely national-focused statistics on demography. To work across a continent, it is most beneficial to include publicly available data on population as proxies. In the extracted table below, dataset (1) was applied for all the 6 ULLs as described by Wu et al. (2022b) for the mapping across ULLs (https://doi.org/10.3390/rs14143488). They include these data to evaluate how ES patterns contribute to environmental equity in the ULLs. Data sets (2) and (3) show optional usage of demographic data at global and continental extent. When linking these datasets, ES patterns and processes can much better explain the quality of life in cities in a spatially allocated way for local urban populations. Hence, incorporating vital statistics or spatially referenced demographic information into environmental research enhances the targeted outcome of NBS in a differentiated and comparable way across cities. Such publicly available data show a high transferability with a certain choice of data.

Table 4. Publicly available dataset for spatially referenced demographic studies.

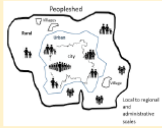
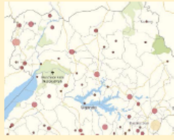
	Earth Observation Hub	Data Description	Resolution Temporal [yrs.]	Resolution Spatial [m]	No. of Categories	Illustration
1	Gridded Population of the World (GPW), v4 ǀ Center for International Earth Science Information Network ǀ Population Statistics https://sedac.ciesin.columbia.edu/data/collection/gpw-v4/sets/browse (accessed on 26 September 2022)	To provide estimates of population density and count for the years 2000, 2005, 2010, 2015, and 2020, based on counts consistent with national censuses and population registers	2000 2005 2010 2015 2020	1000	2	
2	High Resolution Population Density Maps https://data.humdata.org/ (accessed on 26 September 2022)	Humanitarian data created to respond to humanitarian emergency crises				
3	AfriPolis https://africapolis.org/en/data?country=Angola&keyfigure=totalPop&type=abs&year=2015 (accessed on 26 September 2022)	Africapolis data is based on a large inventory of housing and population censuses, electoral registers and other official population sources	1950–2015	-	2	Accra, Kampala, Cape Town 

Figure 23: Publicly available datasets for spatially referenced demographic data. Adapted from Banzhaf et al. (2022).

For European urban areas, we have archives of the EU funded institution Eurostat, the home of high-quality statistics and data on Europe. The archives comprise a myriad of data, and hence, we can only give a brief overview over urban area statistics and demographic information:

- Statistics on European cities https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Statistics_on_European_cities/de&oldid=360440#Weitere_Informationen_von_Eurostat
- the European statistical atlas https://ec.europa.eu/statistical-atlas/viewer/?year=2017&chapter=13&mids=BKGCNT,BKGNT0,C13M01&o=1,1,1&ch=GRP,C13&center=49.97812,19.97593,3&
- Methodological manual on city statistics – 2017 edition. https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/KS-GQ-17-006
- Facts and figures on life in the EU. https://european-union.europa.eu/principles-countries-history/key-facts-and-figures/life-eu_en
- Information on microdata. https://ec.europa.eu/eurostat/web/microdata/overview
- Data on urban areas and the urban audit. https://ec.europa.eu/eurostat/web/main/search/-/search/estatsearchportlet_WAR_estatsearchportlet_INSTANCE_bHVzuvn1SZ8J?p_auth=9aKK3xvt&text=Urban+Europe+%E2%80%94+Statistics+on+cities%2C+towns+and+suburbs&_estatsearchportlet_WAR_estatsearchportlet_INSTANCE_bHVzuvn1SZ8J_collection=&_estatsearchportlet_WAR_estatsearchportlet_INSTANCE_bHVzuvn1SZ8J_theme=

As there are large differences within Europe on ES, quality of life in urban areas, and socio-spatial exposition towards environmental stressors, such data help to undertake comparable analytic investigations across EU cities.

To summarise viewpoints on transferability, it is essential to understand the quality of the data, especially their consistency regarding definition and comparability of categories, similarity of temporal and spatial scales, matching spatial extent of urban areas to name some. To understand the quality of transferable methods and derived data sets, it is therefore crucial to discuss comparability and consistency of the applied approach and the related data sets.

3.2 Comparability and consistency

For some mapping and modelling approaches, applied methods differ between the ULLs. The choice of methodology depends on data availability and trade-off between desired details and needed resources (see also section 3.3). One of the aims in the REGREEN project is to compare ecosystem service provision and outcomes of scenarios across ULLs. Therefore, it is important to examine comparability and consistency of outputs from different alternative methodological approaches.

3.2.1 High resolution mapping for Aarhus, Paris region and Velica Gorica

When applying the GEE approach for mapping urban land cover over time, all outcome maps are comparable at global level. As a prerequisite, the method demands for pre-defined categories to map. These categories make the mapping consistent. Comparability is true to two facts: (1) mapping relates to satellite imageries that are captured around the globe and allow free download (open access data); (2) the GEE approach is applicable for all satellite imageries and allows comparable maps with pre-defined categories for an urban area, and over time. Different spatial scales relate to different earth observation satellite images as input and are not or at least less comparable, e.g., 30 m ground resolution [Landsat series], 10 m ground resolution [Sentinel satellites].

Mapping ULLs at high-resolution scale is done by different alternative approaches. By object-based image analysis of orthophotos, or of high-resolution satellite images, or even by obtaining thematic land-cover information. Yet, homogenisation of categories allows for comparisons.

Implementing nature-based solutions in urban areas demands a high-resolution mapping for modelling, decision making and spatial statistics. The 3 European ULLs in this study were quite diverse in terms of data availability. Still, the potential to transfer the 3 different approaches to other cities inside and outside of the European Union is given.

We tried to summarise the potential transferability of the different mapping approaches mostly by data availability, although factors such as budget and technical background of the partners involved also play a role.

Using satellite imagery, such as in the case of Velika Gorica ULL, potentially provides the highest level of transferability in terms of data availability, as satellites usually have fixed revisit times and follow a pattern. However, acquisition and analysis of this data can be costly and involves project partners to be trained in remote sensing.

A second approach is to use digital orthophotos. This was used in Aarhus ULL. Countries in Europe usually have digital orthophotos taken once every couple of years. This data is often publicly available for free and can serve the same purpose as satellite imagery. The level of technical expertise required is somewhat comparable and training in remote sensing indispensable, but usually no further costs are required.

A third option is to go with readily available land-cover and land-use products, as chosen for the ULL Paris Region. These are maintained on different levels, such as Europe-wide under e.g., the Copernicus programme or on a national, sometimes even down to a city level. Usually, no costs are involved in acquiring this type of data. The type and level of detail can vary widely. Different products can, however, be combined by experts with GIS knowledge, and provide a reliable source of information. These types of data, spatial and temporal coverage keep the level of transferability low, although most products can be supplemented by others. Thus, the most time is needed to identify suitable data sources and adapt processing chains when changing area of interest.

In short, these three categories of input data can all be made to serve the same purpose. They are however greatly varying in cost, level of expertise required as well as spatial and temporal coverage. Of course, any number of combinations between these data sources can also be used to achieve a high-resolution urban land cover mapping.

Table 25: Applied data and required expert knowledge for the 3 different applied approaches for high resolution land cover mapping.

ULL	Input data	Data type	Required level of expert knowledge
Velika Gorica	Satellite data, normalised digital terrain model	Remote sensing data, raw	Remote sensing, image analysis
Aarhus	Digital orthophotos, normalised digital terrain model	Remote sensing data, raw	Remote sensing, image analysis
Paris Region	Existing land cover products	Thematic land cover/ land use product	GIS expertise

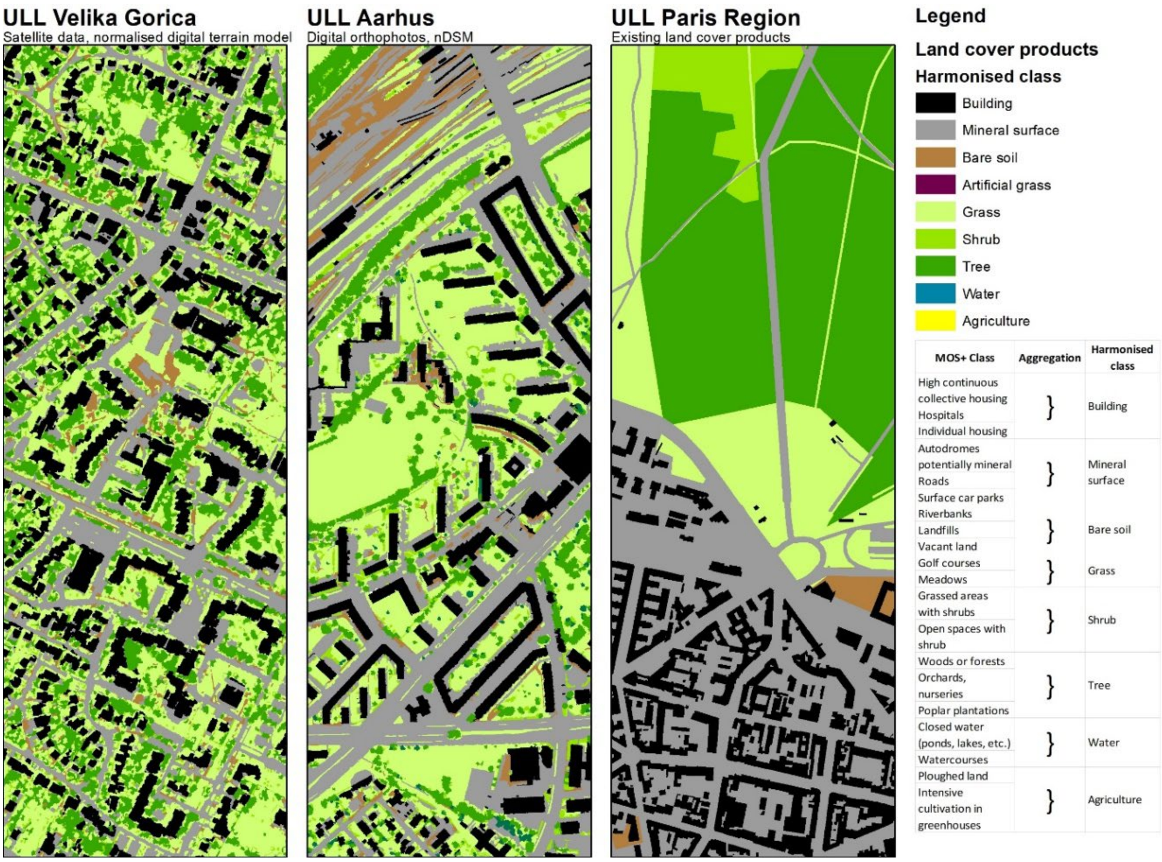


Figure 24: Illustration of high-resolution land cover mapping for the three ULLs.

3.3 Trade-off between detail and resources

Some mapping and modelling approaches provide a high level of detail at high spatial and temporal resolutions but are rather resource and data demanding, while other approaches are less resource and data demanding and provide outputs with less detail and lower spatial and temporal resolution.

The choice of approach depends on the requirements for the level of details and resolution for applications of e.g., ecosystem service assessment and scenario development.

3.3.1 Two alternative approaches for water quality modelling

Of the approaches described in the factsheet on water quality modelling (Section 2.5), we are adopting the simpler approach (method #2) for the purpose of comparisons between cities. This approach is relatively easy to apply in each city because the data demands are relatively small. The trade-off is that the simulated river water quality has not been tested against data in specific rivers. However, validation can be built in later by adapting the approach iteratively. Refinements may happen naturally, for example in response to specific needs of local users for scenario analysis.

When using the simpler approach, it is important to understand how the outcomes may differ from more locally detailed approaches. This is both for quantifying present day baseline water quality and the response to scenarios of NBS establishment. To illustrate this, the two approaches are compared for the case of Birmingham. In this example a 74 km^2 basin covering the southwest part of the city (River Rea) was studied using the locally detailed approach. It comprises a narrow (<5m variable width) 12km river with 6 reaches, some bounded by weirs and tributary influences, and with varying amounts of riparian tree cover (mean: 45%). It is characterised by periodic water quality observations at 5 sites (3 for input from tributaries, 2 for model testing) over 2 years (2013-14). Water quality from this model was compared to that of a river specified using the simpler standard setup (a spatially homogeneous 30km^2 basin with a 10km long stretch of unshaded 3.5m-wide river into which diffuse urban runoff inputs feed in uniformly). In both cases, hypothetical establishment of NBS involved a 4% increase in the land cover share of woodland with a tenth of the tree planting focused along riverbanks and the remainder in headwater catchment areas. For the locally detailed model the riparian planting was prescribed to take bankside tree occupancy up to 100%. This was based on expert judgment giving priority to planting in riparian locations wherever possible. In translating this amount of planting to the standard model, this equated to an increase to 26% in tree bankside occupancy.

Results are shown in terms of five summary metrics of water quality: nitrate-N (NO_3-N, mean), soluble reactive phosphorus (SRP, mean), water temperature (90th percentile), chlorophyll-a (Chl-a, 90th percentile) and dissolved oxygen (DO, 10th percentile) (Figure 25). Although availability of observations was sparse, the locally detailed model produced a close fit to the data and a beneficial water quality response to NBS establishment for all five of the metrics. Likewise, the simpler standard approach also predicted a universally beneficial response to NBS. The predicted level of benefit due to NBS was in fairly close accordance between the two approaches, in particular in terms of water temperature and DO metrics, indicating that the simplification has potential to yield reliable and robust information about the value of NBS for water quality (Figure 26).

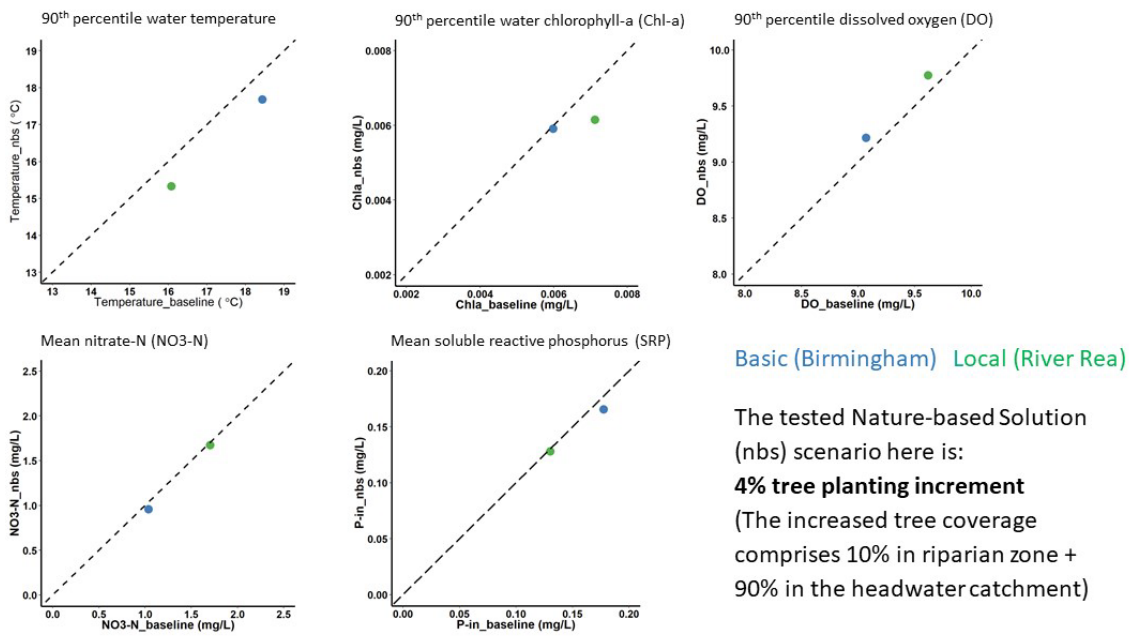


Figure 25: Comparison between basic and local model outcomes for water quality at the downstream outlet reach.

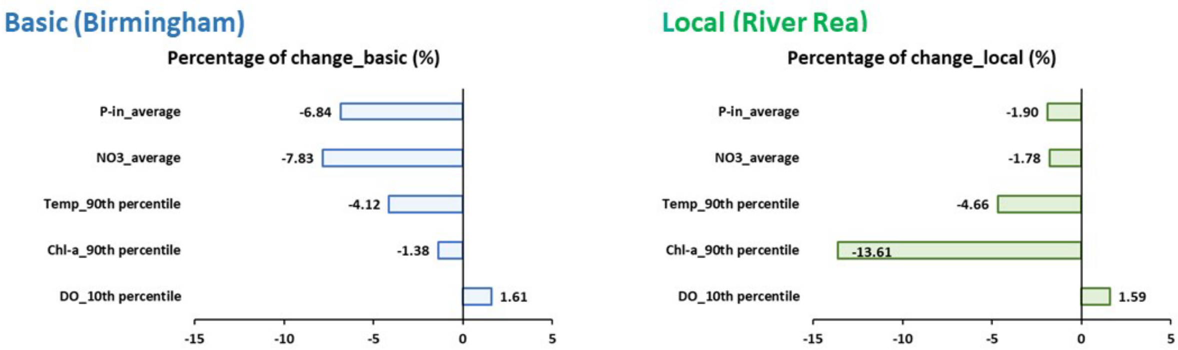


Figure 26: Percentage change in water quality metrics from present day baseline to the NBS scenario for basic and local model approach.

Some differences arising from the simplification are apparent, however. Simulated present day 90th percentile water temperature is approximately 2°C lower in the locally detailed model. This is probably due to the influence of a few unusually low summer water temperature observations in the headwater tributary. Also, the differences between the two models in 10th percentile DO levels can likely be largely attributed to this. Similarly, differences in present day simulations of nutrient concentrations are likely a manifestation of the observations used to describe headwater model inputs. For suppression of algal biomass (Chl-a) the benefit is underestimated by the basic model relative to the local model. This is likely due to differences in present day level of riparian shade between the two applications. For the basic setup it is assumed there is no shade. Differences are propagated through to differences in nutrient concentration benefits. Nutrient concentrations are largely controlled by two processes (runoff inputs from the land and biotic uptake in the channel). The basic model simulates larger nutrient reductions than the local model because the reduced nutrient load in input runoff (due to increased uptake by trees in the catchment) is minimally offset by reduction in biotic uptake by algal biomass in channel. In the local model, as there is considerable reduction in biotic uptake under the NBS scenario, the two processes are closer to being in balance.

Although less representative of local situations, the simpler approach has advantages in that it:

- has less demanding data requirements. To maximise the value of detailed local applications much information is needed on specific rivers, including overlapping periods of hydrological and water quality time-series data, information about channel hydrodynamics and flow control structures, details of influences (e.g., effluent discharges and weirs) along the river stretch. This can be challenging for modellers and local contacts to acquire. The simpler approach solely requires some data on flow and water quality from a typical river in the city. Data need not all come from the same time period.
- allows a direct comparison to be made between any cities in the world based solely on climate. The comparison can be repeated for a range of river hydrodynamic situations. Doing so isolates and quantifies the influence climate and geographic location have on how vulnerable typical urban rivers are to poor water quality and the degree of potential for beneficial response to NBS establishment. As demonstrated for the Birmingham case that differences in model complexity do not give rise to large differences in results, the simpler standard approach shows promise in providing a basis for global knowledge exchange. Aside from tree planting scenarios, the approach can be applied for a range of other NBS including restoring river channels (re-naturalisation, including daylighting).

3.4 Exploring linkages between people and ecosystem services

To assess impacts of 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.

3.4.1 Access to green-blue space in Aarhus ULL

In order to show how linkages between people and ecosystem services can be explored, we present an analysis of access to green-blue spaces in Aarhus ULL. For Aarhus ULL, there exists different types of spatial information at different spatial resolutions and units. Land use / land cover (LULC) information is available from high-resolution LULC mapping at a resolution of 0.2m (see factsheet in section 2.2) and building and ownership information is available at cadastre level (see factsheet in section 2.4). Population numbers are available at spatially explicit address scale. Information on age distribution, at district level and information on household income at 1km resolution were dis-aggregated to address scale (see factsheet in section 2.12).

We assess access to green-blue space with two alternative approaches: 1) private green-blue space in m² pr. inhabitant (Figure 27), and 2) Distance to publicly accessible green-blue space in meters (Figure 28). We analyse access to green blue space in relation to 1) residential housing types, B) Age groups and C) Household income.

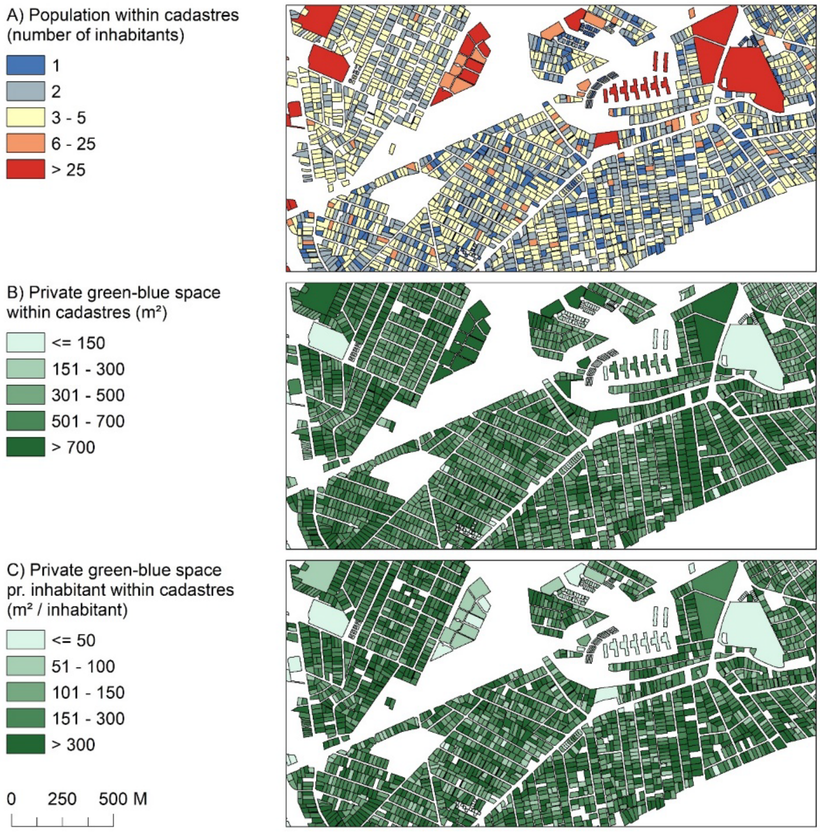


Figure 27: Illustration of calculation of private green-blue space pr. inhabitant for an extract of Aarhus ULL. Based on an overlay with population at address level, for each cadastre the total number of inhabitants is calculated (A). Based on an overlay with privately owned green-blue space, for each cadastre, the total areal of privately owned green-blue space is calculated (B). For each cadastre, the area of privately owned green-blue space pr. inhabitant is calculated (C).

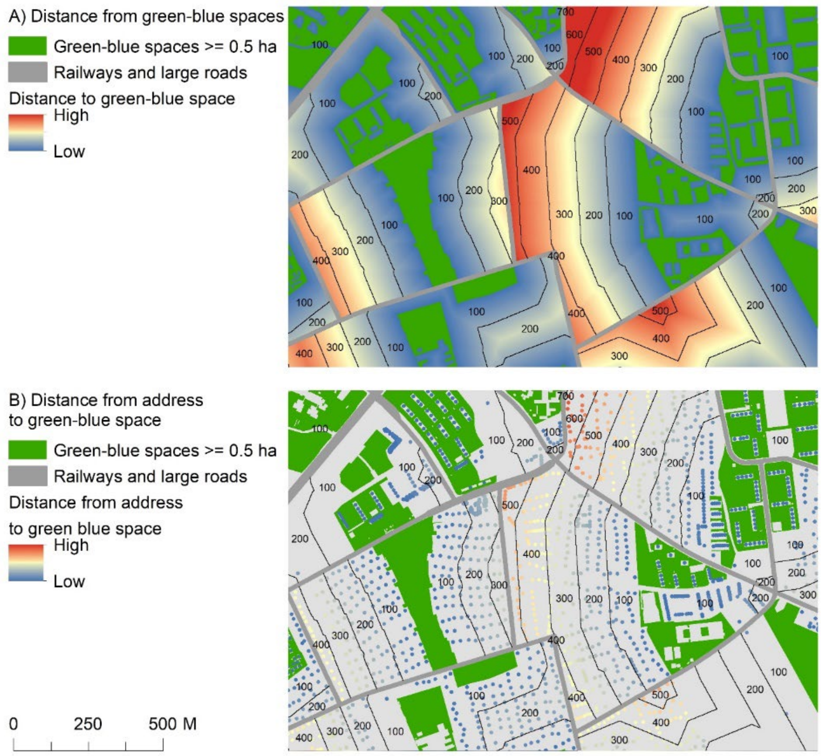
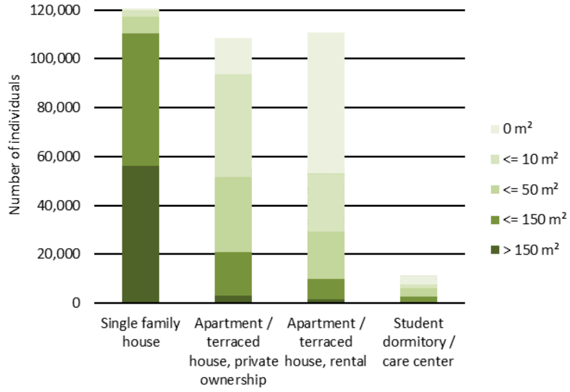
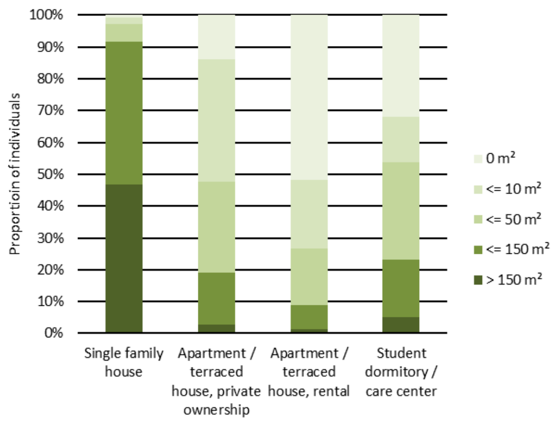


Figure 28: Illustration of calculation of distance from population to green-blue spaces for an extract of Aarhus ULL. The distance to green-blue spaces is calculated. Railways and larger roads (Highways and primary roads) are assumed barriers, which are not passed (A). Calculated distances are spatially assigned to addresses with population information (B).

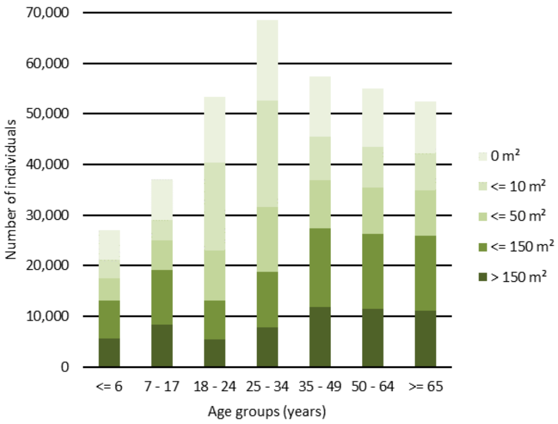
The charts in Figure 29 show available area of privately owned green space in m² pr. individual. For residential housing types (Figure 29 A and B), available private green space is largest for single family houses, smaller for privately owned apartments and terraced houses and smallest for rental apartments and terraced houses. For age groups (Figure 29 C and D), available private green space is lowest for individuals from 18 to 24 and from 25 to 35 years, while for other age groups there is no noteworthy difference. For household income (Figure 29 E and F), available private green space increases with increasing income.



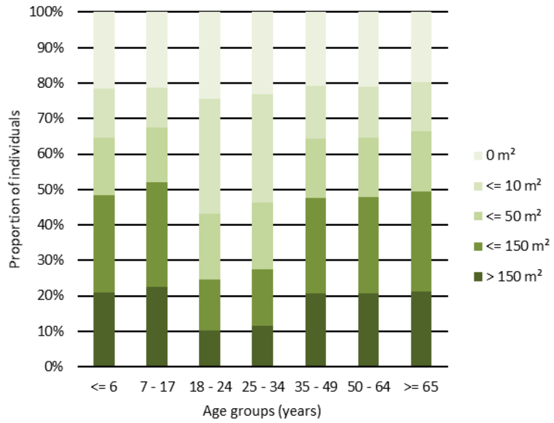
A) Available private green space pr. individual for different residential housing types. Number of individuals



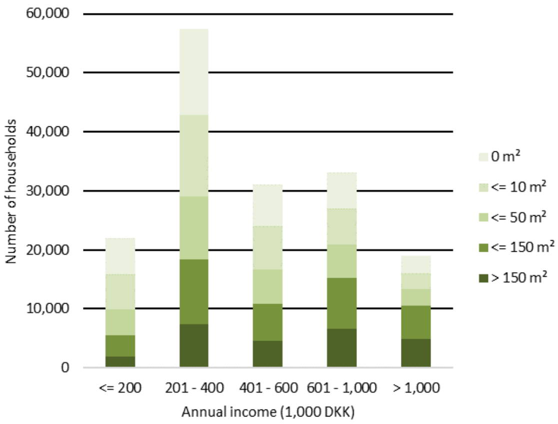
B) Available private green space pr. individual for different residential housing types. Proportion of individuals



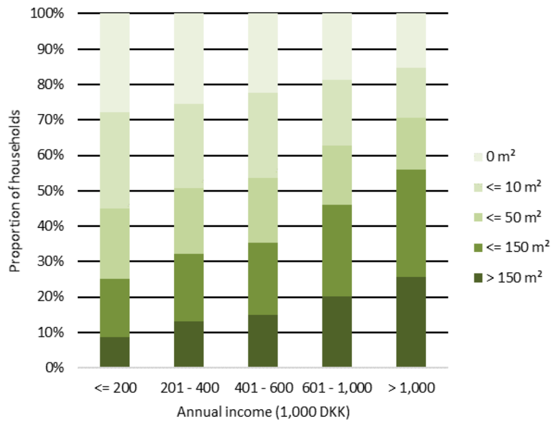
C) Available private green space pr. individual for different age groups. Number of individuals



D) Available private green space pr. individual for different age groups. Proportion of individuals



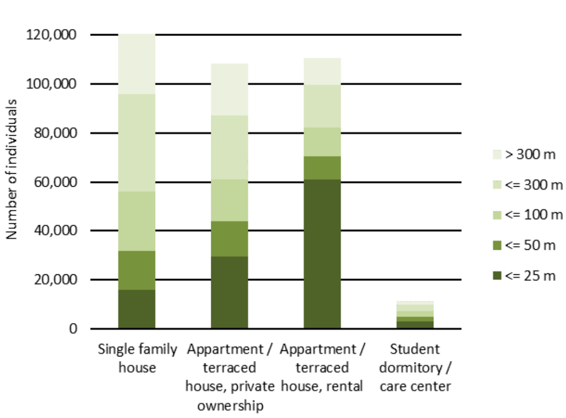
E) Available private green space pr. individual for different income groups. Number of households



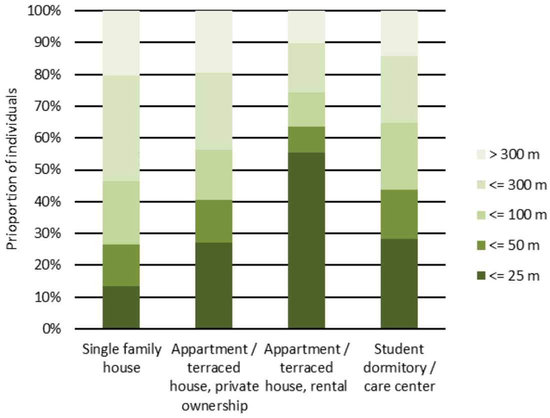
F) Available private green space pr. individual for different income groups. Proportion of households

Figure 29: Available private green space in Aarhus ULL.

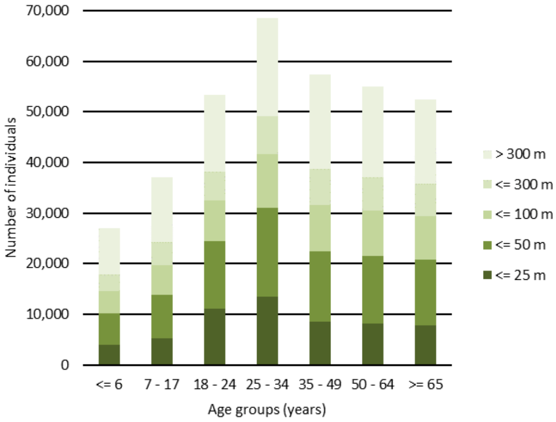
The charts in Figure 30 show distances to green-blue spaces >= 0.5 ha. For residential housing types (Figure 30 A and B), distances are largest for single family houses, smaller for privately owned apartments and terraced houses and smallest for rental apartments and terraced houses. For age groups (Figure 30 C and D), distances are lowest for individuals from 18 to 24 and from 25 to 35 years, while for other age groups there is no noteworthy difference. For household income (Figure 30 E and F), no there is no noteworthy difference.



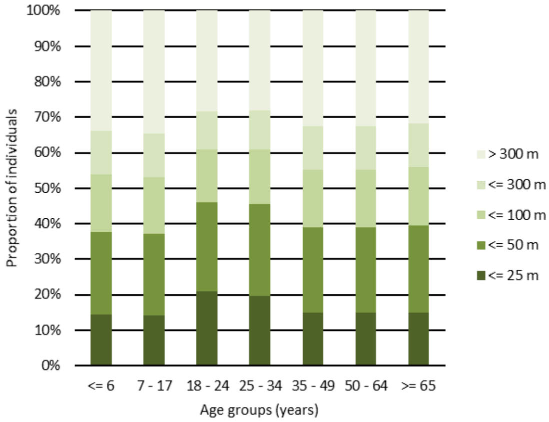
A) Distance to publicly accessible green-blue spaces > 0.5 ha for different residential housing types. Number of individuals



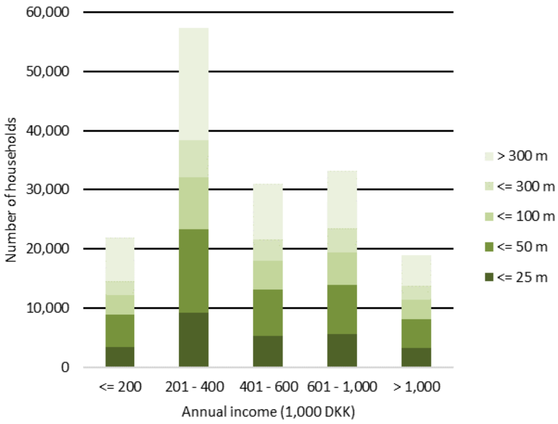
B) Distance to publicly accessible green-blue spaces > 0.5 ha for different residential housing types. Proportion of individuals



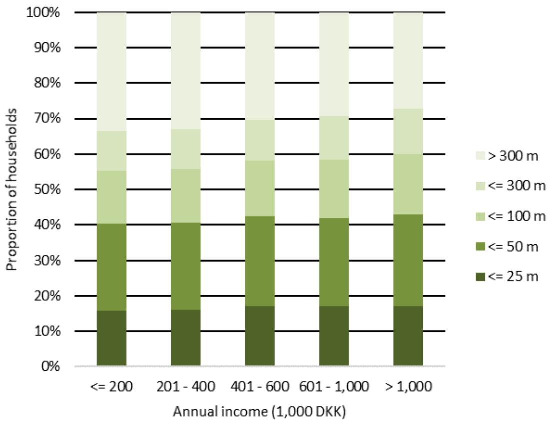
C) Distance to publicly accessible green-blue spaces > 0.5 ha for different age groups. Number of individuals



D) Distance to publicly accessible green-blue spaces > 0.5 ha for different age groups. Proportion of individuals



E) Distance to publicly accessible green-blue spaces > 0.5 ha for different income groups. Number of households



F) Distance to publicly accessible green-blue spaces > 0.5 ha for different income groups. Proportion of households

Figure 30: Distance to publicly accessible green-blue spaces >= 0.5 ha in Aarhus ULL.

3.5 From maps and models to ecosystem service assessment

The aim behind ecosystem services assessment in REGREEN is to incorporate data and model passes from WP2 (Challenges and nature-based solutions) through WP3 (Mapping and modelling ecosystem services) to WP4 (Wellbeing assessments and valuing benefits of nature-based solutions). The creation or collation of data on land-cover and socio-economic and socio-demographic information occurs to a large extent in WP2 (but also some activity in WP3), which is used as input into the ES models created and run in WP3. Outputs from WP3 are then passed as input to economic valuation conducted in WP4. In order to achieve this data-chain, frequent iteration is required between WPs to ensure each component is designed so that it is compatible with the needs and constraints of other components. Two examples are presented here.

3.5.1 Application with noise modelling in Paris

Detailed input data includes:

- High-resolution land-cover datasets for Paris, created by the ULL and adapted to needed model input by UFZ, initially at 3m resolution, but aggregated to 5m resolution for input to the noise modelling.
- Data on road traffic noise, at 5m resolution, obtained from IPR.
- Data on residential buildings, obtained from IPR.
- Data on population, attributed to residential buildings, in order to conduct health and economic assessments, obtained from IPR.

The noise model (see factsheet in section 2.7) uses a spatial calculation of the noise mitigation provided by those urban trees situated between the source (roads) and receptors (residential buildings). The model calculates a reduction in noise level by comparing different scenarios of urban tree planting with a reference scenario which assumes no mitigation by trees. The spatially explicit model identifies which residential buildings are experiencing noise mitigation, and by how much.

The number of people experiencing a reduction in road noise levels as a result of urban trees, can be converted into an economic benefit (in WP4), as a factor of the initial noise levels they experience, the quantity of mitigation they receive (reduction in noise levels), the number of people benefitting at each location, and the economic value associated with changes in noise levels at different intensity bands.

Table 26: Results of economic valuation for two woodland scenarios for Paris region ULL. For two woodland scenarios (no woodland and current woodland), the woodland cover, the costs of noise exposure (annoyance and health), the value of noise mitigation provided by woodland, and the average value of mitigation per hectare of woodland (€2019). Mitigation value is calculated using the total costs, by subtracting the costs for the 'Current' scenario from the costs for the 'No woodland' scenario.

Scenario	Woodland cover (ha)	Annoyance cost (millions)	Health cost (millions)	Total cost (millions)	Mitigation value (millions)	Average mitigation value ha^{-1}
No Woodland	0	€2,922	€495	€1,449	NA	NA
Current	305,380	€2,733	€462	€1,342	€223	€730

3.5.2 Application with valuing the benefits of urban heat mitigation

We created high resolution (30 m x 30 m) maps of air temperature for the Paris region for numerous days in 2019 by combining remotely sensed high resolution LANDSAT normalised differential vegetation index (NDVI) and lower resolution (1000 m x 1000 m), MODIS land surface temperature (LST) and NDVI, and calibrating the resulting product to air temperature data from two weather stations (Le Bourget and Orly Airport). For details of the methodology, please see Bird et al. (2022).

Using the air temperature maps, we calculated the cooling effect for public green spaces that were at least 1,000m^2 and at least 100 m from other green spaces or water bodies in, or overlapping with, the four central departments that constitute the Metropolis of Greater Paris (L'Institut Paris Region, 2020). For each green space, we calculate the average temperature of rings in increasing distance from the greenspace boundary (Figure 31). The maximum cooling distance is the distance beyond which we can no longer detect cooling. We then calculate the cooling effect by finding the difference in temperature between the boundary and the maximum cooling distance.

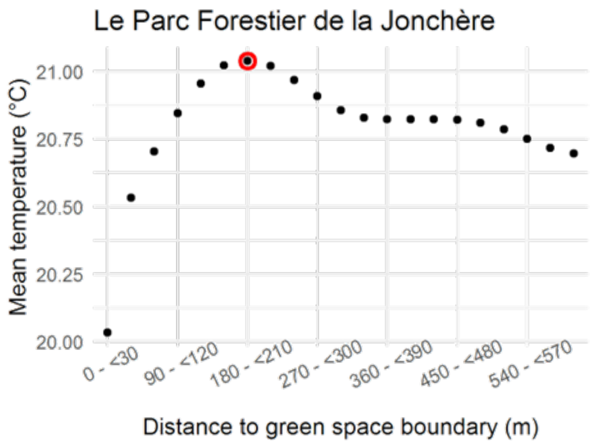


Figure 31: Example of a green space in Paris and the temperatures at a range of distances from the boundary for July 25, 2019. The red circle indicates the maximum cooling distance, or the furthest distance at which a cooling effect from the green space can be detected.

We then calculate the number of people affected by the cooling and the expected number of lives saved. This is based on the mortality rate, calculated from the number of deaths (INSEE, 2021a) in Paris and the population of Paris for 2018 (INSEE, 2021b) and data on population, attributed to residential buildings, obtained from IPR. Finally, to calculate the economic value, we apply the value of a statistical life to the number of lives saved. We apply the European default value of €3.371 million for the EU-28 (World Health Organization, 2014).

3.6 Applying maps and models in scenarios

There are a number of different scenarios which can be implemented in REGREEN for the purpose of ecosystem services assessment. We illustrate examples for three different types here:

- Scenarios developed in collaboration with a single ULL based on their existing NBS plans, and run for multiple models or ecosystem services outcomes;
- Scenarios applied consistently across all ULLs, with a focus on comparing a common suite of scenarios and exploring differences in outcome between cities, due to variations in e.g., climate, city structure, amount of existing NBS, population and demographics; and
- Scenarios exploring possible futures or policy directions, comparing across cities.

3.6.1 Afforestation in Aarhus ULL

The first type explores scenarios developed in detailed discussion with ULL partners – in this case in Aarhus ULL. This involved liaising with the Municipal authority to get information on planned (or ongoing) NBS interventions in the ULL, including information on spatial extent, timeframes for establishment, and detail on the type of land cover and other infrastructure changes taking place as part of the intervention. This information is then converted into mapped input layers for both a reference scenario of no change, and the intervention scenario. Where necessary this also involves specifying the rules by which land-cover should be change in the input land cover layers. For example: I) tree planting will avoid existing built-up areas, private gardens and water bodies, ii) in the remaining space tree planting will achieve 50% land cover overall, comprising entirely deciduous tree species, iii) tree planting will occur with equal probability on existing farmland, grassland but will avoid heathland.

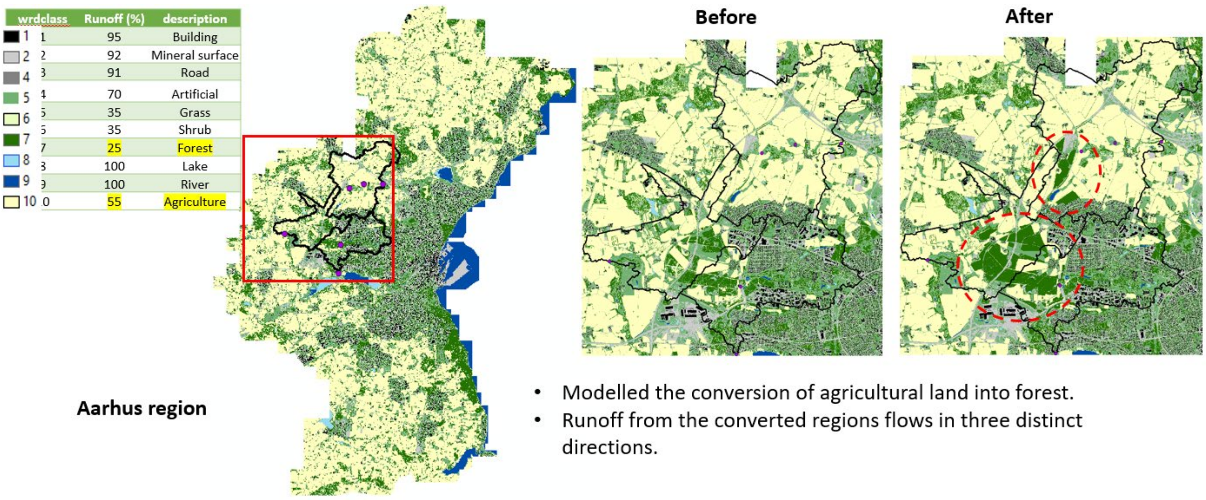
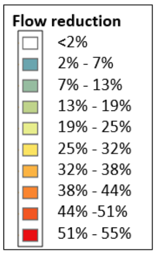


Figure 32: Design of the scenarios to explore role of tree-planting on western edge of Aarhus to improve groundwater quality.

- A maximum reduction in flow of 55%
- The effect is quickly diluted downstream (- 4% at outlet 4).



Catchment	Area	Q (BASE, m3/s)	Q (GREEN, m3/s)	Reduction (%)
1	19.86	35.50	34.96	-1.54
2	0.89	2.49	2.02	-18.92
3	17.34	37.56	36.89	-1.77
4	11.04	26.28	25.21	-4.08
5	12.71	20.50	20.37	-0.67
6	0.50	1.17	1.13	-4.13

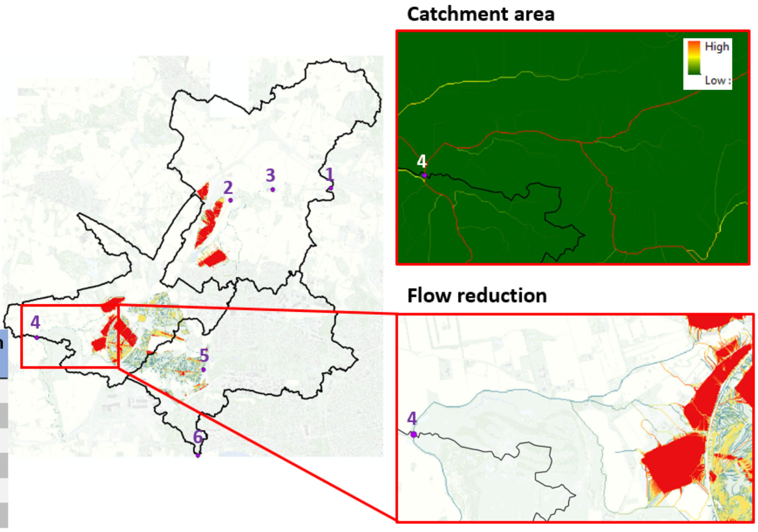


Figure 33: Outputs of the ANaRM model evaluating tree-planting scenarios on the edge of Aarhus for co-benefits of water flow mitigation.

3.6.2 Tree planting in European ULLs

The second type uses a common set of scenario options which are implemented across multiple cities. This approach lends itself well to the application of the air quality modelling approach, where all 3 European ULLs can be run in the same modelling domain in the EMEP-WRF model. The scenario options explored in this approach include a range of urban vegetation management choices, designed to explore basic questions like: What is the performance of current urban vegetation in each city in removing air pollution? What are the benefits of additional tree planting within the urban footprint of each city? Would you get the same benefits by planting the same area of trees outside the city? As with the scenario in Case 1, there is substantial data processing required to generate the spatial maps of scenarios. This includes rules about which types of land cover should be replaced by trees, and what the counterfactual is if you remove trees. Following approaches defined in Jones et al. (2019), in scenarios which remove vegetation to calculate the effects, we choose bare soil as the alternative land cover. In other scenarios, the reference scenario used is the status quo. The figure below shows spatial scenarios of additional tree planting within the urban footprint, for the three European ULLs.

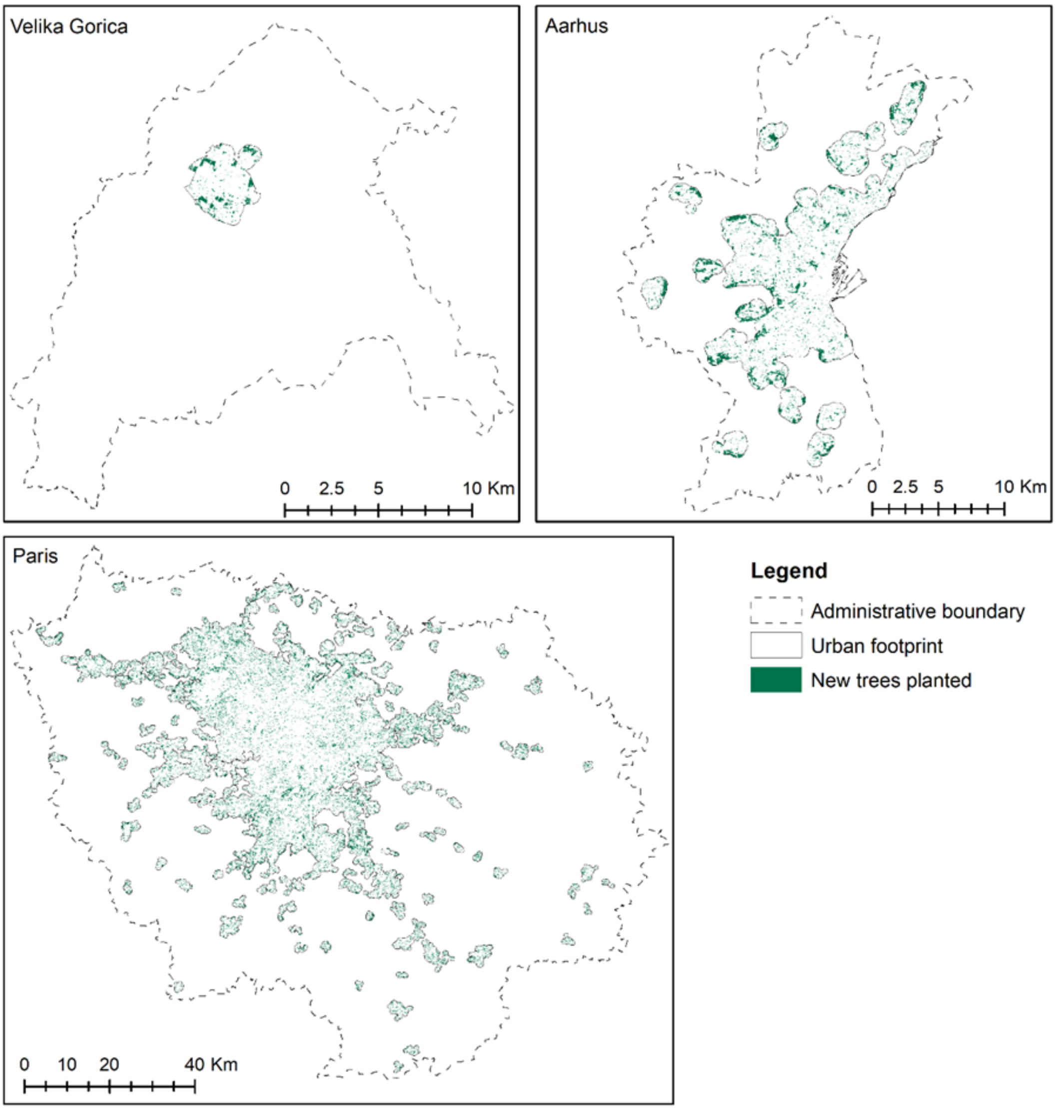


Figure 34: Example of land cover layers created for the three European ULLs, for the air pollution removal scenario which involves additional tree planting inside the urban footprint for each city. The source land cover was the 10m consistent land cover created for all six REGREEN ULLs.

3.6.3 Cross-ULL scenarios for 2030

In order to simulate land cover in the future for all the 6 ULLs, several driving factors including natural geographical, location, and socio-economic factors were considered as spatial distribution drivers. We started with the observed land cover situations mapped for two decades, thus covering the three time slots 2000, 2010 and 2020.

To process three different scenarios across our ULLs, we used the CLUE-S model (Wu et al. 2022b) combined with landscape metrics and ES evaluation. The CLUE-S model has been widely used for future land cover/use simulations. It is a dynamic, spatially explicit LULC model, which can consider location characteristics of land cover distribution, the demand of requirements, spatial policies and restrictions of land-cover changes and also land cover conversion settings. In addition, various scenarios could also be considered during the simulation. In this study, the spatial resolution of 60 x 60 m2 was used for the simulation.

To estimate different development patterns for the year 2030, three different scenarios were created. The first is the so-called business-as-usual (BAU) that predicts land-cover change progressing in a linear way following the current trend without new policies influencing changes neither towards environmental protection nor towards economic growth and built expansions. The second is market-driven by economic prosperity (MLS) in which urbanisation continues to expand, at the cost of environmental protection. The third is set towards environmental protection (EPS) that assumes a less extreme growth rate with the target of a gain or at least maintaining of ES for urban dwellers.

The land cover demands were calculated based on three different scenarios. Specifically, under the BAU, the demand areas of land cover were consistent with land-cover change trend based on land cover maps from 2010 to 2020. Under the MLS, the change trend of built-up area was increased by 50% compared with BAU (Peng et al., 2021). Finally, under EPS, the demand of ecological lands was increased by 50% when it is increasing during 2010 to 2020, otherwise, the decrease rate was slowed down by 50%.

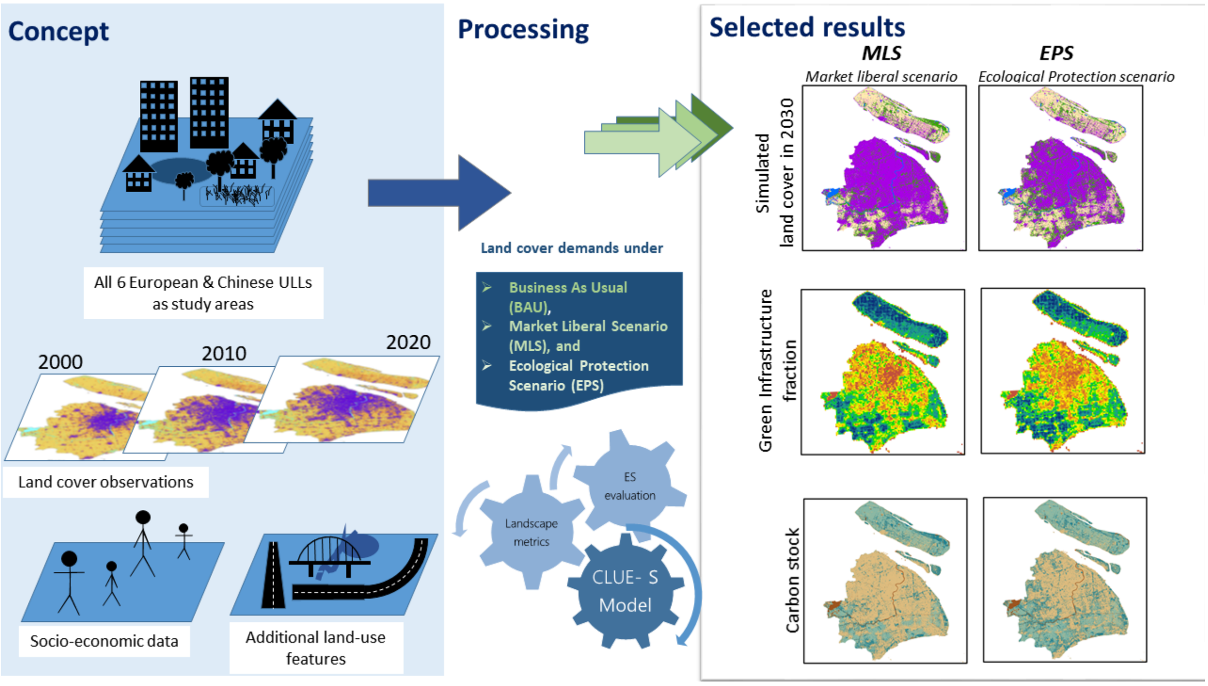


Figure 35: Framework from past to future for ES evaluation illustrated for Shanghai, China. (BAU= business-as-usual scenario; MLS= market-liberal scenario; EPS= ecosystem protection scenario).

By having carried out these scenarios, we could predict green infrastructure (GI) and ES patterns over the next decade under these three different demand-driven assumptions. Beyond, we could explore changes in GI and ES distribution from the past to the future and assess the differences between Chinese and European ULLs.

4 CONCLUSIONS

In this report we provide an overview of mapping and modelling procedures which are developed and applied during the first three years of the REGREEN project. The different mapping and modelling approaches are described in short and comprehensible factsheets. These factsheets can be used to guide mapping and modelling approaches in other urban projects, as well as explaining in a concise form the methods used within REGREEN. At the time of publication, REGREEN is an ongoing project. Consequently, the status and completeness of the different mapping and modelling approaches vary.

We provide guidance to other users by identifying and discussing relevant critical issues for mapping and modelling ES in urban settings. We do this in factsheets for those mapping and modelling approaches, where it is relevant, and illustrate these issues in more detail for examples from finalised or ongoing work in the REGREEN project.

We also discuss the transferability of the applied approaches and show examples of such transfer work. This helps to transmit the mapping and modelling approaches applied in the REGREEN project to other study areas and to use them in further environment-related research questions.

While it is valuable to have comparable mapping and modelling outputs, data availability and applicable methods often vary across Europe and other regions. We describe how different data sources and modelling approaches can be applied, while still ensuring comparability and consistency of outcomes across case studies.

When choosing mapping and modelling approaches, it is necessary to weigh up between desired detail and spatial and temporal resolution of outcomes and available resources. For the applied approaches, we give recommendations on this trade-off between detail and resources.

A central aim of the REGREEN project is to investigate how NBS and ES impact on people in different urban areas in Europe and China. Therefore, we explore how vital statistics can be applied location-based to assess links between socio-economic and socio-demographic aspects and NBS interventions and ES provision.

In REGREEN, we aim to use maps and model outputs for wellbeing assessment and economic valuation of ES. We present pilot studies for noise and heat mitigation in Paris Region ULL, where this chain from mapping over modelling to economic assessment has been completed.

In REGREEN, we implement several scenarios, where we apply maps and models to assess impacts of NBS on ES. In this report we use case studies to illustrate three different types of scenarios: 1) Scenarios developed in collaboration with a single ULL based on their existing NBS plans, exemplified by a case on afforestation in Aarhus ULL; 2) Scenarios applied consistently across multiple ULLs, with a focus on comparing a common suite of scenarios and exploring differences in outcome between cities, exemplified by tree planting to mitigate air pollution, and 3) Scenarios exploring possible futures or policy directions, comparing across ULLs, exemplified by cross ULL scenarios for the year 2030.

The disciplinary research approaches receive their added value through the partnership with the ULLs. The ULLs define the locally pronounced focal points of environmental pressures, they enrich through their local knowledge and through the local to regionally available data situation and they formulate the place-based need for NBS. Only through this close and good cooperation is it possible to carry out such a wide range of ES analyses and evaluations. Most themes that are presented here are due to the ongoing exchanges between scientists and planners. These illustrated tools and guidelines can be used as a reference tool by other cities and municipalities with similar environmental problems and demands, to guide their NBS implementations.

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