REGREEN
NATURE-BASED SOLUTIONS

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

Deliverable **N°3.1.**

WP **N°3** Mapping and modelling ecosystem services

Synthesis report on current datasets and their applicability of ecosystem services mapping and modelling

Authors: **Ellen Banzhaf (UFZ), David Neil Bird (JR), Eduardo Blanco (MNHN), David Fletcher (UKCEH), Laurence Jones (UKCEH), Julius Knopp (UFZ), Xiangyu Luo (THU), Wanben Wu (FU), Jun Yang (THU),** – with contributions from **Nuria Bachiller-Jareno (UKCEH), Michael Hutchings (UKCEH), Jun Ma (FU), James Miller (UKCEH), Massimo Vieno (UKCEH), Bin Zhao (FU)**

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EXECUTIVE SUMMARY

This synthesis report is part of the deliverables of the EC funded REGREEN project and elaborates a profound baseline for further integrated research in Work Package 3, "Mapping and Modelling Ecosystem Services" in their multiple expressions for human well-being provided by nature-based solutions (NBS). It covers the first nine months of the project's runtime in which we evaluate scale-dependent data and models by exploiting existing frameworks and collating data at various scales to quantify ecosystem services (ES), spanning green and blue infrastructure in varied cultural and climatic contexts.

Based on the indicator frameworks EKLIPSE and Nature4Cities, we continue to develop an integrated and lean indicator framework to capture synergies and trade-offs from NBS for multiple ES, thus allowing for weighting and setting priorities of the demand and supply indicators and fulfil the best adapted NBS at differing spatial scales. Existing maps and models, aiming at quantifying specific ES, vary in complexity and applicability. The purpose is to evaluate available data at different scales as well as mapping characteristics and modelling in order to explore suitability and applicability for quantification of ES in the respective urban living labs (ULLs).

By pulling the different disciplinary strands together and understanding each other's research approaches, we are able to formulate the common need for data, and establish a common understanding of indicators and their related frameworks for ES, as well as illustrating the linkages to other work packages.

Our most important results are a first mapping of land use and land cover in different ULLs presented in Section 5, and, and first modelling achievements exemplified in Section 6. Beyond, to deepen our common understanding of ES mapping and modelling, we developed eight fact sheets that display our products, methods, and pinpointed aims for NBS implementations in REGREEN (see Appendix).

To conclude, we continue our research for the very specific need of the respective ULLs. Evidently, not all ULLs have the same demand for NBS interventions. Hence we distinguish between these specific NBS demands regarding type and scale of intervention. To do so, we will pinpoint on the supply by respective mapping and modelling of ES to carve out the most suitable bundles of NBS interventions.

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1 INTRODUCTION

1.1 Purpose of the document

This document is part of the deliverables of the EC funded REGREEN project. Its design is aiming at elaborating a profound baseline for further integrated research in Work Package 3 (WP 3), “Mapping and Modelling Ecosystem Services” in their multiple expressions for human well-being provided by nature-based solutions (NBS).

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 this is: Aarhus, Denmark, Paris Region, France, Velika Gorica, Croatia. In China this is: Beijing, Ningbo and Shanghai.

During this initial phase, WP 3 evaluates scale-dependent data and models by exploiting existing frameworks and collating data at various scales to quantify ES from green and blue infrastructure in varied cultural and climatic contexts. Existing models, aiming at quantifying specific ES, vary in complexity and applicability. Therefore, one purpose of this WP is to evaluate available data at different scales as well as mapping characteristics and models in order to explore suitability and applicability for quantification of ES in the respective ULLs. Data that delineate spatial characteristics like land use, range from primary remotely sensed data (satellite imageries, aerial photos, digital elevation and surface models) to categorical (processed) datasets. To model ES for NBS interventions within the ULLs, we depict collated data at refined level and utilise coarse scale land-use and land-cover information for all ULLs in Europe and China. In this Synthesis Report, we present existing indicator frameworks, amongst them those like the *Knowledge and Learning Mechanism on Biodiversity and Ecosystem Services* (EKLIPSE), the *Common International Classification of Ecosystem Services* (CICES) and the *Mapping and Assessment of Ecosystems and their Services* (MAES) framework, and then adjust those for further development of integrated analyses. We first make use of existing indicators and, as innovative approach, develop new indicators to fill gaps in those that we select as a baseline indicator framework. Furthermore, we apply the latest modelling approaches to quantify the multifunctional services provided by green and blue infrastructure. Especially through the close collaborations with the European ULLs we develop a deeper understanding of the pinpointed needs for ES to select the appropriate model and scale. By tailoring them to specific sites, they allow optimal design of operational NBS.

This is a synthesis report covering the first nine months of the project’s runtime and pictures the disciplinary efforts undertaken in WP 3 so far. Hence, we pull the different strands together and make the exertion of this first interdisciplinary product. It makes the scientific cooperation between the disciplines evident by picturing our understanding of each other’s research approaches, formulate the common need for data, and establish a common understanding of indicators and their related frameworks for ES. By doing so, this report illustrates the linkages to other work packages. As the potential of ES is rooted in a holistic understanding of social, ecological and physical systems, WP 3 grasps the information on drivers and pressures elaborated in WP 2 (Challenges and nature-based solutions) and jointly discusses on how to delineate the urban structure at different spatial scales for multiple model purposes. WP 3 intends to benefit from the knowledge established in WP 4 (Wellbeing assessment and valuing benefits of nature-based solutions) to integrate qualitative information on human dimension further on during the project phase. Closely intertwined with WP 7 (Urban Living

Labs), this WP works with all the three European ULLs and exchanges intensively with the Chinese ULLs, especially with Shanghai and Beijing.

The large authorship of this Synthesis Report bears witness of the close collaboration between the different institutions across Europe and China. By doing so, we are convinced to progress towards an integrated assessment in a case-sensitive way by combining quantitative and qualitative information, thus establishing tools and guidelines for mapping and modelling ES to achieve socio-culturally well-founded NBS interventions at the appropriate scales.

1.2 Scope and structure of the document

The scope of the undertaken research covers the discussion of the most prominent indicator frameworks for ES (Section 2). By doing so, it sheds light on existing indicator frameworks funded through EC projects, and, beyond, illustrates the first Chinese urban ecological development initiatives. As part of the research and innovation action funded by EC, REGREEN reflects the selection of the most appropriate indicator framework to integrate knowledge and test tools to address urban challenges and proving evidence for benefits from NBS.

While exploring data needs and availability (Section 3), the document pays tribute to the different dimensions and aspects, which represent influencing categories for data analysis in the urban ecological context. When reflecting on indicators, their levels of detail are manifold and quite sensitive to the application of ES models. Another important issue is to immerse into the database on current datasets. Specifications of available data must be examined in relation to the needs for mapping and modelling of the respective ES. WP 3 also clarifies other collecting entities if necessary input data is not publicly available.

The tool of fact sheets (Section 4) is used to present information and data on mapping and modelling for specific ES in a short and simple format, which emphasizes key points concisely. Each mapping and modelling fact sheet informs on the model or mapping product name and responsible scientist. It gives a short description and basic information of map / model output and explains the general methodological background. The specifics for the approach in WP3 are displayed by how ES are mapped and modelled. An important matter is the upscaling / downscaling inherent to each model as well as its limitations. Finally, a data table for input requirements lists data types, needed features, spatial and temporal resolutions. The fact sheets are living documents with date of update provided. The fact sheets are elaborated for:

- Mapping by using Google Earth Engine (GEE);
- Urban land-cover mapping framework;
- Urban morphology mapping framework;
- Water quality assessment model QUESTOR;
- Atmospheric chemistry transport model (EMEP) and weather research and forecast model (WRF) - EMEP-WRF;
- Hydrological modelling;
- Traffic noise mitigation modelling; and

- Heat mitigation modelling.

All fact sheets are documented in the Appendix.

Section 5 provides examples for first mapping products of land cover and land use in the respective ULLs. In REGREEN, urban remote sensing techniques stretch out over different scales and intrinsic methods. For this reason, several approaches will be employed during the project phase. A starting point is to understand the spatial extent and land use / land cover (LULC) of each ULL. Therefore, Landsat data were selected to map LULC for all ULLs. For the analytical steps, Google Earth Engine (GEE) was chosen for the following reasons: our Chinese partners at Fudan University, Shanghai, and at Tsinghua University, Beijing, both use GEE intensively. Furthermore, in GEE a manifold of satellite images is freely available, and GEE facilitates to exploit all available datasets for a defined region and time period. Therefore, all partners take advantage of data availability and analytical techniques provided by GEE. Different analytical approaches are chosen and fuel our discussion on the appropriate outcome for ES modelling and related NBS. That again allows for an intensive exchange between the European and Chinese ULLs.

Section 6 illustrates first examples of applied ES modelling. They comprise a noise mitigation model and a heat mitigation model. At this early stage in the project, the first example on noise mitigation depicts how datasets will be used for one ES model by taking the ULL Paris Region as a case study example. It illustrates the underlying input data layers and offers a first product map. The heat mitigation model example also focuses on the ULL Paris Region as case in order to explore the outcomes at a regional scale. Further information of the second model shows distinct outcomes at different spatial scales with respect to inner urban differentiation. At this stage of the project, the refined illustrations are taken from other projects and present examples of Austria and Italy. They are promising regarding site-specific heat mitigation NBS and related interventions for various ULLs in the project.

Finally, Section 7 concludes the Synthesis Report by giving a short summary of achievements, relating to further developments, and how we intend to move forward. Finally, it discusses constraints and bottlenecks for the project as well as lessons learned.

2 REPORT ON EXISTING INDICATOR FRAMEWORKS FOR ECOSYSTEM SERVICES

The ES concept is the subject of vast research and application in sustainable urban sciences. Developed in the 1990s, it has been proposed as a framework to facilitate the understanding of human dependencies on ecosystems and to provide elements on the economic valuation of these benefits (Costanza and D'Arge 1997; Daily et al. 1997).

Haines-Young & Potschin (2010) explored the theory to understand the supply process of ES. This work resulted in the cascade of ES theory, which defines and organizes the critical elements for the creation of ES and provides a unified analytical framework for advancing their implementation (Haines-Young & Potschin, 2010; Potschin et al., 2018). The ES cascade is composed of five elements that are biophysical structures/processes, functions, services, benefits, and values. It represents the necessary sequence in socio-ecosystems to create the goods and benefits from the ecosystems, and puts an accent on the role of ecosystems' structures as the starting point of services supply.

In the urban management field ES have been mostly used to explore issues related to the preservation of ecosystems and biodiversity in cities and as a decision-making tool in urban public policies, infrastructure investment and urban planning (Cortinovis & Geneletti, 2019; Haase et al., 2014; Kaczorowska, Kain, Kronenberg, & Haase, 2016). Since the concept formalization, several research projects have been conducted regarding the development of methodologies and frameworks to assess ES. However, its operationalization at the urban scale faces challenges such as the lack of available data (Hermelingmeier & Nicholas, 2017; Kaczorowska et al., 2016), and the difficulties in understanding ES supply and demand on complex socio-ecosystems as cities (Alberti, 2005; Haase et al., 2014).

Concerning the development of indicators frameworks to assess ES at urban scales, data availability, public policies, and project objectives are crucial elements to select relevant indicators and assessment methodologies (Pandeya et al., 2016). ES indicators can refer to and assess different elements of the ES cascade (such as ecological structure, social benefits, added values, or even pressure on ecosystem) (Braat & de Groot, 2012; Van Oudenhoven, Petz, Alkemade, Hein, & De Groot, 2012). Haase et al. (2014) realized a first systematic review to understand the actual application of ES evaluation in urban studies, and raised the lack of homogeneity and adequate use among these indicators to illustrate the complexity, diversity, and quality of the benefits to society rendered by ecosystems. The research also identified that almost 50% of the ES evaluated in the studies were regulating services, followed by supporting services, by cultural services, and lastly, provisioning services. Local climate regulation, freshwater supply, and recreation were the three most prominent services in urban studies. Prominently applied strategies to ES supply in urban space are identified as increasing land-use diversity, as well as intensified green and blue infrastructure.

Wang and Banzhaf (2018) expanded the systematic review on ES based on green infrastructure by not only investigating upon those articles published in English language, but also those in Chinese, and undertook an in-depth analysis for 301 related articles. Due to language conventions, quite a large number of Chinese studies in Mandarin have attracted little attention on the international level. The related research articles on urban ES are important to be examined, because in China urbanisation processes are under an environmental strain of an unprecedented scale. For this reason, some Chinese research related to ES, especially the China Sponge city concept and Turenscape design of green infrastructure, is considered to be an innovative and proactive response to environmental pressures.

As early as in 1995, Yu (1995; 2006) developed the ecological concept of Security Patterns (SP) to support abiotic, biotic and cultural functions, thereby providing sustainable ES. This key strategy was adopted by his planning team at Beijing University and Turenscape, and was applied in the context of Chinese urbanisation. In 2008 the National Ecological Security Pattern Plan included ecological process analysis and evaluation based on individual ecological SPs, mainly headwater conservation, storm water management, flood control, remediation of desertification, soil erosion prevention and biodiversity conservation (Yu, 2008). When Turenscape exemplified the ES approach in Taizhou city, the planning concept combined man-made bifurcation to restore the ecological (flood risk management) and social functions (neighbourhood connectivity) in urban river landscapes. Yu's core idea of SPs and their application are regarded as a milestone in the quest for more resilient cities in China.

Finally, the categorisation and description of ES are the base of any assessment approach, and several classification systems exist (like those used by the Millennium Ecosystem Assessment, by The Economics of Ecosystems and Biodiversity, by the Intergovernmental Panel on Biodiversity and Ecosystem Services). The Common International Classification of Ecosystem Services (CICES) has been developed based on the ES cascade framework to promote homogeneity on the extensive classification of ES. With its hierarchical structure, it is proposed to be comprehensive and complex. Due to its high level of detail and the highest number of included services, CICES is used by several EU initiatives and urban studies (Haines-Young & Potschin-Young, 2013; Maes et al., 2018).

The need to better understand and analyse ES is faced by ongoing research on the topic, but understanding and assessing their supply remains a significant challenge in urban planning and urban ecology. Due to their complexity and multidimensionality, ES remain difficult to measure, but their analysis is essential as a tool to support planning and decision-making in urban development (Tolvanen et al., 2016; Wright, Eppink, & Greenhalgh, 2017).

At EU level, different frameworks and methodologies have recently emerged that aim to assess ES relying on multifunctional green and blue infrastructure through indicators (e.g. United Nations, 1996; Maes et al., 2018), given that a systematic combination of several indicators is the best way to represent their overall performance and functions (Naumann et al., 2011; EC, 2012). Wang et al. (2019) investigate different indicator frameworks and find that the concentration on demand and supply indicators vary strongly between them. Another distinction between the indicator frameworks refers to the spatial scales of relevant ES indicators (regional, metropolitan, urban, site-specific scales).

Indicator frameworks

Several authors proposed specific analytical frameworks suitable for the assessment of urban ES with different levels of complexity and focus. Some of them, like those developed by the EKLIPSE and Nature4Cities projects, presents an accent on the performance assessment of NBS and have a broader focus, and some of them have a narrow focus, like on regulating services. In the next sub-sections, we present and explore the following frameworks:

- A framework to explore the effects of urban planning decisions on regulating ES in cities by Cortinovis & Geneletti (2019).
- A framework for classifying and valuing ES for urban planning by Gómez-Baggethun & Barton (2013).
- An integrated indicator framework for the assessment of multifunctional green infrastructure – exemplified in a European city by Wang, Pauleit and Banzhaf (2019).
- The EKLIPSE framework for impact evaluation to support planning and evaluation of NBS projects by Raymond et al. (2018).
- The MAES analytical framework for ecosystem conditions by Maes et al. (2018).
- The NATURE4CITIES indicator framework (NATURE4CITIES, 2018).

2.1 A framework to explore the effects of urban planning decisions on regulating ES in cities

Among the different ES typologies for urban areas, special attention is given to regulating services (Haase et al., 2014). The typology developed by Cortinovis & Geneletti (2019) plays a significant role in relation to the well-being of urban residents who can among others, be affected by urban planning actions. They focus on these services to propose an analytical framework that links the supply of this ES with urban planning decisions and proposes some exemplary indicators for social and economic benefits from these services. To build this framework, the authors build upon the ES cascade theory (Haines-Young & Potschin, 2010), the supply-demand approach for ES mapping and assessment (Baró et al., 2016; Burkhard, Kroll, Nedkov, & Müller, 2012) and reviewed studies regarding regulating ES in urban spaces.

Table 1 shows the seven urban regulating ES selected by the authors and potential exemplary indicators to assess social and economic benefits from urban regulating ES.

Table 1: A framework for urban regulating ES

Urban regulating ES	Social benefits exemplary indicators	Economic benefits exemplary indicators
Air purification	Reduction of premature deaths and hospital admissions	Monetary benefits based on avoided externalities Return on investment of tree planting (beneficiaries x mitigation/cost)
Global climate regulation moderation	*	Monetary value based on estimated marginal social costs of carbon Monetary value based on carbon market prices
Moderation of extreme events	Reduction of human deaths	Replacement cost of engineering structures
Noise reduction	Number of persons with change from annoyed to not annoyed dB(A) change per person/household per year	Economic value of noise reduction based on hedonic pricing
Runoff mitigation and flood control	Reduction of number and frequency of combined sewage overflow Reduction of localised flooding	Avoided damage based on the total value of properties protected
Urban temperature regulation	Reduction in cumulative population-risk weighted exceedance heat index Total number of people and number of vulnerable people exposed to the cooling effect of urban green infrastructure	Avoided damage based on specific depth-damage functions for different Replacement cost of manmade
Waste treatment	*	Savings based on replacement cost

* Benefits for the urban regulating ES were not identified by the authors

Source: Adapted from Cortinovis & Geneletti (2019)

2.2 A framework for classifying and valuing ES for urban planning

Gómez-Baggethun & Barton (2013) conducted a literature review to identify those ES which are most relevant to urban ecosystems. They identified eleven ES (eight regulating, two cultural, and one provisioning) and proposed possible indicators to monitor and evaluate these services.

Table 2 presents the proposed ES and potential indicators.

Table 2: A framework for urban ecosystem services

Ecosystem services	Example of indicators/proxies
Food supply	Production of food (tons yr−1)
Water flow regulation and runoff mitigation	Soil infiltration capacity % sealed relative to permeable surface (ha)
Urban temperature regulation	Leaf Area Index (LAI) Temperature decrease by tree cover×m^2 of plot trees cover (°C)
Noise reduction	Leaf area (m^2) and distance to roads (m) Noise reduction dB(A)/ vegetation unit (m)
Air purification	O_3, SO_2, NO_2, CO, and PM10 µm removal (tons yr−1) multiplied by tree cover (m^2)
Moderation on environmental extremes	Cover density of vegetation barriers separating built areas from the sea
Waste treatment	P, K, Mg and Ca in mgkg−1 compared to given soil/water quality standards
Climate regulation	CO_2 sequestration by trees (carbon multiplied by 3.67 to convert to CO_2)
Pollination and seed dispersal	Species diversity and abundance of birds and bumble bees
Recreation and cognitive development	Surface of green public spaces (ha)/inhabitant (or every 1,000 inhabitants)
Animal sighting	Abundance of birds, butterflies and other animals valued for their aesthetic attributes

Source: Adapted from Gómez-Baggethun & Barton (2013)

2.3 An integrated indicator framework for the assessment of multifunctional green infrastructure – exemplified in a European city

Wang, Pauleit, & Banzhaf (2019) designed an integrated indicator framework for the assessment of multifunctional green infrastructure, aiming to develop an approach to conduct an assessment using remote sensing datasets at multiple spatial and spectral scales.

The authors used three existing frameworks (MAES framework, Institute for European Environmental Policy (IEEP) framework, and East Midlands Development Agency (EMDA) framework) to propose the assessment methodology. In their study, the authors analysed existing frameworks' potential coverage of four sustainability dimensions (Ecology, Social Economy, Social Culture, Human Health) and developed a comprehensive methodology for indicators selection, based on available data, and relevant spatial and temporal scales.

Table 3 presents a lean indicators framework to exemplify the proposed assessment.

Table 3: A lean indicators framework to assess multifunctional green infrastructure

Indicators	Units
Average Carbon storage	MgC/ha
Community gardens/allotments for food self-consumption per inhabitant	m^2/inhabitant
Share of water surface	%
Shares of wetlands for water regulation	%
Vegetation areas alongside with watercourses for water regulation	ha
Share of green areas in municipal districts in danger of floods	%
Share areas of municipal districts potentially exposed to urban flooding	%
Cooling effects of GI compared to sealed surfaces	◦C/m^2
Recreation spaces per inhabitant	m^2/inhabitant
Total areas of urban alluvial forests for habitat, species and genetic diversity	ha
Areas exposed to extreme flood risk	km^2
Share of areas exposed to flooding	%
Share of population exposed to flood risk	%
Population without urban green spaces in their neighbourhood	%
Increased physical activities in GI areas	-
Employment in directly GI related sectors (agriculture, forestry, and fishery)	%
Residential land and property increment value, defined as 1 km from green spaces	€/m^2 or $/$m^2$
Total number of visits specially related to education or for cultural reasons	Inhabitant

Source: Adapted from Wang, Pauleit & Banzhaf (2019)

2.4 The EKLIPSE framework for impact evaluation to support planning and evaluation of nature-based solutions projects

The EKLIPSE framework (Raymond et al., 2017) explored peer-reviewed documentation to develop an impact evaluation framework to assess the performance of NBS dealing with climate resilience in urban areas. The project identified ten urban challenges related to NBS strategies and developed an indicator framework and an assessment guide. The authors also explored the applicable geographical and temporal scale for each proposed indicator.

The explored urban challenges are:

1) Climate mitigation and adaptation;

2) Water management;

3) Coastal resilience;

4) Green space management (including enhancing/conserving urban biodiversity);

5) Air/ambient quality;

6) Urban regeneration;

7) Participatory planning and governance;

8) Social justice and social cohesion;

9) Public health and well-being; and

10) Potential for new economic opportunities and green jobs.

The EKLIPSE framework presents some similarities and divergences to the MAES framework, presented later in this document.

Table 4 shows 26 selected indicators and their relation to EKLIPSE urban challenges.

Table 4: The EKLIPSE framework for NBS performance indicators

Challenge	Indicator	Unit of measurement
2	Economic benefit of reduction of stormwater to be treated in public sewerage system	Cost of sewerage treatment by volume (€/m^3)
5	Reduced energy demand for heating and cooling	€ /kwh
10	Jobs created	No. of jobs
2	Nutrient abatement, abatement of pollutants	% of mass removal
5	Reduced energy demand for heating and cooling	CO_2 emissions reduced
1	Net carbon sequestration by urban forests (incl. GHG emissions from maintenance activities)	t C per ha -1/year
5	Annual amount of pollutants captured and removed by vegetation	*
2	Increased evapotranspiration	ET
1, 2	Temperature reduction in urban areas	Min. and max C° / day
1, 2	Heatwave risks	Persons / ha
1, 3, 6	Temperature	(Changes) in mean and daily min and max temperatures (°C)
2	Infiltration capacities	mm/h
2	User values attached to green/blue areas	Qualitative or €
6	Index of biodiversity	
4	Number of users and public awareness	€, no. of visitors/year
4	% of accessible public green space per capita	m^2/person
4, 6	% of citizens living within a given distance from accessible public green space	Persons
8, 3	The availability and distribution of different types of parks and/or ecosystem services with respect to specific individual or household socioeconomic profiles and landscape design	E.g. mean distance (or time to reach) parks per inhabitant
8	Security against violent assault, including indicators of crime by time of day	No. of cases / year
7, 8	Being able to participate effectively in political choices that govern one's life, including indicators on level and quality of public participation in environmental management	No. of connection /threshold for the definition of sufficient levels of connections
8	Structural aspects - family and friendship ties	No. of connection /threshold for the definition of sufficient levels of connections
9	Chronic stress and stress-related diseases as shown in cortisol levels	Social (physiological, benefits)
9	Increase in number and percentage of people being physically active (min. 30 min 3 times/week)	Days with physical activity (n)
9	Reduced % of obese people and children	%

Challenge	Indicator	Unit of measurement
9	Reduction in total mortality and increased lifespan	No. of deaths per 1,000 individuals / year
9	Reduction in number of cardiovascular morbidity and mortality events	No. of deaths per 1,000 individuals / year; Morbidity scores

* Authors did not propose a specific unit of measurement for the indicator

Source: Adapted from Raymond et al. (2017)

The main diverging point is related to the fact that the EKLIPSE framework relies in the broader notion of co-benefits than on the concept of ES. The authors consider urban areas as socio-ecosystem that co-produce benefits in a straight link with ecological systems. This way, indicators were chosen to demonstrate the effectiveness of different NBS actions for dealing with identified challenges and rely on a broader panel of socio-ecological indicators.

2.5 The MAES analytical framework for ecosystem conditions (MAES)

The mapping and assessment of ecosystems and their services (MAES) framework (Maes et al., 2018) highlights links between pressures on ecosystems, the ecosystem's condition, the ES supply, human well-being, and related public policy strategies. The framework aims to ensure consistent approaches to ecosystem assessments within the EU. It promotes the CICES ES classification and proposes indicators to assess pressure on ecosystem and its conditions. It infers, that once ecosystems face lower pressures and have a better condition, human well-being is enhanced (Wang et al. 2019).

Table 5 and Table 6 present the pressure and condition indicators proposed by the MAES framework.

Table 5: The MAES urban ecosystem pressure indicators

	Indicators	Unit
Habitat conversion and degradation (Land conversion)	**Land annually taken for built-up areas/person**	m^2/person/year
	Soil sealing	ha/year
Climate change	Number of combined tropical nights (above 20 °C) and hot days (above 35 °C)	no./year
Pollution and nutrient enrichment	**Emissions of NO_2, PM10, PM2.5**	kg/year
	Number of annual occurrences of maximum daily 8 hour mean of O_3 > 120 µg/m^3	no./year
	Number of annual occurrences of 24 hour mean of PM10 > 50 µg/m^3	no./year
	Number of annual occurrences of hourly mean of NO2> 200 µg/m^3	no./year
	Number of annual occurrences of (traffic noise at levels exceeding 55 db(A) during the day and 50 db(A) during the nights (possibly broken down over the source of noise)	no./year
Introductions of invasive alien species	Number of annual introductions of invasive alien species*	no./year

Key indicators are in bold

* This indicator can only be assessed at level 1 of the MAES ecosystem typology (for all terrestrial ecosystems combined).

Source: Adapted from Maes et al. (2018)

The MAES framework presents specific indicators to each of the twelve ecosystem types that are explored in the project, including urban ecosystems. Proposed indicators have been structured in a hierarchical system with pressure and condition indicators and have been evaluated regarding MAES project requirements (scientifically sound indicators, policy-relevant indicators, spatially explicit indicators, etc.). It proposes 43 lines of possible indicators, but two classes of indicators were considered by the authors as not applicable (n.a.) in urban ecosystems.

For urban ecosystems, the framework compiles a set of 41 indicators: 9 pressure indicators, related to habitat conversion, climate change, pollution and nutrient enrichment, and invasive species and 32 ecosystem condition indicators, related to environmental quality and ecosystem attributes.

Among these 41 indicators, twelve were selected as key indicators: two pressure indicators and ten ecosystem condition indicators. Key indicators were selected among those that have two policy uses and for which baseline data is available at European scales.

Table 6: The MAES urban ecosystem condition indicators

	Indicators	Unit
Environmental quality	Urban temperature	°C
	Noise level	dBA
	Percentage of population exposed to road noise within urban areas above 55 dB during the day and above 50 dB during the night	%
	Percentage of population exposed to air pollution above the standards	%
	Concentration of air pollutants NO_2, PM10, PM2.5, O_3	µg/m^3
	Concentration of nutrients and biological oxygen demand in surface water	mg/l
	Bathing water quality	Quality levels
	Percentage of population connected to urban waste water collection and treatment plants	%
	Number of inhabitants per area	No./ha
	Artificial area per inhabitant (m^2/person)	m^2/person
	Length of the road network per area	km/ha
	Percentage of built-up area	%
	Weighted Urban Proliferation	Urban permeation units/ m^2
	Imperviousness	%
	Sites with contaminated soil	No.
Structural ecosystem attributes (general)	**Percentage of urban green space**	%
	Percentage of natural area	%
	Percentage of agricultural area	%
	Percentage of abandoned area	%
	Canopy coverage	ha
	Foliage damage crown dieback	No. of trees affected
	Connectivity of urban green spaces	%
	Fragmentation of urban green space	Mesh density/pixel

	Indicators	Unit
Structural ecosystem attributes based on species diversity and abundance	Number and abundance of bird species	No.; no./ha
	Number of lichen species	No.
	Number of invasive alien species	No.
Structural ecosystem attributes monitored under the EU nature directives	**Percentage of urban ecosystems covered by Natura 2000 area**	%
Structural soil attribute	Bulk density	kg/m^3
	Soil organic carbon (SOC)	g/kg
	Soil biodiversity	DNA-based richness and abundance
	Earthworms	No., no./ha
Functional soil attributes	Available water capacity	mm/year

Key indicators are in bold

* This indicator can only be assessed at level 1 of the MAES ecosystem typology (for all terrestrial ecosystems combined).

Source: Adapted from Maes et al. (2018)

2.6 The NATURE4CITIES indicator framework

The NATURE4CITIES (N4C) project aims to create a comprehensive platform for NBS, aggregating technical solutions, methods, and tools to foster NBS in urban planning practices. The D2.1 project report proposes a multi-thematic indicator framework to assess the performance of NBS solutions on urban challenges. The project team defined 11 urban challenges and 26 urban sub-challenges and selected 50 relevant key performance indicators using a Relevant, Accepted, Credible, Easy, Robust (RACER) methodology. The D2.1 NATURE4CITIES project report (NATURE4CITIES, 2018) documents each of the selected indicators in detailed fact sheets. Since the focus of the project is to follow urban challenges and the performance of NBS, their framework is broader than for projects with a specific focus on ES. Therefore, Table 7 to Table 11 present Nature4Cities selected indicators and the links between urban challenges.

Table 7: Climate - Nature4Cities key performance indicators framework

Urban Challenge	Urban sub-challenge	Indicator
Climate issues	Climate mitigation	Annual carbon sequestration
		Avoided GHG emissions
	Climate adaption	Air temperature
		Adaptive Comfort (indoor)
		Thermal Comfort Score (outdoor)
		Physiological equiv. temperature
Water management and quality	Urban water management and quality	Peak flow variation
		Stormwater quality
	Flood management	Total rainfall volume
		Water Detention Time

Source: Adapted from NATURE4CITIES (2018)

Table 8: Environment - Nature4Cities key performance indicators framework

Urban Challenge	Urban sub-challenge	Indicator
Air quality	Air quality at district/city scale	Common Air Quality Index
	Air quality locally	Exceedance of air quality limit value – Local scale
Biodiversity and urban space	Biodiversity	Urban Green Space Proportion
		Shannon Diversity Index of Habitats
	Urban space development and regeneration	Biotope Area Factor
		Connectivity of green spaces
		Normalized Difference Vegetation Index
	Urban Space Management	Sustainable Practices Index
Soil management	Soil management	Soil biological activity
		Soil classification Factor

Source: Adapted from NATURE4CITIES (2018)

Table 9: Resources - Nature4Cities key performance indicators framework

Urban Challenge	Urban sub-challenge	Indicator
Resource efficiency	Food, energy and water	Energy Security
		Per Capita Food Production Variability
		Buildings Energy needs
		Cumulative Energy Demand
		Water scarcity
	Raw Material	Raw Material Efficiency
	Waste	Specific waste generation
	Recycling	Efficiency of valorisation as a result of recycling processes

Source: Adapted from NATURE4CITIES (2018)

Table 10: Social - Nature4Cities key performance indicators framework

Urban Challenge	Urban sub-challenge	Indicator
Public health and well-being	Acoustics	Day-evening-night noise level
		Effects of night noise on health
	Quality of Life	Quality of life
	Health	Perceived health
		Heat induced mortality
		Air quality indicators: short term health effects
		Air quality indicators: long term health effects
Social justice and cohesion	Environmental justice	Recognition
		Procedural justice
		Distributional justice
		Capabilities
		Responsibility
	Social cohesion	Social capital
Urban planning and governance	Urban planning and form	Accessibility
	Governance in planning	Segregation Index
People security	Control of crime	Percentage of gender violence
		Percentage of victimization
	Control of extraordinary events	Domestic Property Insurance Claims
		Number of deaths and missing people

Source: Adapted from NATURE4CITIES (2018)

Table 11: Economy - Nature4Cities key performance indicators framework

Urban Challenge	Urban sub-challenge	Indicator
Green Economy	Circular economy	Construction and demolition waste
		Material Circulatory Indicator
	Bioeconomy activities	Gross Value Added in the local Environmental Good & Services sector
	Direct economic value of NBS	Adjusted Net Saving
		House Pricing Index

Source: Adapted from NATURE4CITIES (2018)

As for the targeting question on whether the presented indicators are applicable, measurable, and transferable, REGREEN will make potential compromises on indicator selections with respect to various cultural contexts within Europe, and between Europe and China. To balance out, the optimal indicator framework is currently under discussion and will serve as an integrated framework for REGREEN NBS implementation.

3 DATA NEEDS AND AVAILABILITY

For Europe, there is a rich variety of databases and datasets readily available mostly through projects funded by the European Commission[3]. REGREEN commits to using these publicly available databases before generating own products. ULLs in Europe and in China, especially the Beijing and Shanghai ULLs, have direct access to remote sensing data through Google Earth Engine (GEE), including satellite images and some high-resolution aerial images. For this reason, we are capable to derive multi-temporal land-cover and land-use information.

In Chinese cities, most data that are needed for quantifying ES are available if considerable efforts are committed to collect them from various sources. Meteorological data can be obtained from around 700 stations included in the national network of weather stations. This data are managed by the data centre of the National Bureau of Meteorology. Users need to register to get access to the data. Air pollution data are managed by the data centre of the Ministry of Ecology and Environment (MEE). The hourly data for the current day of the 366 cities are available online. Historical data can be obtained from the data centre of MEE by submitting the data request. The water quality data of rivers at the watershed level can be obtained from the data centre of MEE. However, the water quality data for rivers and lakes at a city scale are not available for most cities. Similarly, noise data are only made available to the public in a few cities. MEE releases an annual report that contains the annual average noise level for around 100 cities. Flooding data inside cities are maintained by the Department of Water resource in each city. Some cities make the data available to the public, but most do not. Ministry of Water Resources monitors flooding in major rivers and lakes across the country. The data is annually published in yearbooks. The majority of cities do not have biodiversity data. Most biodiversity data were collected by researchers and stored individually. Vital statistics of cities at or above the prefecture-level are available from yearbooks from the Ministry of Housing and Urban-rural Development and the Ministry of Civil Affairs. Social-economic statistical data is therefore publicly available, comprising demographic data, socioeconomic classes as well as the spatial distribution of GDP and population.

As a prerequisite, we aim at understanding the needs and availability of data that WP 3 may need throughout the REGREEN project phase. For this reason, we structure the aspects related to those sustainability dimensions (see Wang et al. 2019) that are of major importance for our project regarding ES and NBS.

Research on data collection was focused on potential mapping and model input requirements, linkages to ES and data availability. In the following sub chapters, different levels of these datasets are introduced and evaluated. The related database, compiling all relevant data applied in WP3 is currently being elaborated.

3.1 Aspects of major importance for mapping and modelling of ES

In a first step, we extract aspects of major importance for mapping and modelling of ES in the REGREEN project. These aspects are described in more detail below.

[3] See also Sections 2, 5 and 6, such as Urban Atlas and CORINE Land Cover, both provided by the European Union's Earth Observation Programme (Copernicus); the Common International Classification of Ecosystem Services (CICES) and the Mapping and Assessment of Ecosystems and their Services (MAES) project, to mention few.

Biophysical aspects of ecosystems
The natural setting covers geomorphology, soil, plant and animal life, water, and atmospheric conditions in specific regions. This is the prerequisite of non-human origin, influencing the availability and status of ecosystems and their services, which again affect potential NBS.

Ecosystem services (ES)
The ES, which provide the basis for the envisaged NBS cover urban heat, noise and flood mitigation, water quality and biodiversity as well as air pollution removal and cultural services (recreation, aesthetics, etc.). Ecosystems provide multiple services and relate to the above-mentioned biophysical aspects. The choices for specific NBS implementation in the ULLs set priorities and therefore require prioritisation between these ES.

Nature-based solutions (NBS)
We undertake the attempt to develop new approaches, which account for the manifold interrelations and linkages between urban and rural spaces. During rapid urbanisation processes, historically evolved intricate urban-rural metabolisms are often at risk to exacerbate environmental, social and economic sustainability challenges. In this context, NBS offer a useful conceptual framework in which to readdress multi-dimensional and multi-scalar contemporary challenges facing both urban and rural areas such as climate change resilience, biodiversity loss, and social equity. To implement NBS in relation to human well-being, it is necessary to identify those urban sites with the need of the local community for benefits of local dwellers.

Planning aspects
The ULLs support knowledge by sharing up-to-date data of the subdivisions of the urban areas into administrative units, from municipal boundaries down to statistical block units. Furthermore, datasets and information related to planning help to understand the role of local government and stakeholders when implementing NBS. Sharing urban sites of special demand due to environmental pressures helps to prioritize NBS and to focus on the respective ES, ensuring that the proposed NBS can be pinpointed to targeted locations for interventions.

Land cover and land use
The current urbanisation status of the ULLs is defined by its land-cover and land-use properties. While land cover reflects the physical properties of an area, such as vegetation, water or bare soil, the land use refers to the anthropogenic use of an area. Depending on the governance (and thus planning) system of a country, administrative units can affect land use. For this reason, vegetation types, such as agriculture, forest and urban green spaces are human-induced land-use types. Its amount, distribution and structure are central to our mapping and modelling research tasks.

Socio-economic dimension

Socio-economic and demographic aspects
In this WP, we concentrate on the analysis of quantitative information. Therefore, vital statistics are an important data source that contains a wide range of information concerning residents living in a certain area, such as their age, gender income, and many more. Case-sensitive, such data may be spatially allocated but not necessarily. If spatially specific, such data can be linked to spatial information on drivers and pressures for modelling ES demanded within specific locations. If not, then these pieces of information may give evidence in a qualitative, and more general way.

Aspects of human well-being
With respect to drivers and pressures of the urban environment onto humans, this WP relates to ease pressures by modelling ES for maintaining and enhancing the quality of life and human well-being.

Hence, amount, distribution and accessibility to green spaces play a vital role. The collaboration between WP 3 and WP 4 aims at integrating quantitative and qualitative data (such as perception of cooling in a park, sense of well-being, or sensation when walking through urban wilderness) to prioritize NBS towards an optimal implementation. These different aspects provide the frame to better understand the measuring indicators, which describe our research targets and the adjustments for models.

3.2 Indicators & level of detail

For the applicability to model ES in REGREEN, the set of indicators and the level of detail, its spatial resolution and its distinction between different elements, has to be adapted to each individual model and to specific context in each ULL.

The level of detail is determined by the spatial and temporal resolution of input data. Furthermore, it is determined by the scope of categories of the publicly available datasets. For instance, modelling processes in the context of urban heat mitigation might be feasible a medium spatial resolution with a few distinct land-cover categories, whereas research on biodiversity is greatly influenced by the amount of details represented in the mapped landscape, thus needing a higher spatial resolution and very distinct categories (e.g. distinction between deciduous and coniferous trees). Models, which operate at a larger extent, and with coarser spatial resolution, such as air pollution removal, involve input data at a range of scales, e.g. coarse mapping of pollutant emissions at the urban region scale, but can also involve finer resolution input data on land-cover categories and the coverage of green space.

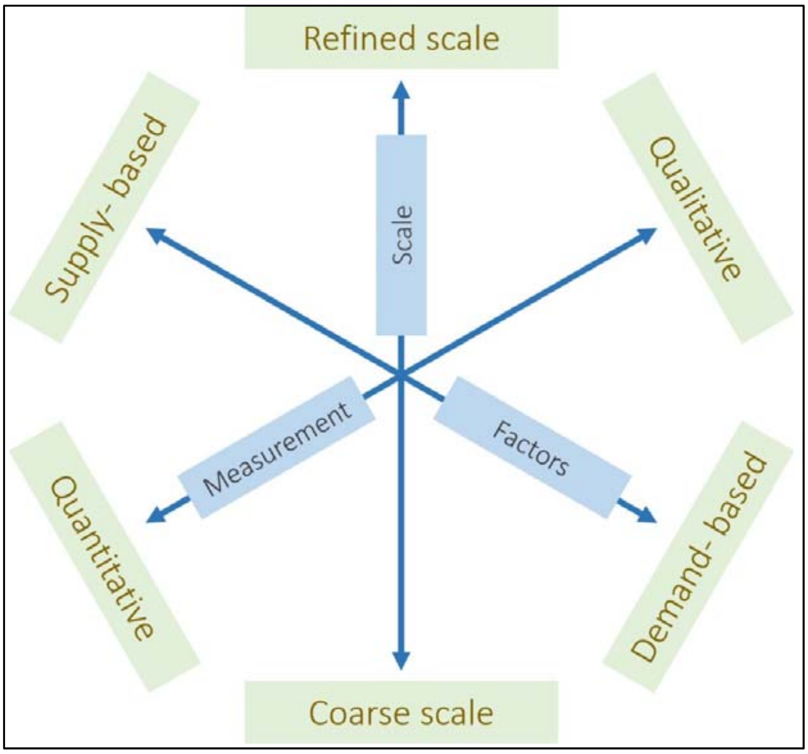

Figure 1: Concept of basic parameters for data compilation to map and model ES.

Figure 1 illustrates the parameters measurement and scale including their end nodes. It further points at the very important ES factors for REGREEN that are supply-based and demand-based. Understanding these poles and ranges is necessary when compiling data to analyse and assess ES for mapping and modelling procedures. None of them excludes the other one. For ES analysis there may be a selection of appropriate scales, of demand or supply factors, and of the best-fitting quantitative and/or qualitative datasets. For site-specific benefits, there is an intentional bias towards the one rather than the other. The assessment should take into account the effects of prioritising one parameter higher/lower than the other, and can be repeated applying different weightings. The measure of supply and demand-based factors in particular determines the starting point of the analysis. So the analysis may either get started with the current situation of ES supply and outline possible impacts, or it may start by analysing the demands, and then overlay them with the presently provided ES.

3.3 Database on current datasets

Data specifications

The data specifications range from spatial resolution to units or number of categories, as well as data type and temporal resolution (Banzhaf et al., 2019). This serves to give an overview of the different units, which are applied, such as metres, kilometres, albedo in %, mm of precipitation and data which cannot be represented in a continuous spectrum such as categorical data, e.g. plant species or land-use and land-cover type.

Data availability

Within the REGREEN project, the focus is set on using readily available data, preferably acquired through EC funded projects and missions, such as the EC knowledge base INfrastructure for SPatial InfoRmation in Europe (INSPIRE) and European Union's Earth Observation Programme (Copernicus) with its Sentinel sensors, other satellite Earth Observation, and in situ (non-space) data. Where possible, the datasets will be tested and compared to further available data such as data provided by the ULLs.

In the REGREEN project, the European ULLs provide site specific data and information. Furthermore, they point out demands for provision of specific ES and their spatial location. To provide the best basis for NBS implementation, the ULLs offer a variety of data and information. Starting from the municipal boundaries to vital statistics, various spatially specific information for one or more points in time is shared. Examples range from digital orthophotos to digital surface models, cadastral data and information on current and historic land use and land cover at different scales of detail. Not all ULLs can provide the same types of data. E.g., a rather vast data collection exists for the ULLs Paris Region and Aarhus with profound databases on vital statistics, on mapping of structural and functional biodiversity, etc. In contrast, the ULL Velika Gorica suffers from a lack of data that is provided at national level. For instance, a digital surface model for Croatia will be captured by LiDAR data at the earliest in 2021 or later, there is a lack of publicly available digital orthophotos (DOPs), and a missing update of vital statistics. In this ULL, some data are outdated, others exist but only at regional scale, and some other data do not exist (such as a digital surface model). This may be a constraint when carrying out mapping and modelling of ES in a comparable way across ULLs. Effort has to be made to bridge these data restrictions during the REGREEN project phase by supplementary data projects (such as offered by ESA), field work or other options to be explored.

For the ULL Beijing, annual average values of noise are available at the city level, which, however, are constrained by a coarse spatial resolution, making them difficult to apply for urban noise monitoring. Information on air pollution for Beijing is available from around 30 air quality monitoring stations while the meteorological data can be obtained from about 20 weather stations spreading across Beijing. Using geo-statistical methods, this information has been extrapolated to cover the entire city. Other ancillary data such as historical land use/land cover, population, and climate records (based on two stations) are also available at coarse scale.

Chinese ULLs may suffer from some constraints regarding data on refined scales, such as urban building structures at centimetre resolution or tree cover information from LiDAR. E.g., water quality monitoring data in China always focuses on main streams in a statistical way, which does not meet the requirement of higher resolution for ES modelling of river catchments. In addition, for the Chinese ULLs there is a general lack of human dimension data for socio-spatial investigations below the prefecture-level (for instance at neighbourhood scale).

Other collecting entities

Although the aforementioned datasets, acquired either through EC affiliated projects and/or the ULLs themselves are substantial, there is still the need for other sources of information. These include, e.g. required input data for some ES models, or data to fill existing gaps within the acquired datasets or in an assisting role, e.g. for data for validation of models or mapping outputs. In China, field sampling investigation data may be useful for modelling ES. In Sections 5 and 6, we give examples of first products that are based on publicly available remotely sensed data.

4 FACT SHEETS

In REGREEN, as in many other large projects with interdisciplinary and transdisciplinary research and collaboration, scientific language is very disciplinary, and there is a need to overcome language barriers. The tool of fact sheets encourages each author to keep information short, simple and well-structured.

To get a common understanding of data needs that enable mapping and modelling of ES, WP 3 uses mapping and modelling fact sheets covering key points of each ES model and mapping framework concisely. Each fact sheet contains focal points of each product: a short description of output information, the underlying methodologies including technical background. For the REGREEN project, the specific approach is explained in bullet points. Answers are briefly given on how NBS are incorporated, and the possibilities or limitations of upscaling/downscaling of gained results are listed. In brief tables, basic information is given on respective mapping or modelling output and on related input requirements. It is an easy-to-read format and summarises complex processes. To keep the fact sheets as living documents, the date of document update is given.

The following fact sheets have been generated so far (see Appendix for each fact sheet). Further fact sheets such as for biodiversity or cultural services (e.g. recreation) may follow.

- Mapping by using Google Earth Engine (GEE)
- Urban land-cover mapping framework
- Urban morphology mapping framework
- Water quality assessment model QUESTOR
- Atmospheric chemistry transport model (EMEP) and weather research and forecast model (WRF) - EMEP-WRF
- Hydrological modelling
- Traffic noise mitigation
- Heat mitigation

5 CURRENTLY IMPLEMENTED DATASETS IN REMOTE SENSING

In REGREEN, we intend to have LULC maps for all ULLs at their respective spatial extents and at the same scale as a knowledge base for mapping and modelling ES. We will elaborate a common LULC database to make informed maps for joint discussions on ES demand and supply and for input to the ES models. Various remote sensing sensors provide specialists with images from huge databases for free download and further exploitation. During the initial stage, we produced intermediate results illustrating intrinsic methods at different sites and different refinements in the classification schemes for European and Chinese ULLs. By further methodological collaboration the applied methods will be made compatible during the next phase to realise a high comparability between the European and Chinese mapping products.

To understand the spatial extent and LULC structure of each ULL, most recent images were selected at a ground resolution of 30 metres (Landsat 8 OLI), and of 20 and 10 metres (Sentinel 2). For the analytical steps presented here, Google Earth Engine (GEE) was chosen for the following reasons: our Chinese partners at Fudan University, Shanghai, and at Tsinghua University, Beijing, both use GEE as well. Furthermore, in GEE a manifold of satellite images is freely available worldwide, and GEE facilitates to exploit all available datasets for a selected region and a defined time period. Therefore, all partners take advantage of data availability and a multitude of analytical techniques.

This section covers remote sensing analyses for the European ULLs (section 5.1) and for the Chinese ULLs (section 5.2).

5.1 Analysed Landsat imageries for each ULL in Europe

For the European ULLs, the following figure is an overview of the acquired Landsat images to calculate the classified vegetation metabolism (CVM) rates for each ULL per year by means of GEE (Figure 2). In GEE, a first step was undertaken to understand the regional land cover of each ULL in Europe (Kabisch et al. 2019). An emphasis was set on urbanisation patterns reaching from entirely sealed surfaces to surfaces entirely covered by vegetation. All other LULC range between these two extremes. The underlying concept is that during the active phenological phase of a plant, its vegetation metabolism rate is reflected and captured on specific spectral bands of satellite sensors. Acquiring suitable remote sensing data was thus undertaken with the set of conditions for each ULL respectively:

- Acquisition date covering the years 2013 to 2019;
- Images taken between April and October, thus corresponding to the active phenological phase of vegetation in each year;
- Cloud cover had to be 10% or below.

The collected scenes are depicted in the two following subchapters. As a first product, the classified metabolism rate for each ULL was quantified.

While Aarhus and Velika Gorica had multiple scenes available per year, the data for Paris Region was more limited due to higher cloud coverage.

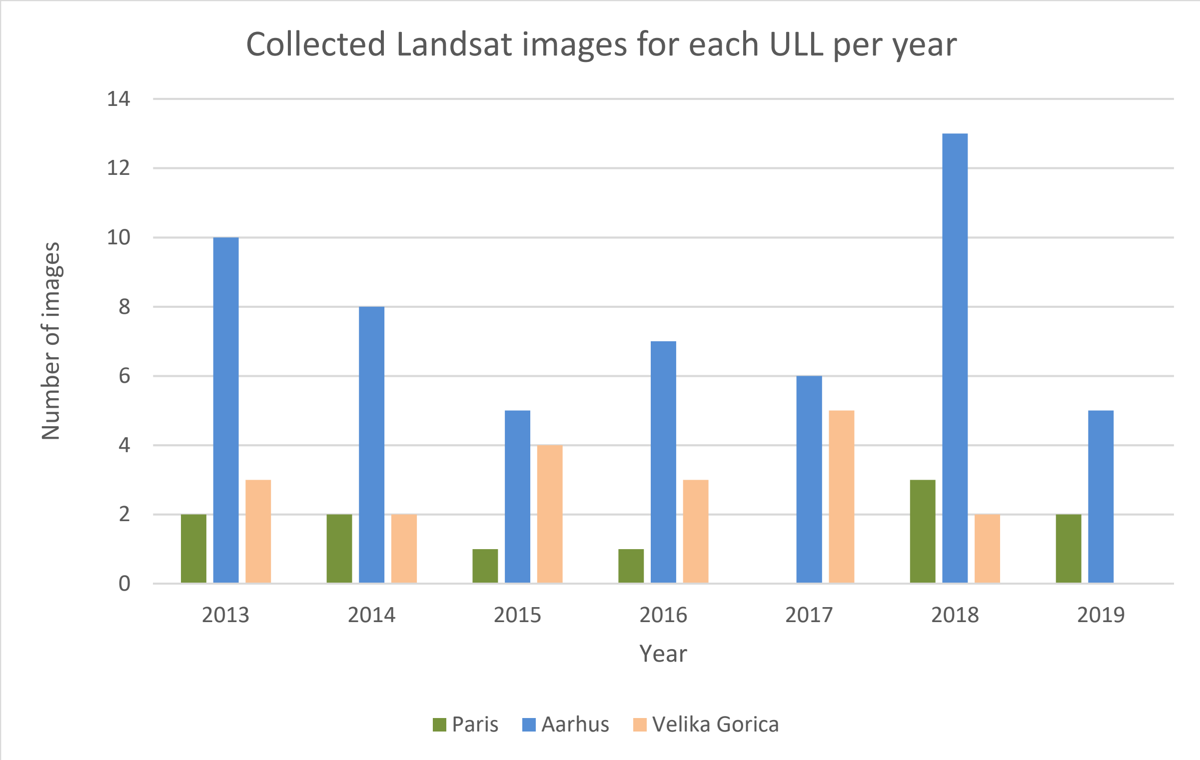

Figure 2: Collected Landsat images for each EU - ULL per year

The following three figures show the distribution of the available data over the phenologically active phase for each European ULL. By comparing each year and each month of the selected period, the resulting classification quality becomes more transparent. The better the distribution of input data over the entire time span, the better is the capture of active photosynthesis of the covered plants and the related mapping of vegetation intensities.

The resulting LULC maps are based on images for Aarhus and for Paris from 2018 to produce results for the most recent years and be in line with ancillary publicly available data. In the case of Velika Gorica, we had more images and produced better results for the year 2017. By visual comparisons between our results for both years, i.e. 2017 and 2018, and being supported by our local GIS expert at Velika Gorica, we decided to take the year 2017 for this ULL.

During this stage of our LULC classification in GEE, we calculate the metabolism rate based on the normalised difference vegetation index (NDVI) for the 3 European ULLs. The NDVI is calculated from spectral reflectance measurements in the visible red band (RED) in combination with near-infrared spectra (NIR) and is mathematically expressed by NDVI = (NIR-RED)/(NIR+RED) (Tucker, 1979). The normalised values range from {−1} to {+1}. Therefore the different LULC classes refer to a subsect of output value range. By setting thresholds to differentiate the classes according to their expression of share of vital vegetation, the calculated NDVI is transferred into a classified NDVI. To do so, we distinguish between different densities of the respective vegetation metabolism rates. Generally speaking, water has an average value of approximately {-1} and represents minima, whereas the highest values are assigned to densely covered forests and meadows right before mowing {up to +1}. For this reason, the NDVI is valuable for mapping and monitoring urban LULC: it does not only give evidence to abiotic land cover, but it distinguishes plant viability, vegetation density and structure. In GEE, the NDVI is a common basis on which all classification schemes further elaborate their procedures (explained in Sections 5.1 and 5.2). The shares between the two poles range from *no vegetation in continuous urban fabric* to *forests or intensively cultivated land* (Figures 4, 6 and 8).

For each ULL in Europe, we apply the NDVI for the active vegetation period based on Landsat data stored in the earth engine at a ground resolution of 30 m. Based on our expert knowledge, we visually inspect the images and derive 10 LULC classes by identifying optimal threshold values. These thresholds are applied for all images as a first approximation.

All LULC classification maps show a preliminary result. Thus, no systematic accuracy assessment has been undertaken so far, but the results were controlled by visual interpretation in comparison to ancillary remotely sensed data as provided by google earth. Additionally, the results were also evaluated by local partners at the respective ULLs.

The classification scheme was developed in the anticipation of gaining a high level of distinction between different urban LULC types. This classification procedure will be expanded further according to the methodology agreed upon amongst the remote sensing experts in the near future, and the input requirements defined by the respective models.

The structure of the classes follows the pattern of the categories found in EC LULC classifications such as Urban Atlas, CORINE land cover (Copernicus land monitoring service), and the functional urban area classification. The two digit unique classification number as well as the names of the classes describe the LULC type.

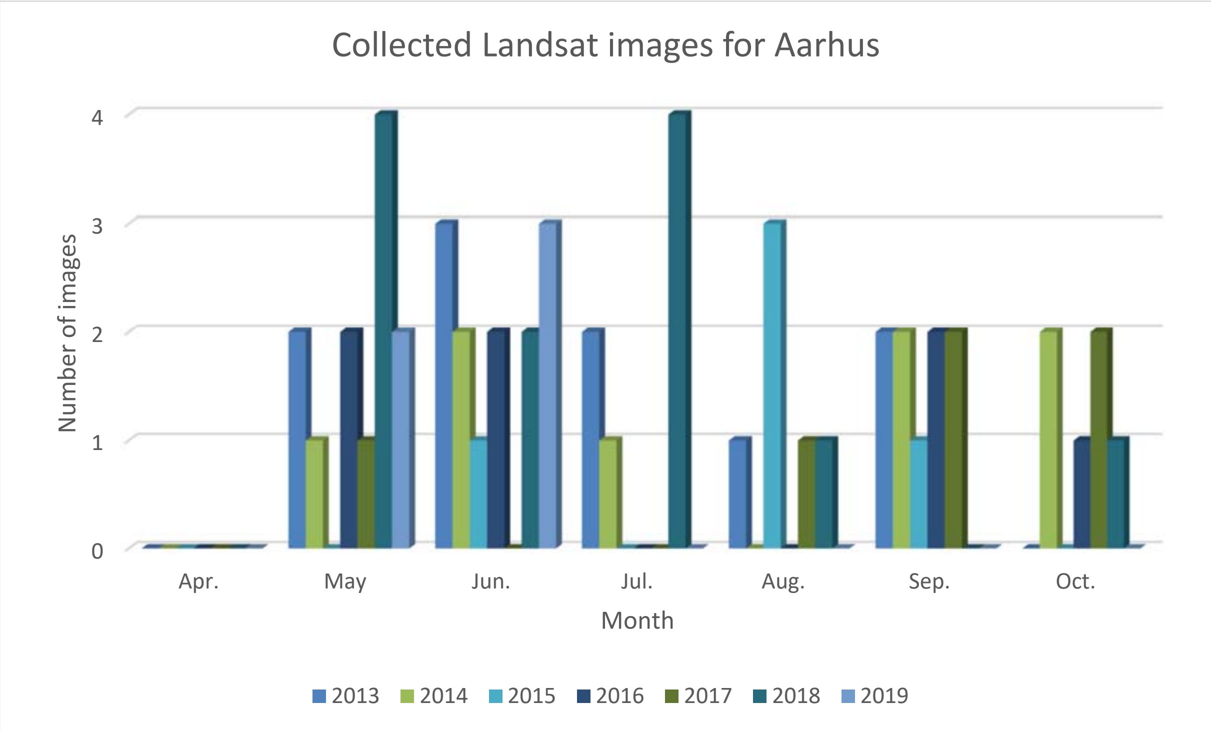

Figure 3: Collected Landsat images for Aarhus ULL

Although predefined by the starting point of the phenologically active phase in Central Europe, it was not possible to incorporate remote sensing data for the month of April due to fairly high cloud coverage. As highlighted in Figure 3 for Aarhus, some loss in image acquisition is also pictured for other months at various intensities such as July for the years 2015/16 and 2019, to mention one. For Paris Region, the data coverage is much less dense, but still shows very good visual results at this preliminary and early stage. A similar result could be achieved for Velika Gorica. All quality assessment was undertaken by visual comparisons of specific hotspots by local GIS experts.

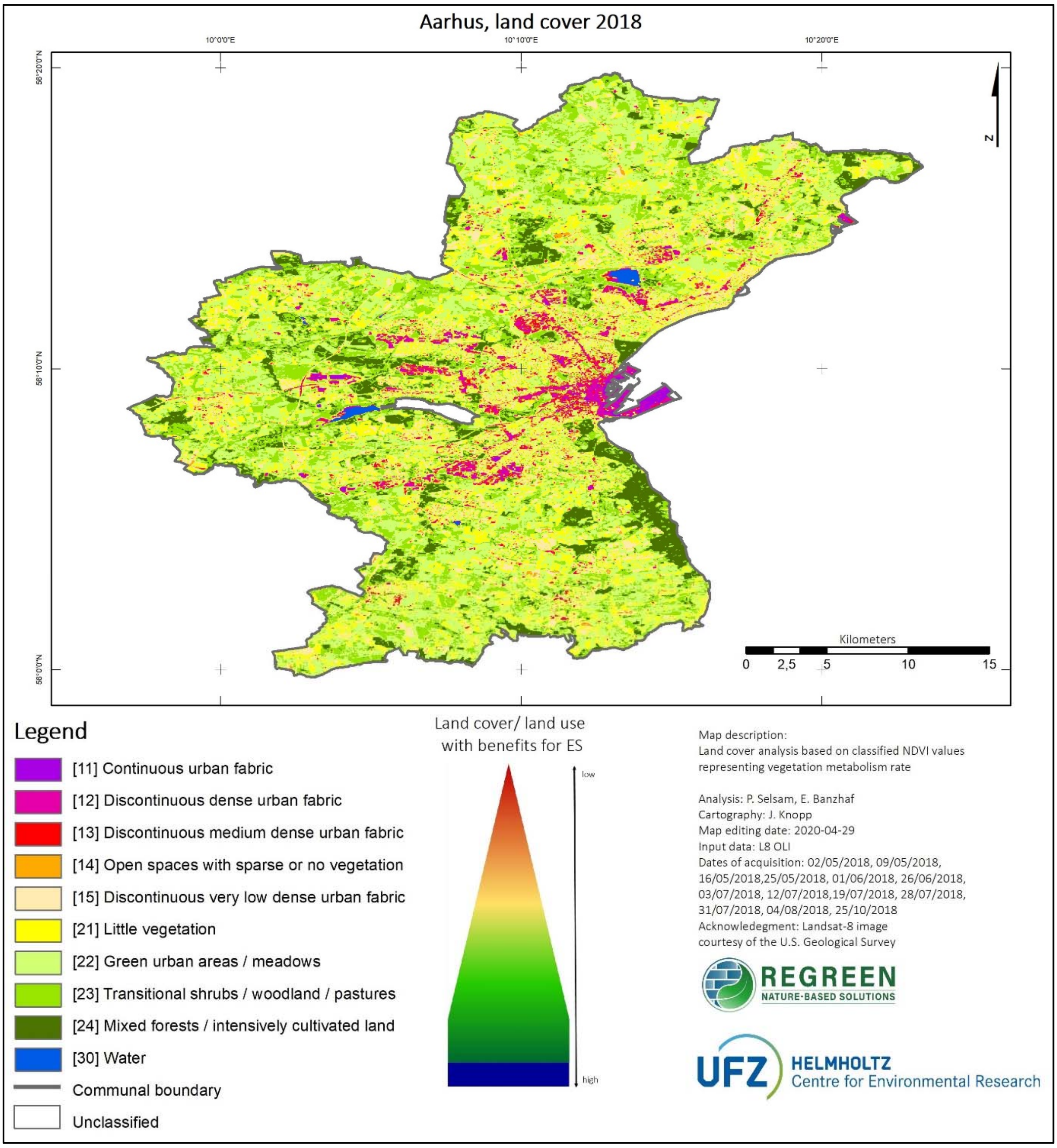

Figure 4: Land-use/land-cover classification (LULC) based on classified vegetation metabolism for ULL Aarhus

Figure 4 shows the result for the classified vegetation metabolism rate in Aarhus and refers to the analysed data illustrated in Figure 3. The following Figures 5-8 show the same method applied to the ULLs of the Paris Region and Velika Gorica. For both of them, data collection in April was not possible. However, inclusion of the subsequent months through the year 2013 to 2019 was sufficient to compute the same product as well.

Each map shows a similar pattern, in that areas towards the city centre are intensively built-up, with impervious surfaces dominating in the inner urban landscape. Towards the rather rural outskirts, woodland and agriculture make up for most of the LULC. In the case of Paris Region, these agricultural areas are regularly interrupted by smaller suburbs. Features like airports are clearly identifiable in

Velika Gorica and Paris, as well as lakes, rivers and larger urban parks like the Bois des Vincennes and Bois de Boulogne in the centre of the Paris Region.

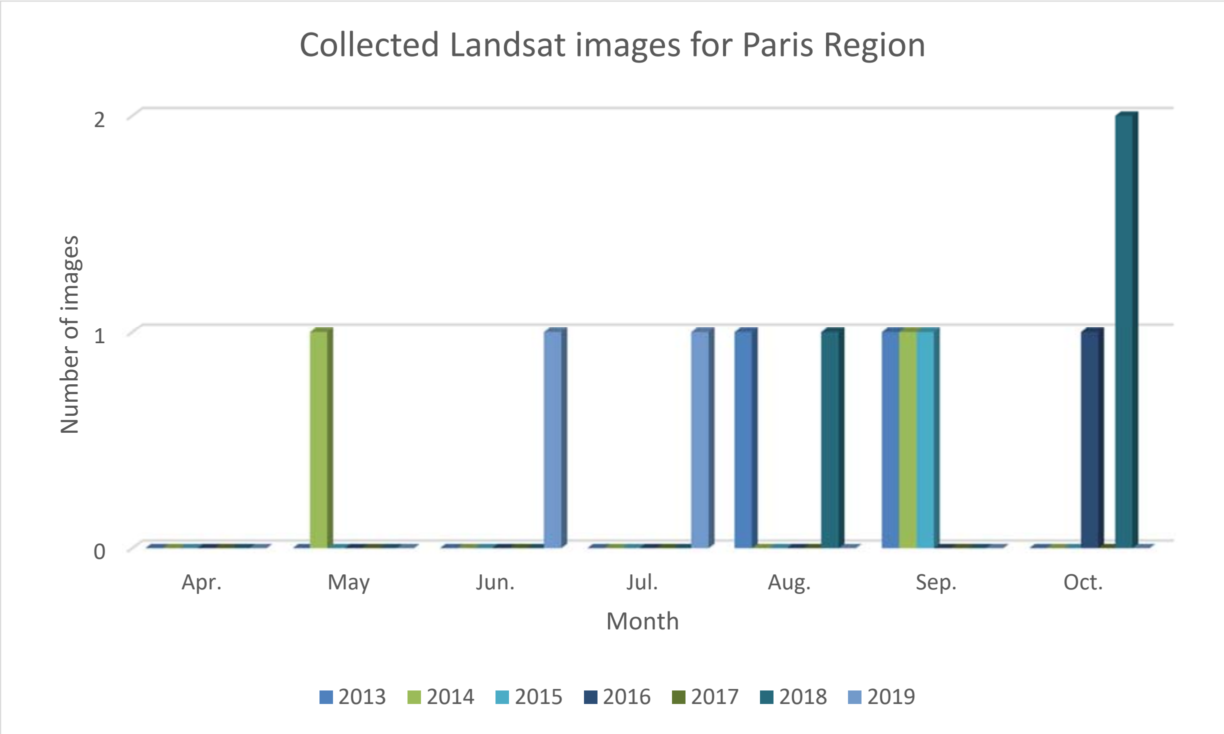

Figure 5: Collected Landsat images for ULL Paris Region

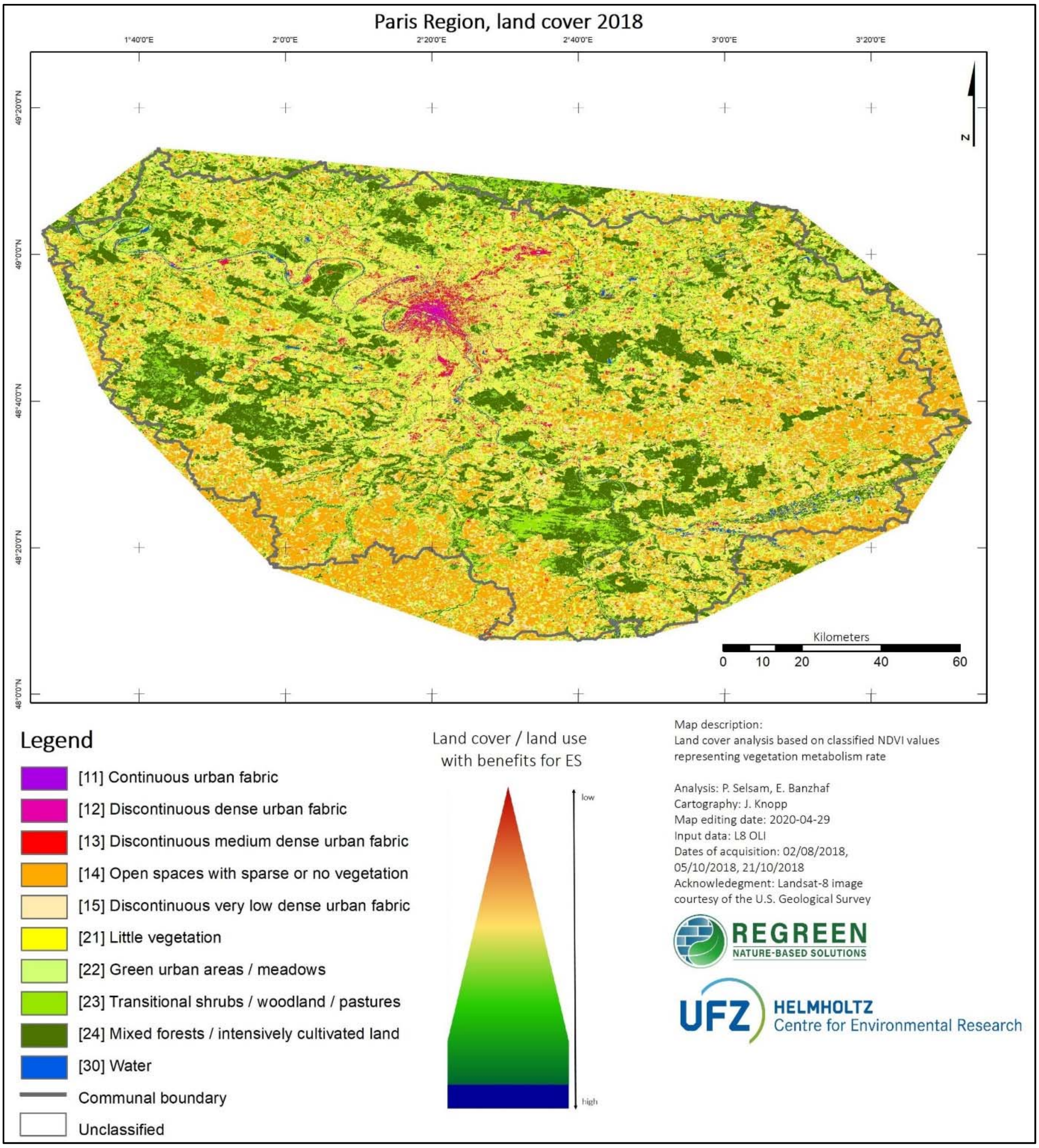

Figure 6: Land-use/land-cover classification (LULC) based on classified vegetation metabolism for ULL Paris Region

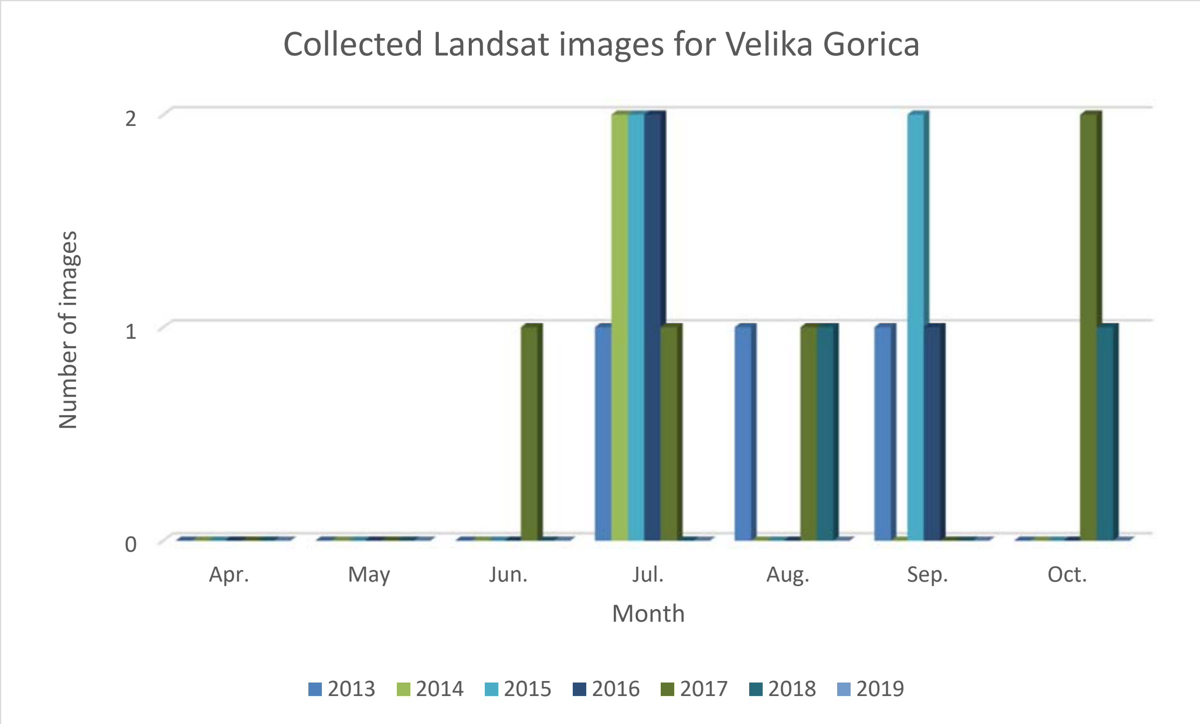

Figure 7: Collected Landsat images for ULL Velika Gorica

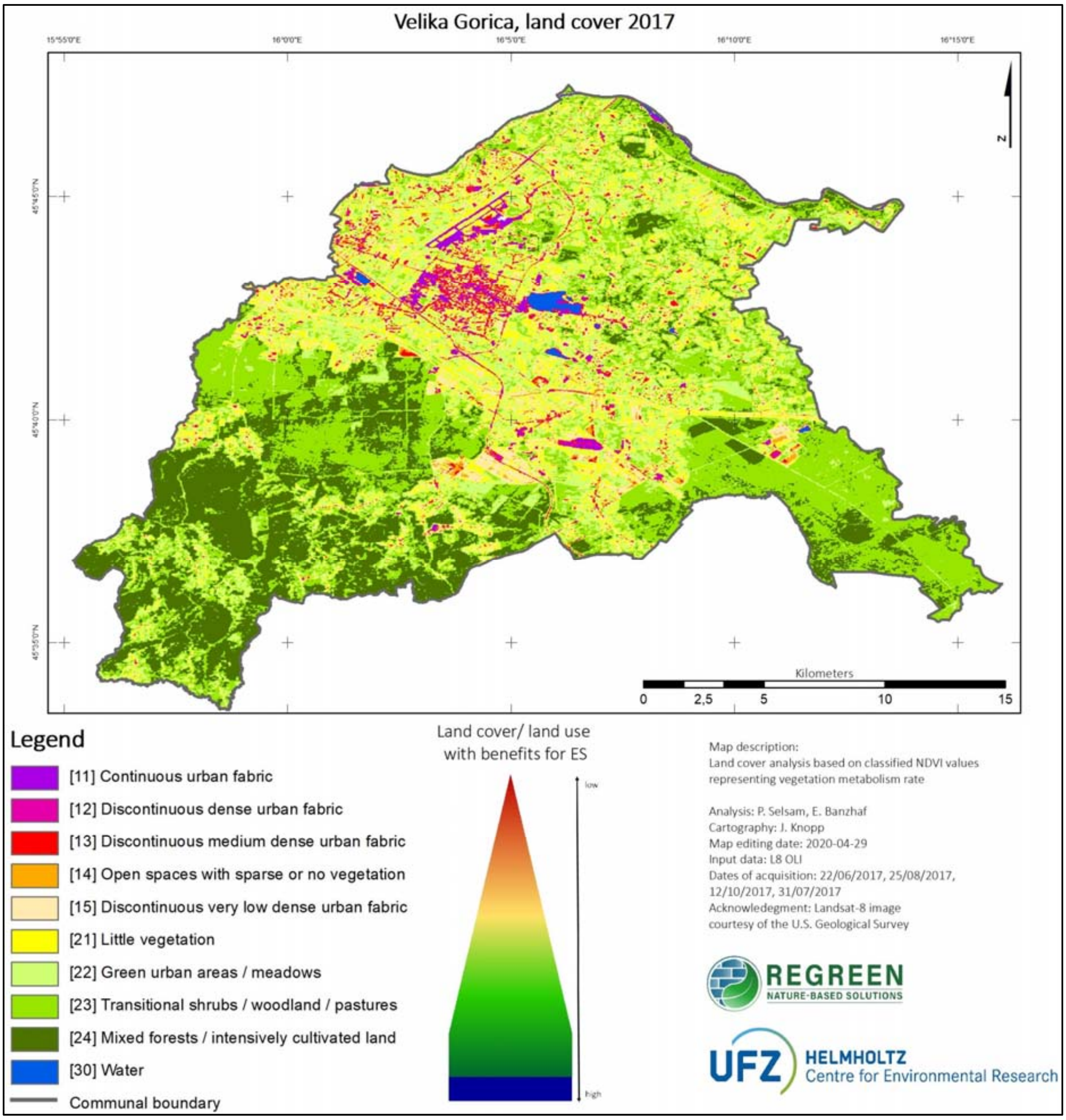

Figure 8: Land-use/land-cover classification (LULC) based on classified vegetation metabolism for ULL Velika Gorica

5.2 Analysed Landsat images for selected ULLs in China

ULL Beijing

A land-cover classification of Beijing in its municipal boundary was undertaken for the year 2015. To do so, several standard terrain corrected (L1T) Landsat 7 ETM+ and 8 OLI/TIRS images were acquired with a cloud cover <70%. Winter images were not used as the main focus lies on the phenologically active season. All images were hosted on GEE. The pixel QA (quality assessment) band of the Landsat images was used to mask the cloud, cloud shadow, and snow pixels. The blue, green, red, near infrared, and two shortwave infrared bands of Landsat images were selected for further processing (Huang et al. 2018).

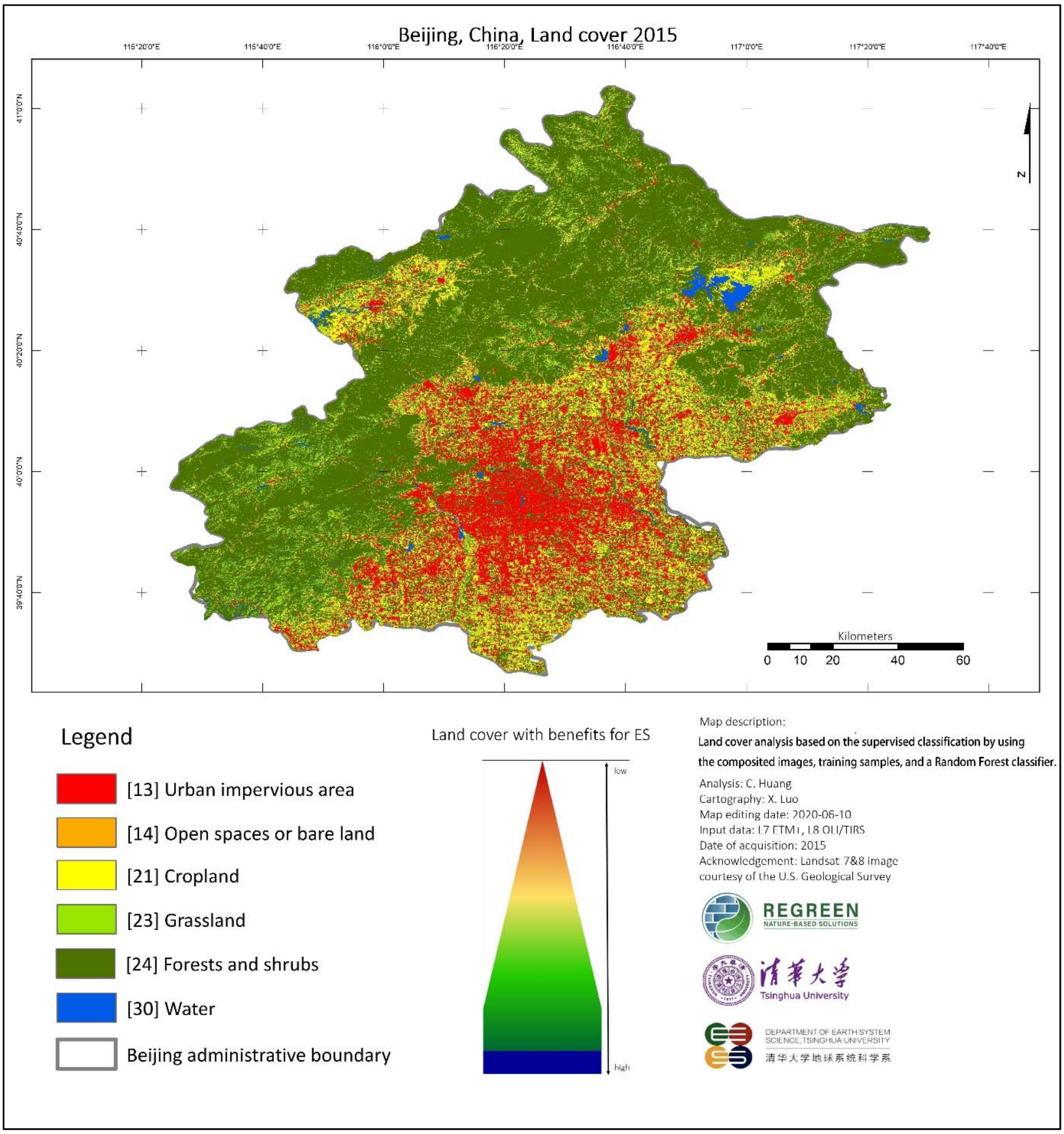

Figure 9: Land-use/land-cover classification (LULC) of ULL Beijing in its municipal boundary in 2015

Then, the NDVI, normalized difference built-up index (NDBI), and the modified normalized difference water index (MNDWI) were calculated to enhance the information on vegetation, impervious surface, and water. These indices were combined with the original six bands.

The greenest pixel compositing method and percentile-based image compositing methods were used to create composite images. Next, the land-cover classification was performed on the GEE platform using the composite images, training samples, and a Random Forest (RF) classifier. To assess the training samples, we manually inspected these validation samples by referencing to high-resolution images on Google Earth and estimated classification accuracies based on the interpretation results.

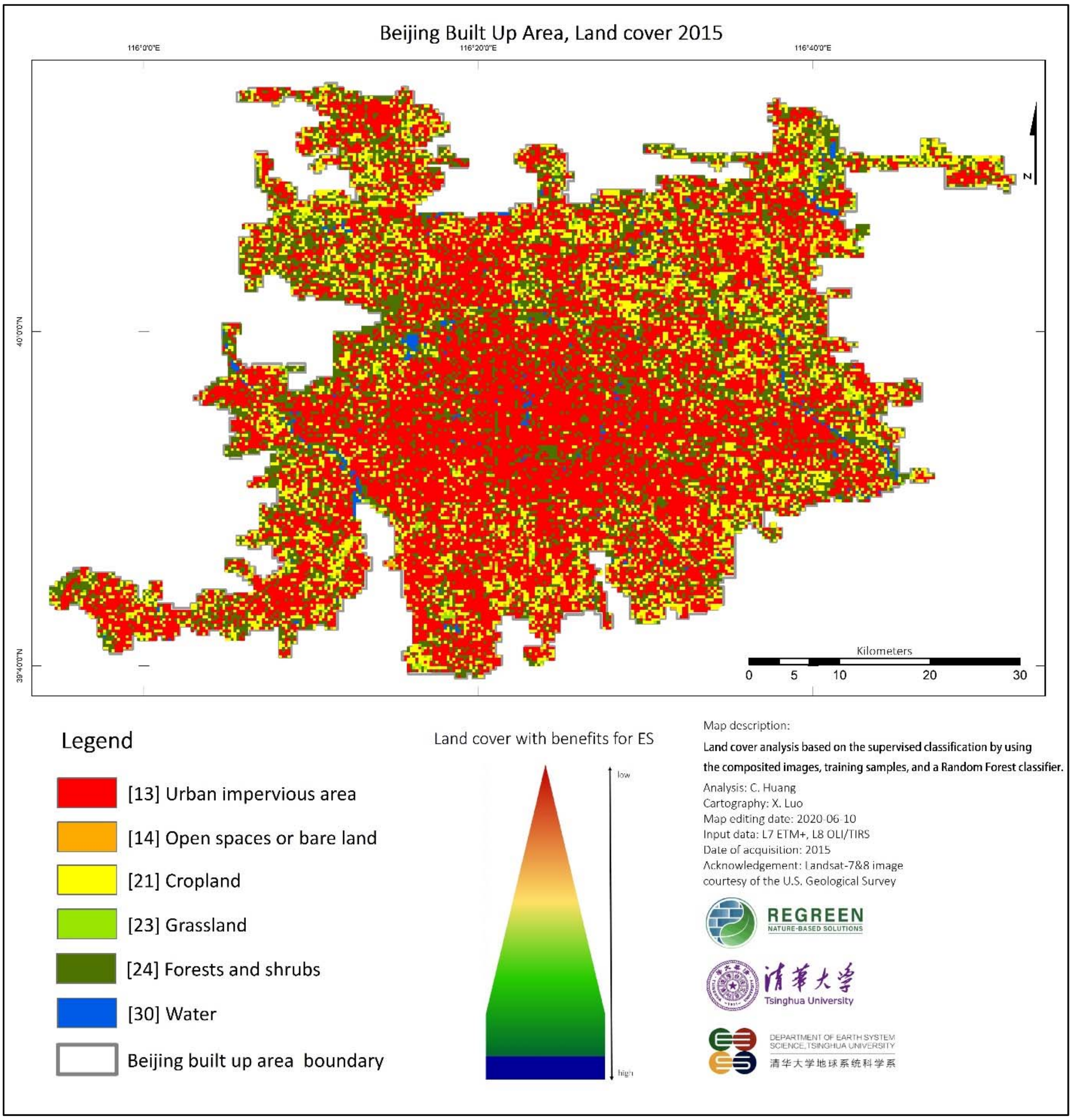

Figure 10: Land-use/land-cover classification (LULC) for the central Beijing built-up area in 2015

The percentile-based composite images were classified following the routine, firstly classifying them into water and non-water type, then classifying the non-water type into vegetation and non-vegetation type using the greenest pixel composite images. Applying the percentile-based composite images, vegetation was then further classified into forest/shrubs, grassland, and cropland, and non-vegetation into impervious area as well as open spaces and bare land. The quality of the classification results have been proved through accuracy assessment: the mean overall classification accuracy of LULC was approx. 89% ± 3.2%. The mean Kappa coefficient was 0.84 ± 0.05. The resulting land-cover maps are presented in Figures 9 and 10.

ULL Shanghai

The land cover in cities is more complex compared to other areas, which leads to main challenges to conduct LULC mapping for cities. In order to map the details of LULC in Shanghai, all available Sentinel-1 and Sentinel-2 images were collected for the year 2019 and processed on the GEE platform.

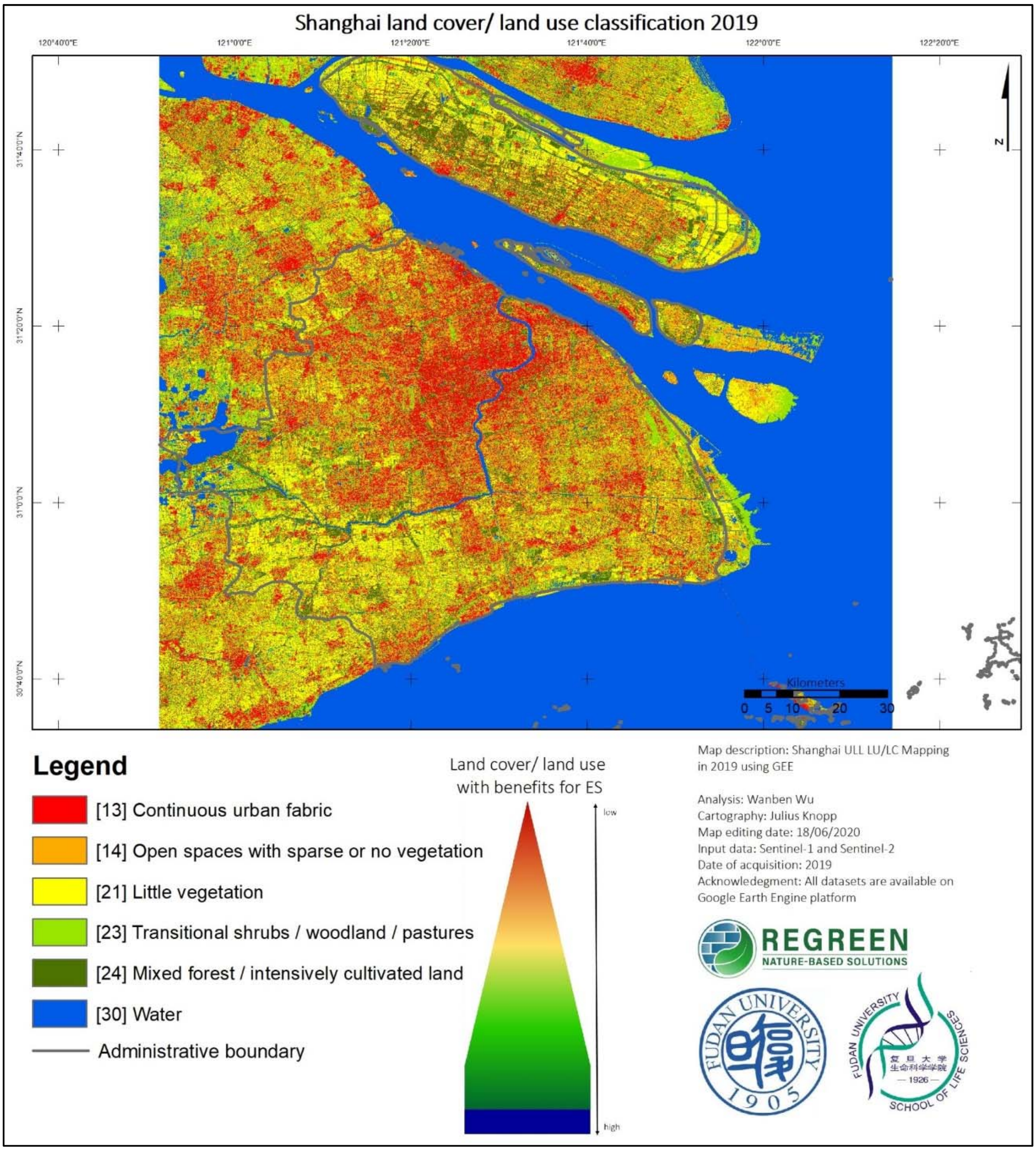

Figure 11: Land-use/land-cover classification (LULC) for ULL Shanghai, 2019

We built different characteristic variables to conduct the LULC classification, including: (1) Sentinel-1-derived backscatter coefficient in four different seasons to highlight the crop information; (2) annual maximum NDVI to highlight the vegetation information; (3) annual mean NDBI to highlight the building information; (4) annual mean NDWI to highlight the water information; and (5) Grey-Level Co-occurrence Matrix (GLCM) method derived contrast of NIR band to highlight the texture information. Thereafter, the Random Forest (RF) classifier was utilized to conduct a supervised LULC classification based on samples we collected using GEE. In total, 270 samples were selected for each type, i.e. forest, grassland, cropland, water, urban impervious area and bare land. For each sample collection, 70% of samples were used as classifier training, and the remaining 30% were used as validation samples for post-classification accuracy evaluation. A confusion matrix was constructed, from which the producer's accuracy (PA), user's accuracy (UA), overall classification accuracy (OA) and Kappa (statistic) index of land-cover mapping were calculated: the overall classification accuracy is approx. 90% and the obtained Kappa value is 0.92.

Figure 11 shows the LULC classification result of Shanghai in 2019 based on multi-temporal Sentinel-1&2 data and RF classifier. All processing were conducted on GEE, and the classification workflow is available in the example code (Google Earth Engine account required), https://code.earthengine.google.com/e8c2d2cf0f076031fd6831cc97dfc46e.

ULL Ningbo

Likewise to the classification procedure for Shanghai, the Ningbo ULL was mapped. In order to detect the details of LULC in Ningbo, all available Sentinel-1 and Sentinel-2 images were collected for the year 2019 and analysed on the GEE platform. The classified LULC is presented in Figure 12, and is approved by an overall classification accuracy of 0.86, and a Kappa value of 0.83.

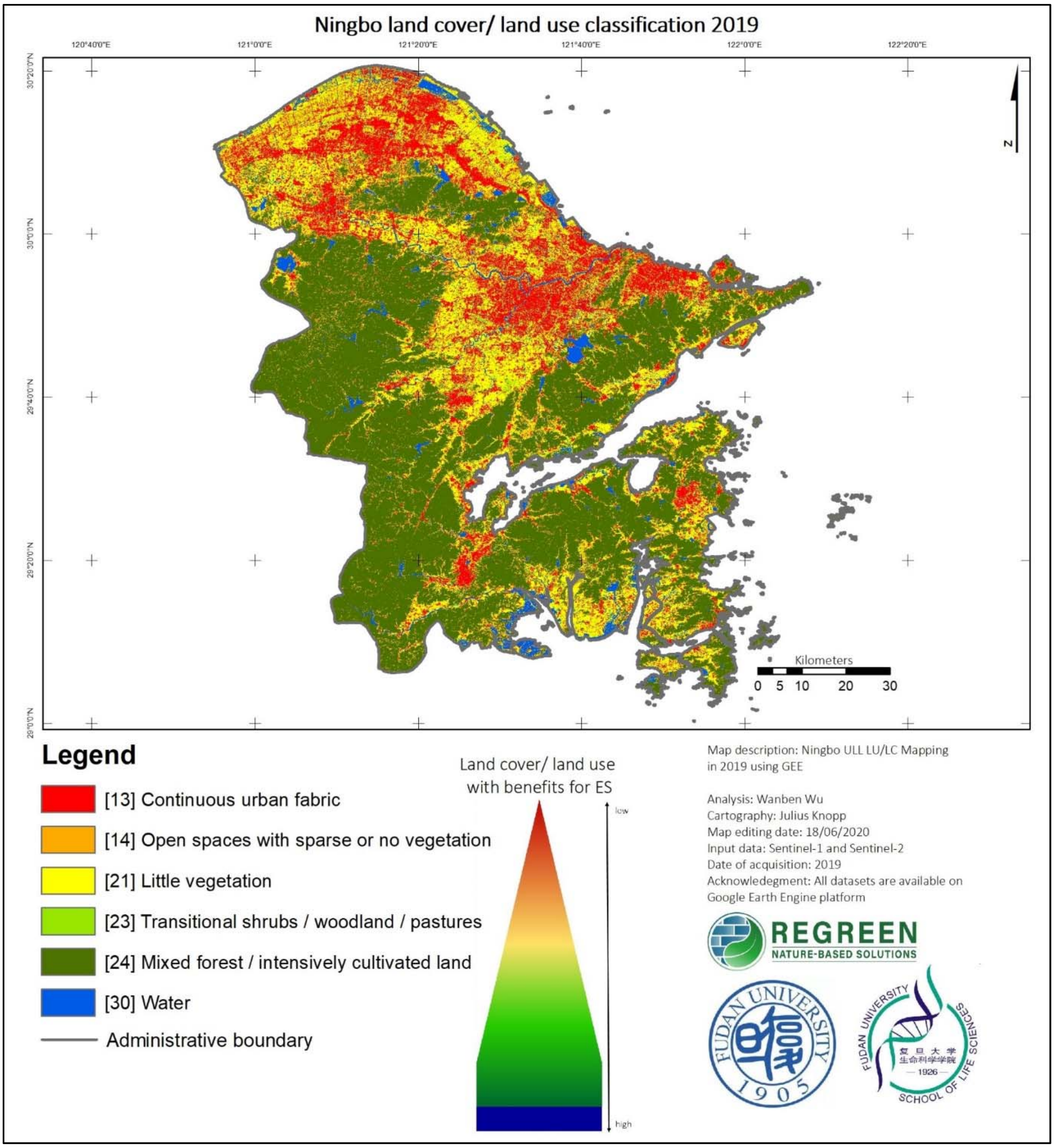

Figure 12: Land-use/land-cover classification (LULC) for ULL Ningbo, 2019

6 EXAMPLES OF APPLICATION OF DATASETS IN ECOSYSTEM SERVICES MODELLING

6.1 Example of noise-mitigation model

Although we are at an early stage in the project so far, we provide a short example showing how datasets will be used for one ES model: noise mitigation, using the ULL Paris as a case study example.

The data requirements of the model estimating the mitigation of traffic noise by trees include:

- Tree cover, from land cover
- Noise data
- Major roads data

Urban tree cover

The model requires fine resolution data on cover of urban trees or woodland. The noise mitigation is only provided by woodland of a certain size or thickness. For this study we use a minimum size of 200 m^2 (Eftec & CEH 2018; Fletcher et al. submitted). As pre-existing data representing the location and extent of trees is not always available, or it is not suitably up-to-date, we have the option to produce a shapefile dataset representing wooded areas from earth observation data. We perform an LULC classification, using data acquired by the Sentinel-2a satellite platform, and create a shapefile from the *tree* LULC class (Figure 13). Because the noise mitigation modelling process involves accurate representation of relative location, direction and proximity to linear features (i.e. major roads – the sources of modelled traffic noise), it is important that the tree data are captured at a sufficient resolution (minimum 10m).

Noise data

Statutory noise modelling data should be available in all EU countries, performed to satisfy the EU Noise Directive (Directive 2002/49/EC). This modelled traffic data, along with data representing the major road sources that were used to model the traffic noise is often available from public websites. The statutory EU noise data for Paris (Figure 14) encompass a number of different noise metrics and different sources. For this analysis, we are conducting the model on road noise data, and use the metric Lden, which is a measure of noise levels adjusted to the frequencies which can be heard by the human ear. In the Lden metric, the data are summarised for Day, Evening and Night, in a weighted summary metric which meets international standards. The data for Paris are available as shapefiles, and so need to be converted to raster format, at a 10m horizontal resolution, matching that of the Sentinel-2A-derived tree data.

Noise mitigation model

The noise mitigation model uses the noise data, tree-cover data, and major roads data to identify the areas that receive noise mitigation from the trees and to quantify the level of mitigation provided. Data on dwellings, or buildings, can then be overlaid in order to estimate the benefits of this mitigation from a human perspective.

The analysis for this service is still ongoing, but the figures above provide an indication of how the different data sources are used to create the model output, and an example is provided of what the modelled output will look like (Figure 15). This example is provided from existing modelling done in a UK city, but illustrates the basic principles of the results that will be available for each of the ULLs.

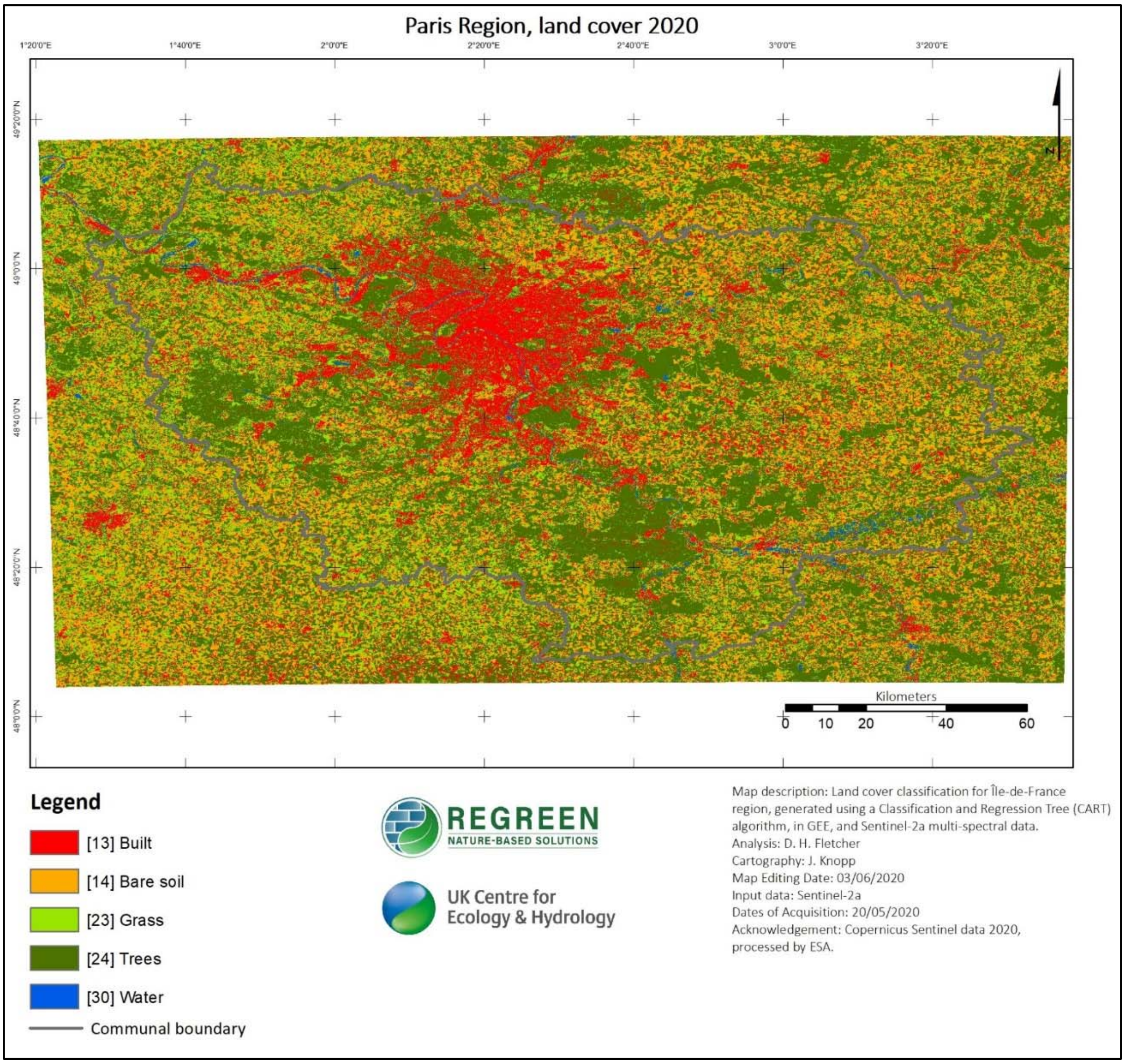

Figure 13: Example land-use/land-cover classification (LULC), performed with a classification and regression tree (CART) in Google Earth Engine (GEE), using Sentinel-2A data, at 10m horizontal resolution, for Paris Region, France.

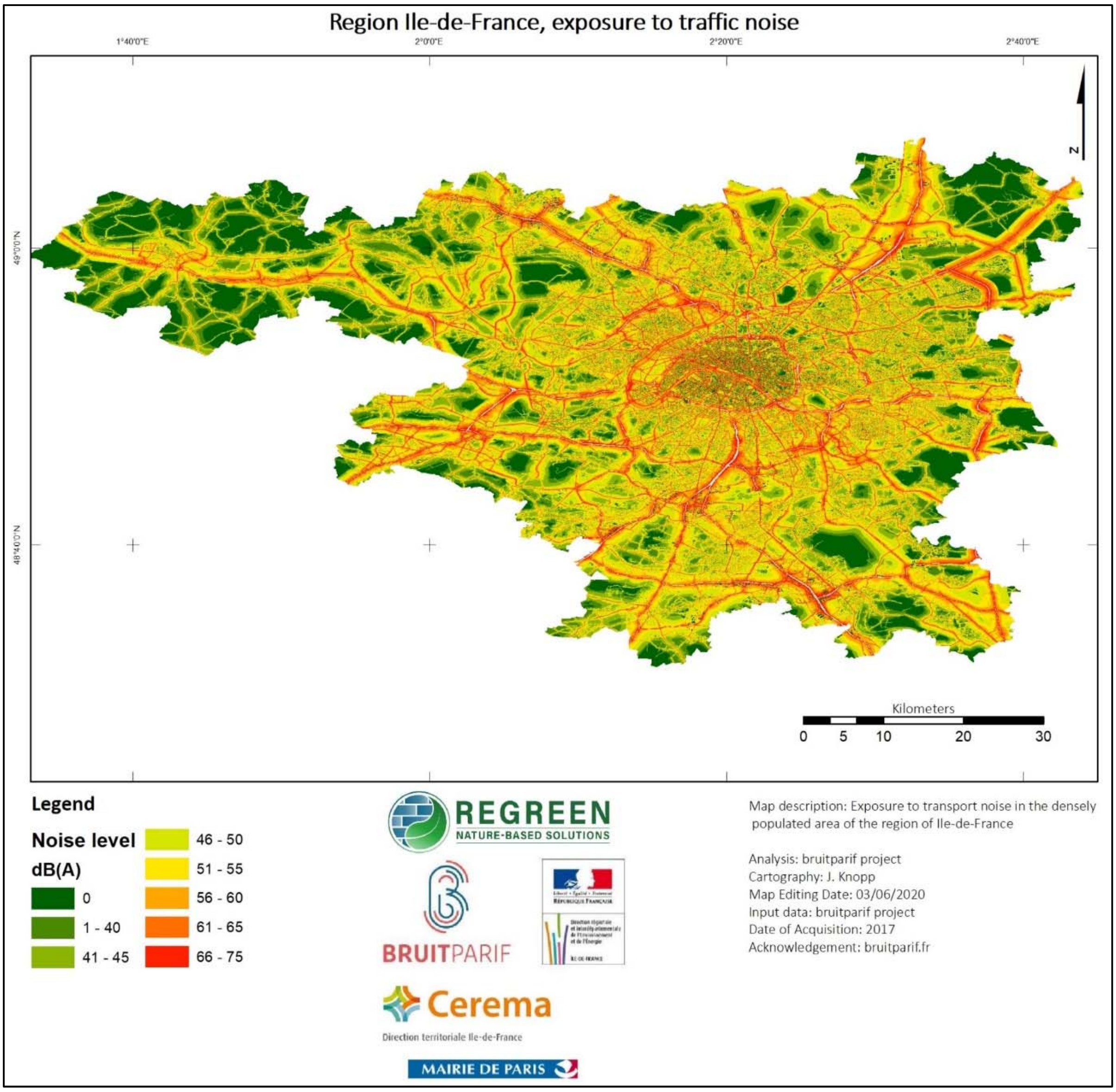

Figure 14: Statutory modelled noise data from road traffic for ULL Paris Region (frz. Ile de France).

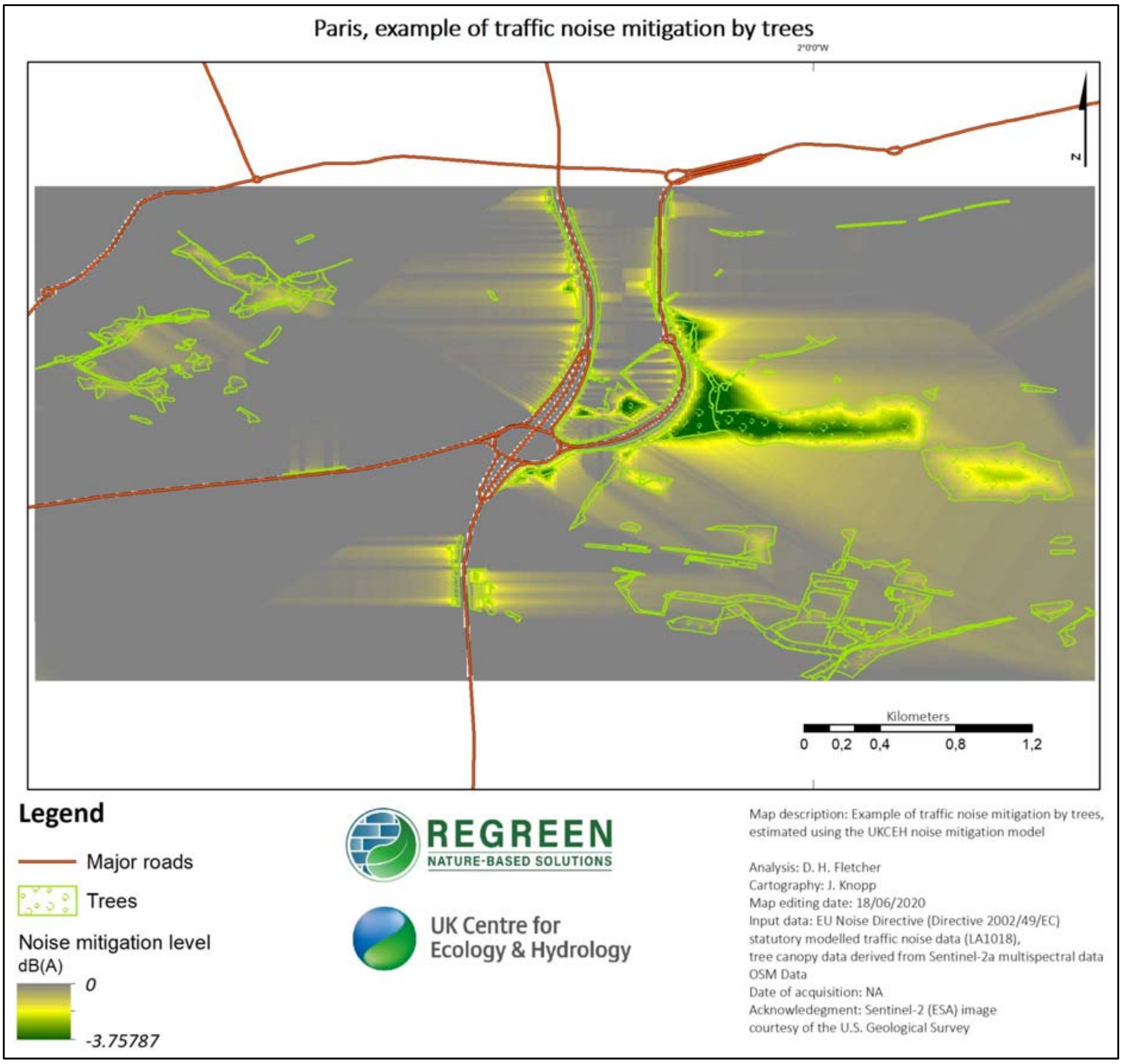

Figure 15: Modelled noise mitigation due to trees, where low values represent a greater reduction in noise levels, i.e. a greater amount of service provided. Exemplified for a site at ULL Paris.

6.2 Example of heat mitigation model

Heat mitigation has been identified as one of the most prolific NBS. Quantifying the heat mitigation can be achieved on different scales from larger public infrastructures such as parks to a refined scale NBS like street trees. For coarse-scale applications, remote sensing may be used for the analysis of historical trends and impacts of NBS. At refined scales and for the analysis of future scenarios or interventions high-resolution models are used more frequently.

In studies using remote sensing, typically MODIS and LANDSAT 8 images are used. These provide estimates of land surface temperature (LST) at different spatial sampling (MODIS 1km x 1km, LANDSAT 30m x 30m) and temporal intervals (MODIS, four times daily; LANDSAT 8, once every 16 days). Relationships are developed between LST and NBS indicators (e.g. NDVI, NDBI, bare soil index or imperviousness index). These relationships are have been used to estimate the NBS of e.g. increasing vegetation coverage and to downscale MODIS LST images to LANDSAT spatial scale (Essa et al. 2012, 2013, Mahour et al. 2017, Bala et al. 2020).

The two high-resolution models currently in use are MUKLIMO-3 (Deutscher Wetterdienst, 2020) and ENVI- MET (Bruse, 2020). These build a detailed model of the cityscape, which includes building heights and materials, roof colours angles and materials, pavement, vegetation heights and types, and water bodies and combines this information with historical weather records to derive temperature indicators based on thermodynamic principles. Typical temperature indicators are the annual number of summer-days (T_{max} > 25°C), hot-days (T_{max} > 30°C) and tropic-nights (T_{min} > 20°C), or the temperature at a specific time of day. The value of NBS can be estimated by altering the model (i.e. increasing or decreasing vegetation).

So far, the remote sensing relationships have been modelled for the ULL Paris Region. A visual comparison between Figure 16, 17 and Figure 18 illustrates the dependency between impervious areas and land surface temperature. Beyond, Figures 16 and 17 depict the different levels of detail for the spatial analysis dependent on the resolution of the sensor is designed to capture (Thermal image of MODIS at 1,000m; of Landsat 8 at 100m).

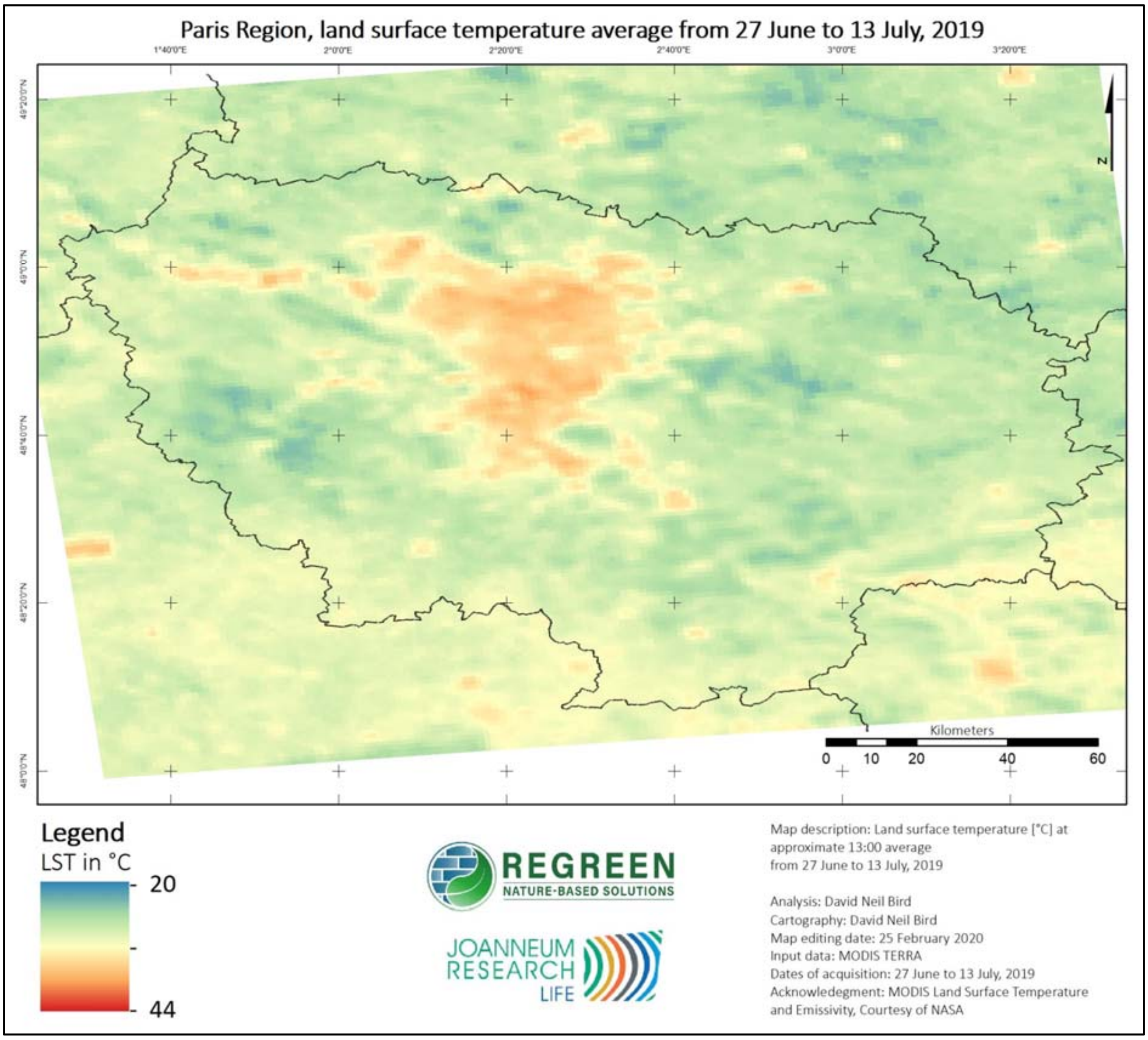

Figure 16: Land surface temperature for the ULL Paris Region, MODIS derived

Figure 16 shows the average MODIS daytime LST from June 27 to July 12, 2016, contrasting Figure 17 land surface temperatures for the same ULL for July 4, 2019, derived from Landsat 8 thermal band at a higher spatial resolution. Figure 18 presents the corresponding CORINE land-cover classification.

Land surface temperature [°C] shows a difference of 16° between the cool blue areas (23°C) and the warm red areas (39°C). As illustrated by CORINE land cover, the warm red areas are categorised as continuous and discontinuous urban fabric. The cool areas marked in blue match with mixed and coniferous forest.

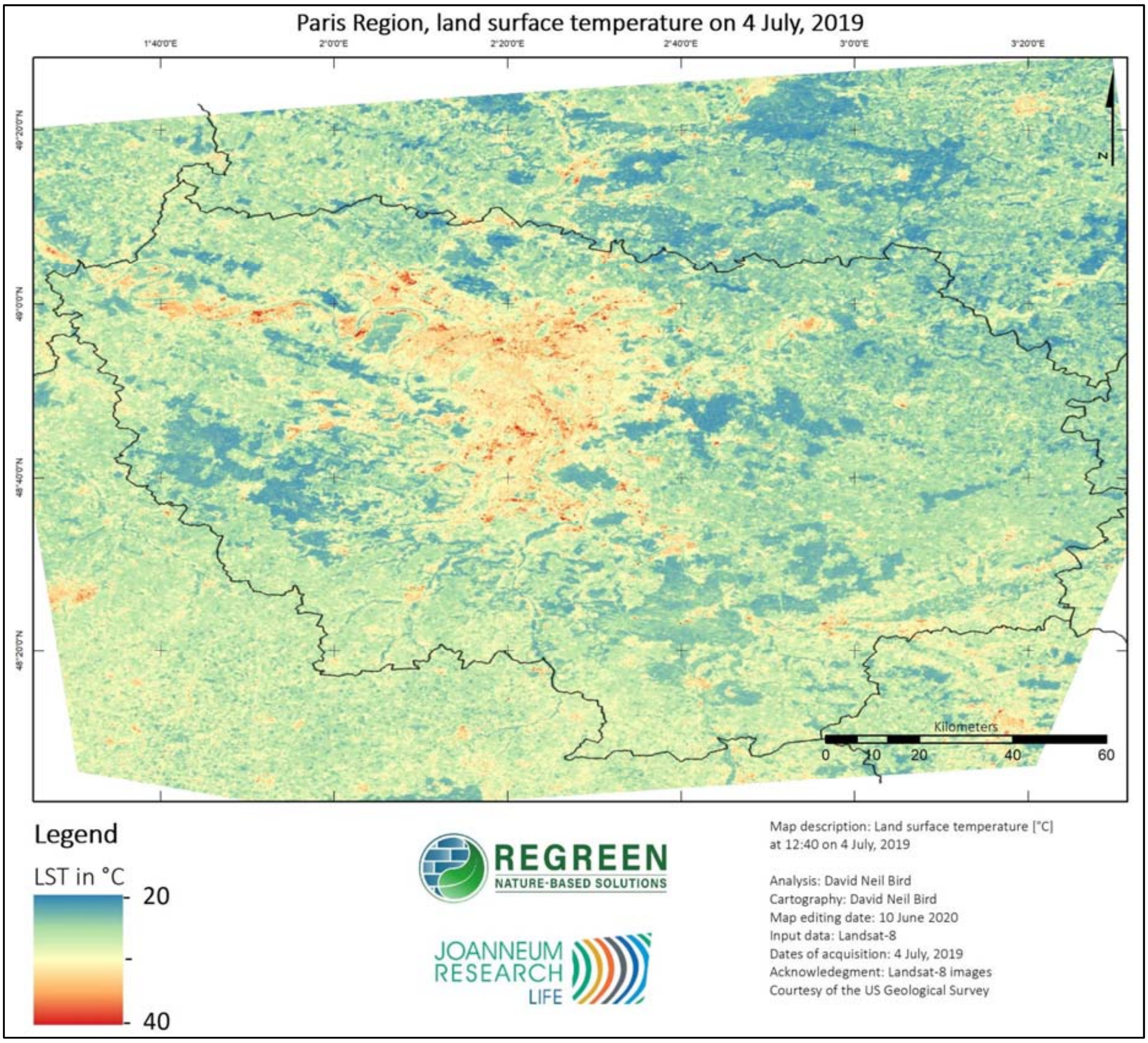

Figure 17: Land surface temperature for the ULL Paris Region, Landsat derived

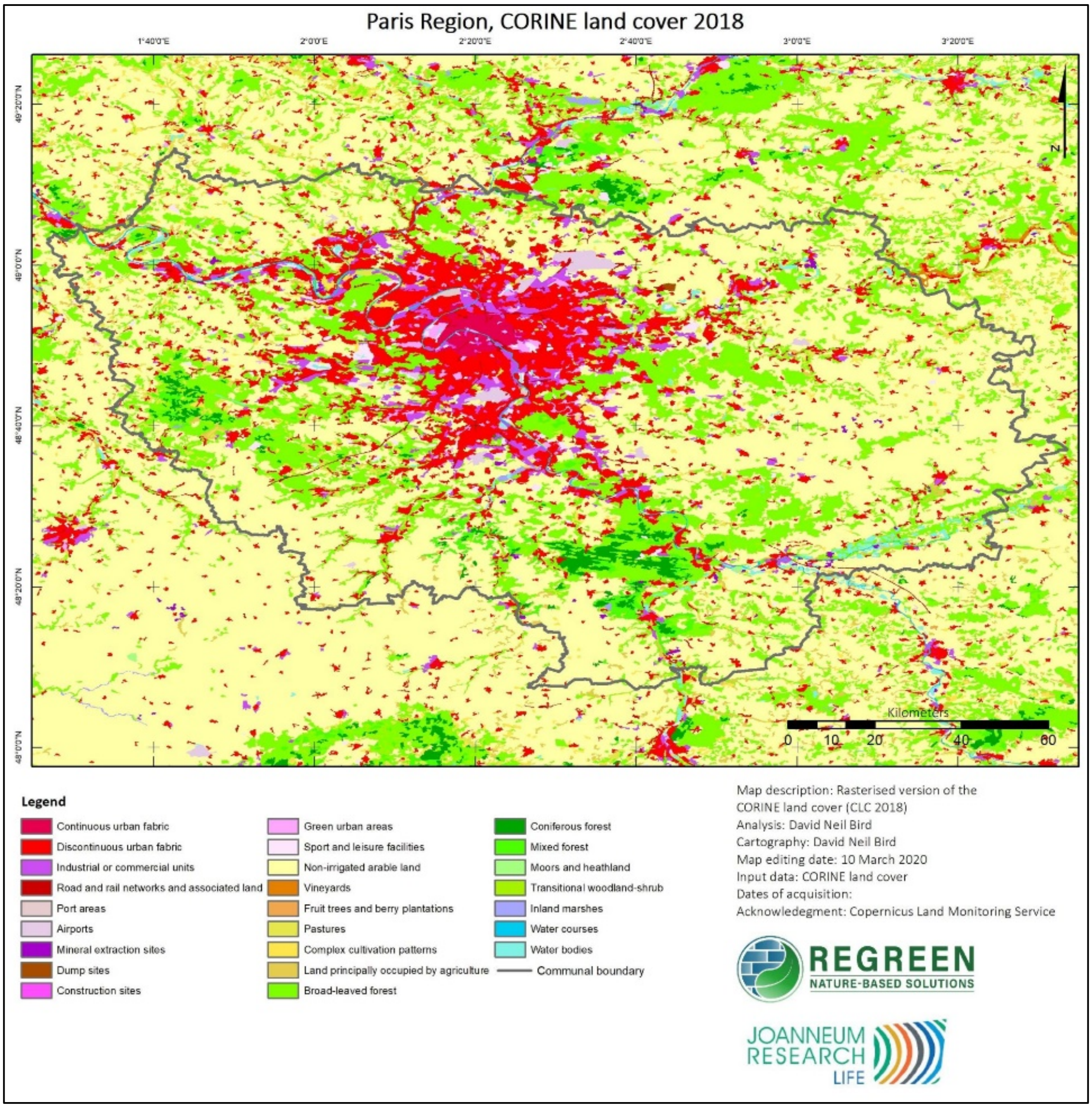

Figure 18: CORINE land cover for the ULL Paris Region. Source: Copernicus land monitoring service, 2018

This analysis of the current situation will then be used to model the influences of NBS on refined scales for which both, MUKILMO-3 and ENVI-MET will be used. So far, this approach has been demonstrated in other research activities (Nemec and Žuvela-Aloise 2012, Žuvela-Aloise et al. 2016, 2018, Žuvela-Aloise 2017). Figures 19 and 20 show two examples at different scales for the cities of Graz, Austria, and Avola, Italy.

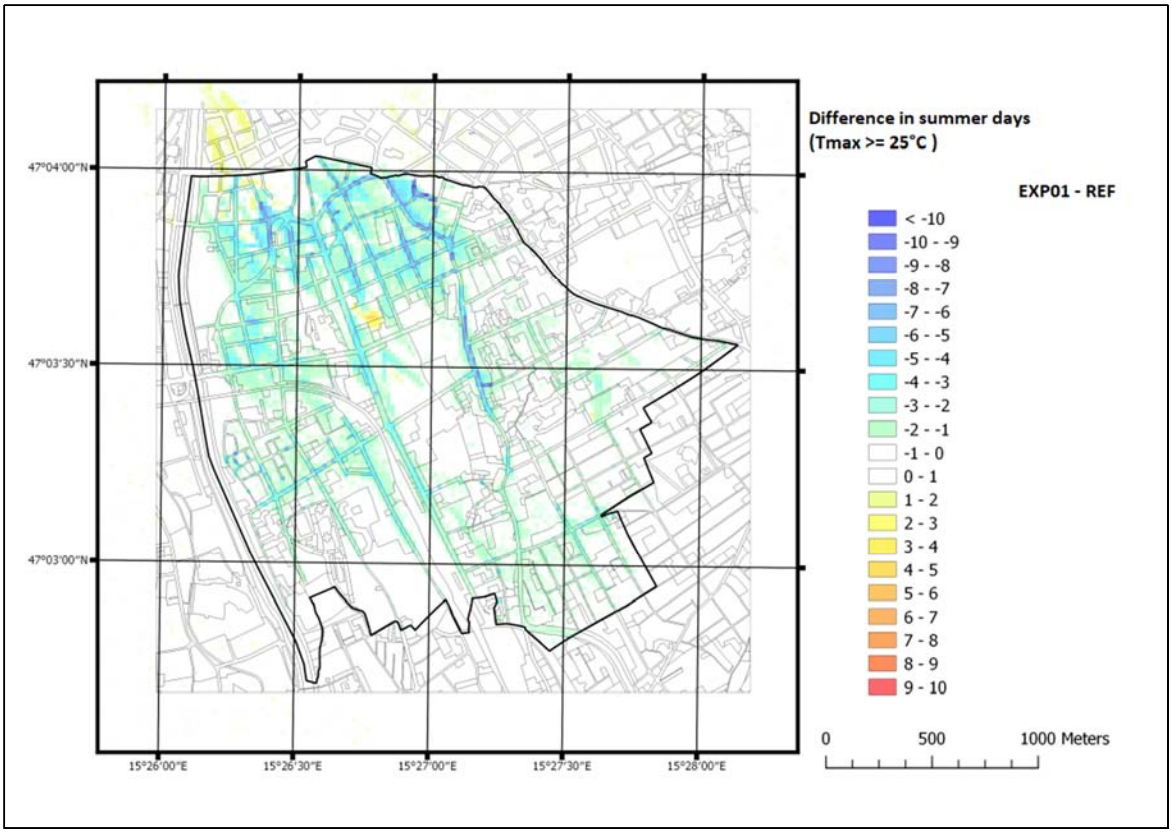

Figure 19: Modelled impact of trees on days above 25°C in Jakomimi district, Graz, Austria. Source: Žuvela-Aloise, 2017

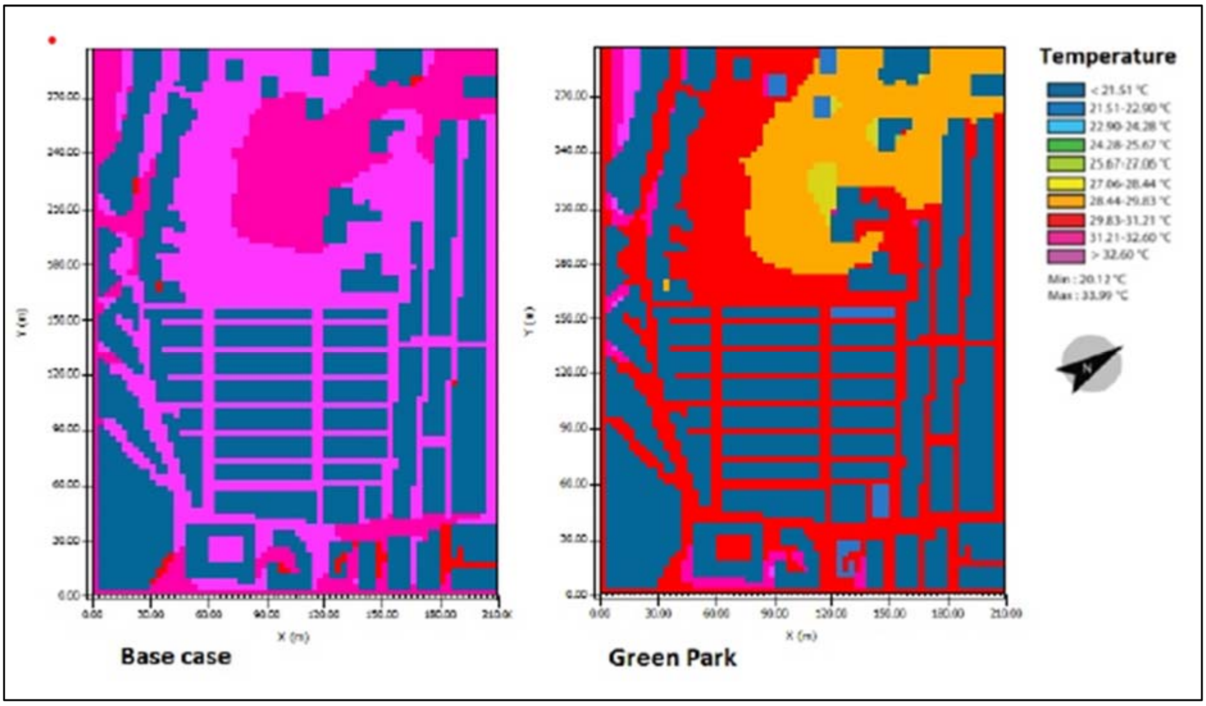

Figure 20: Example of ENVI-met products: The present base case (left), and the modelled impact of a green park (right) in the inner city of Avola, Italy at 1 p.m. CEST. Source: Evola et al., 2017, p. 698.

Usage of the MUKLIMO-3 is applicable to towns or urban districts. It is specifically useful for modelling the impacts of a planned NBS intervention (e.g. tree planting or designing green roofs).

These models are characterised by a high spatial resolution. However, specific data requirements such as LULC, building and vegetation descriptors, are more onerous than satellite-based urban heat island estimates. The outputs are limited to an annual estimate of summer-days or hot-days and the resulting mitigation effect.

ENVI-met, as visualized in Figure 20 from a different study, is ideal for modelling very local impacts of interventions. The results are mono-temporal and highlight the effect of a park on the local air temperature.

7 CONCLUSIONS

7.1 Summary of achievements

This synthesis report renders an overview over disciplinary, interdisciplinary and transdisciplinary investigations in the work package 3 “Mapping and modelling ecosystem services”. It thereby pays tribute to close interactions between scientists of different disciplines, and between scientists and project partners in the ULLs. This report also bears witness of the collaborations between different partner institutions in Europe and China.

A central aim of REGREEN is to account for the totality of the services and benefits delivered by restored or improved ecosystems. We simultaneously notice that “what ecosystems do” for citizens is distinct from the goods and benefits that citizens subsequently derive from ecosystems (Haines-Young & Potschin-Young, 2013, pg. 3). Therefore, we have laid the grounds for the application of an integrated indicator framework that investigates ES at different scales and for different spatial extents by giving an overview of prominent indicator frameworks. By relating them to the demands and tasks we carry out in this project we are prepared for an integrated framework for social and ecological aspects at different scales.

The latter is an essential criterion in our interlinked work because addressing the appropriate scale is vital for a targeted mapping and modelling of ES towards NBS implementation. Some models allow upscaling or downscaling, others would distort the information needed. Likewise, the quality of input data depends on the spatial scale it is derived from. Therefore, restrictions, limitations and assignment to the appropriate scale are discussed and presented in the fact sheets for mapping and modelling tasks. Speaking about input data bears the use of existing data extracted from different European platforms and various Chinese official databases as high priority. So data availability has been checked, and REGREEN can benefit from publicly available data for the European ULLs which is documented for the different urban aspects and indicators, and some public thematic datasets are applied in the first mapping and modelling approaches depicted here. Modelling investigations have, so far, not been undertaken for Chinese ULLs but are foreseen in the next project phase. Plenty of remote sensing and ancillary spatial data can be used and analysed at intermediate scale, but very high resolution data that are demanded for site-specific NBS can only be gathered if stored by the respective ULL data management at local level. We are aware that data gaps exist, are in exchange with the ULLs, and on the way to find solutions for such bottlenecks.

During these first stages of the project, a high sensitivity has been reached beyond the awareness of scale that takes into account to integrate multiple measurements, and different points in time, within a year, and over years, and also to shed light to weighting approaches.

First achievements are given in Sections 5 and 6 where we present our first mapping and modelling results. Other achievements that cannot be visualised as such are the intensive communications amongst researchers of different institutions and disciplines in REGREEN, and between researchers and our partners at the different ULLs. These achievements will be measured later during the project by joint publications and the results of NBS interventions.

7.2 Relation to continued developments

Laid on the grounds of the well-established indicator frameworks EKLIPSE and Nature4Cities, we continue to work out an integrated and lean indicator framework to capture synergies and trade-offs from multiple ES. They allow for including quantitative and qualitative data, setting priorities of the demand and supply indicators and fulfil the best adapted NBS at its spatial scale (from regional to metropolitan to urban to site scale). In terms of moving forward with the use of indicators as well as integrating the outputs of the models for the REGREEN project, we will discuss both as a next priority in the coming project phase. The project outputs will include modelled quantity of ES provided, for a range of services (WP3), as well as the economic value of those services (produced in WP4). These outputs can be taken to inform scenarios to explore options for managing cities (WP7), ideally within a set of spatial or other toolkits. All such created information can easily be employed by a variety of stakeholders, including planners, city officials, and educators through the REGREEN communication and dissemination platform (WP8).

Built on our mapping and modelling results, we can create NBS bundles from ES at each targeted scale and for the very specific need of the respective ULLs. By doing so, it has been communicated that not all ULLs have the same demand for NBS interventions. Example given: in the ULL Aarhus modelling heat mitigation is not an issue of high priority, but at ULL Paris Region it is. Hence, we have started to distinguish between these needs of the specific NBS demands in terms of scale and intervention and will continue to pinpoint on the supply by respective mapping and modelling ES to carve out the most suitable ones.

That again brings up the point of data integration into the ES models that are either being explored, or on their way, and site specific interventions will be discussed further.

Quite a crucial point is the data needs for some models regarding differentiations between deciduous and coniferous forest. This leads to the task in remote sensing to investigate which satellite imageries have the appropriate spectral resolution for further distinction, and the minimum spatial resolution to enable such a subdivision of classes. Hence, the methodological process is yet to be developed to achieve the challenging distinction. Furthermore, ESA offers to submit a project proposal for data acquisition. That is helpful to cover information gaps where the respective ULL cannot obtain data from its public services and thus cannot share data with the other project partners.

Due to Corona pandemic situation, it was not possible to undertake any field work and gather a deeper understanding of local situations and their specific contexts. So further development of our research will also include field work on the site to capture features and elements, relevant structures and other specifics, as well as deepen the communication with project partners and stakeholders.

7.3 Other conclusions and lessons learned

Referring to the special Corona pandemic situation, and the virtual Paris 2020 meeting, it has become obvious that a virtual meeting cannot substitute a real project meeting at an ULL site. Shortcomings are manifold, and some are listed above by having the lack of field trips and exchange visits to stakeholders on-site. Furthermore, small and interspersed meetings between some project members are missed tremendously. First, because through face-to-face meetings we get to know each other better and understand each other’s questions and targets more precisely. Second, meetings during coffee breaks and in the evening foster our common sense of joint efforts to work efficiently, and open our minds for new options and unforeseen opportunities, thus leading to more efficient work progress and may push creative products.

Another aspect of interdisciplinary work based on quantitative data is how to collate metadata and understand each other’s needs in detail. First, the techniques of spreadsheets helped to develop a fruitful discussion on roles and responsibilities, the gap between existing and needed data categories at publicly available level, further collaboration towards well-adjusted optimal datasets at hand, and restrictions of upscaling/downscaling maps and models. Based on that, a template for fact sheets was generated and filled in by all mapping and modelling scientists. They are attached to the report as appendix. As a living document with date of latest update and responsible author, they make our understanding more transparent and easier to follow each other's research and linkages between the various scientists, as well as between scientists and stakeholders at the ULLs.

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9 APPENDIX

Fact sheets for mapping & modelling ES in REGREEN

9.1 Mapping by using Google Earth Engine (GEE)

Model/Service/Mapping product name: Mapping by using Google Earth Engine (GEE)

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

Short description of output:

Mono- and multitemporal medium to high resolution land cover maps based on different features, such as vegetation metabolism rates, simple differences in reflectance and multiple ratios.

Methods

GEE allows online processing of remotely sensed data. Along with a database containing a vast set of remote sensing data, such as Sentinel and Landsat sensor imageries, GEE provides a set of implemented processing algorithms, which can be further expanded by the user. Mono- and multi-temporal studies are possible.

In the context of REGREEN, GEE is used to produce a medium resolution land cover mapping of the ULLs and the surrounding areas, as well as a classification of vegetation metabolism rates.

Approach for REGREEN

- Generating classified vegetation metabolism (CVM) rates in order to map land cover types at one point in time
- Continuous gradients from fully sealed (built-up area) to peak vegetation density
- Detection of water bodies
- Optional: multi-temporal analysis of land cover for all EU ULLs based on Landsat 5-8 and Sentinel 2 data
- Note: Differentiation of land cover classes based on user demand

How NBS are incorporated:

One goal of our mapping results will lead to spatially allocating NBS. We cannot map solutions as such. We can map proxies and indicators to derive ES from. These services may then be used to establish NBS.

Upscaling/Downscaling:

Upscaling and downscaling of mapping results is limited. Extraction of mapped data for various urban extents is simple and easy to undertake within the same spatial scale.

Basic information on map/model output

Scale of extent (e.g. single park, city centre or part of city, whole city, small area but up-scale to whole city)	Urban area / urban region
Approximate spatial resolution of output (e.g. metres, city block)	10 to 30m
Temporal resolution (time points) of output (if relevant)	Mono- or multi-temporal
Scope of categories	Ca. 10 land-cover classes

Data table for input requirements

Data type	Other information (e.g. requirements; thematic classes or features needed)	Spatial resolution (& vertical if important)	Time points, year(s)
Satellite imageries	Landsat or Sentinel 2	10 to 30m	Monthly to weekly

Date this document was updated: May 13th 2020

9.2 Urban land-use/land-cover (LULC) mapping framework

Model/Service/Mapping product name: Urban land-use/land-cover mapping framework

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

Short description of output:

High to medium resolution mapping of the urban land cover for the European ULLs. This product represents coherent spaces of similar features, such as, but not limited to, forests, lawns, buildings, impervious surfaces and waterbodies.

Methods

Urban LULC mapping for each ULL will be accomplished by using existing EU datasets such as the Urban Atlas and data from the CORINE project and complemented, if demanded by an ecosystem service model, by own analysis of remote sensing data. Further information, such as ground truthing and additional information on the specifics of each ULL will be provided through field trips, the respective partners in each ULL and Google Earth/ Google Street View. This land-cover classification will consist of multiple classes. Hierarchy of these classes will follow those of the aforementioned urban land cover products. In contrast to the very high resolution urban morphology mapping, the focus of this mapping will not be on detecting single elements (e.g. tree), but rather on a more coherent spatial level (e.g. woodland). The final product is supposed to serve as an input for those models that only need intermediate spatial resolution. This method offers the possibility to aggregate its resolution to a coarser one, depending on the model input requirements.

Approach for REGREEN

- Rather coarse resolution for different models possible
- Flexible class hierarchy based on publicly available input
- Based on mono- or multi-temporal input data, a single or multiple LULC maps can be produced

How NBS are incorporated:

One goal of our mapping results will lead to spatially allocating NBS. We cannot map solutions as such. We can map proxies and indicators to derive ES from. These services may then be used to establish NBS.

Upscaling/Downscaling:

Upscaling and downscaling of LULC mapping results is limited. Extraction of mapped data for various urban extents is simple and easy to undertake within the same spatial scale.

Basic information on map/model output

Scale of extent (e.g. single park, city centre or part of city, whole city, small area but up-scale to whole city)	Urban area/region
Approximate spatial resolution of output (e.g. metres, city block)	Decametres
Temporal resolution (time points) of output (if relevant)	Mono or multi-temporal
Scope of categories	Several land cover and land use classes describing the urban area

Data table for input requirements

Data type	Other information (e.g. requirements; thematic classes or features needed)	Spatial resolution (& vertical if important)	Time points, year(s)
Public EU data	CORINE, Urban Atlas, INSPIRE	10 to 100m	Dependent on source
Satellite imagery	Landsat or Sentinel 2	10 to 30m	Monthly to weekly coverage, aggregated
DOP CIR Raster dataset	Multiple Bands, at least RGB and NIR	Sub-meter	Single or multi-temporal

Date this document was updated: May 13th 2020

9.3 Urban morphology mapping framework

Model/Service/Mapping product name: Urban morphology mapping framework

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

Short description of output:

Very high resolution dataset of the urban structure, including different land cover classes down to functional urban area types and single elements such as trees and buildings. The mapping is supposed to

- Serve as an input for models (e.g. noise)
- Be used to link other data in the same spatial dimension, such as information gathered from questionnaires and simple point data like biodiversity and prevailing species and types
- Enhance knowledge on social demographic and social economic implications of residents for various pressures at allocated hotspots

Methods

Mapping background: By using an object-based image analysis approach, the spatial relations between single objects can be evaluated, such as tree density in relation to other objects (houses). Measuring the influence of objects by spatial distance, and the accessibility and distribution of elements in residential areas supports NBS.

The map will be produced for each European ULL at the highest resolution possible and feasible, and can be resampled to a coarser resolution, such as functional urban areas or local urban climate zones.

The underlying workflow for this approach has been developed and tested at UFZ, and will now be enhanced for a better transferability.

Approach for REGREEN

- Input data has to be provided by each ULL
- If required input data cannot be provided by the ULL, data need to be acquired from other sources
- Need for test sites and ground truthing, which should be mapped by fieldwork or assisted by Google Maps/ Street View
- Results will be evaluated on site by ULL
- Object-based approach to incorporate as many different spatial features as needed to model different ES

How NBS are incorporated:

One goal of our mapping results will lead to spatially allocating NBS. We cannot map solutions as such. We can map proxies and indicators to derive ES from. These services may then be used to establish NBS.

Upscaling/Downscaling:

Upscaling and downscaling of mapping results is limited. Extraction of mapped data for various urban extents is simple and easy to undertake within the same spatial scale.

Basic information on map/model output

Scale of extent (e.g. single park, city centre or part of city, whole city, small area but up-scale to whole city)	Whole city/ urban area at the level of single elements
Approximate spatial resolution of output (e.g. metres, neighbourhood, statistical block level)	Sub-meter
Temporal resolution (time points) of output (if relevant)	Mono- and multitemporal
Scope of categories	Multiple classes with subdivisions, ranging from continuous land use (e.g. perimeter blocks) to single urban elements (e.g. street tree)

Data table for input requirements

Data type	Other information (e.g. requirements; thematic classes or features needed)	Spatial resolution (& vertical if important)	Time points, year(s)
DOP CIR Raster dataset	Multiple Bands, at least RGB and NIR	Sub-meter	Mono or multi-temporal
nDSM Raster dataset	DSM and DEM can be delivered separately	Meter	Mono or multi-temporal
Residential building structure	Regional differences in architecture	Sub-meter	Snapshot
Urban development characteristics	Levels and processes of urban (sub-) development	Sub-meter	Snapshot

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9.4 Water quality assessment model (QUESTOR)

Model/Service/Mapping product name: Water quality - QUESTOR

Main contact, (and other people involved): Mike Hutchins, (James Miller, Nuria Bachiller-Jareño) (UKCEH)

Short description of output:

The river model 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.

Methods

Model background: 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 rivers of size ranging from <50 km^2 to ~10,000 km^2. Diffuse inputs can be represented by observations, process-based rainfall-runoff/diffuse pollution models or simple statistical models. Solar radiation inputs control water temperature and primary production.

Approach for REGREEN

- 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 are available. Most likely start with Paris as likely greatest scope and flexibility of choice.
- ULL 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. In Paris, likely NBS to consider: depaving and/or riparian tree coverage.
- Apply similar process in other ULLs.

How NBS are incorporated:

- NBS that influences 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 fact sheet).
- 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).

Basic information on map/model output

Scale of extent (e.g. single park, city centre or part of city, whole city, small area but up-scale to whole city)	"Part of city" and larger scales (but can represent drivers at smaller scales)
Approximate spatial resolution of output (e.g. metres, city block)	Reaches (river stretches of hundreds of metres in length)
Temporal resolution (time points) of output (if relevant)	Hourly or daily

Data table for input requirements

Data type	**Other information (e.g. requirements; thematic classes or features needed)**	**Spatial resolution (& vertical if important)**	**Time points, year(s)**
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

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9.5 Atmospheric chemistry transport model (EMEP) and weather research and forecast model (WRF) – EMEP-WRF

Model/Service/Mapping product name: Atmospheric chemistry transport model (EMEP) and weather research and forecast model (WRF) - EMEP-WRF

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

Short description of output:

The EMEP-WRF model calculates gridded time series of air quality main components (i.e. pollutants & other gases), as well as meteorological variables such as wind speed and temperature, solar radiation. The horizontal resolution varies; typically ~30x30 km^2 for all Europe and 1x1 km^2 for a city domain.

Methods

Background:

The EMEP-WRF is an off-line atmospheric chemistry transport model (ACTM) based on the EMEP MSC-W model (www.emep.int). The EMEP-WRF is a photochemistry model capable of representing the hourly atmospheric composition at a horizontal scale ranging from 100 km to 1 km. The Weather Research Forecast (WRF) model is used as the (3D) meteorological input (www.wrf-model.org). The EMEP-WRF model simulates hourly to annual average atmospheric composition and deposition of various pollutants; including PM10, PM2.5, secondary organic aerosols (SOA), elemental carbon (EC), secondary inorganic aerosols (SIA), SO_2, NH_3, NOx, and O_3. Dry and wet deposition of pollutants are routinely calculated by the model.

Approach for REGREEN

- For Europe, the EMEP-WRF model domain will include the three European ULLs at a horizontal resolution of 1x1 km^2 (if the computational resources allow this). The WRF meteorology is calculated for the REGREEN domains and thereafter the chemistry EMEP model is used to evaluate the changes in air quality and atmospheric compositions and changes due to current and perturbated green areas.
- For China, a similar approach will be run, but with coarser resolution. A single domain will run which covers the three ULLs: Beijing, Shanghai, and Ningbo. It is not yet decided whether finer resolution calculations for the cities will be nested within the China analysis.
- The effect of urban green space is evaluated using a scenario approach, comparing e.g. a scenario with no urban greenspace (or existing greenspace) and a scenario with added or modified green space.

How NBS are incorporated:

The EMEP-WRF calculates the removal of pollutants by the vegetation. The model is used to quantify how much pollution is actually removed (or emitted) by adding or by current vegetation. Different NBS may be tested and the positive and negative effect quantified.

Upscaling/Downscaling:

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

For example, the quantity of pollution removed by woodland can be attributed spatially to the locations in the city where woodland occurs. However, some aspects cannot easily be disaggregated to a finer resolution below the grid cell resolution of the model (1 km^2 for European ULLs). This is because the benefits in terms of reduced pollution concentrations, and the pollution concentrations themselves cannot easily be disaggregated. It may be possible to do some limited disaggregation if finer resolution pollution concentration maps are available, but this also needs to consider other factors such as air mass transport.

Basic information on map/model output

Scale of extent (e.g. single park, city centre or part of city, whole city, small area but up-scale to whole city)	Europe, including the REGREEN ULLs
Approximate spatial resolution of output (e.g. metres, city block)	~30 km for Europe down to 1 km for the cities include here
Temporal resolution (time points) of output (if relevant)	Hourly – meteorology and chemistry

Data table for input requirements

Data type	**Other information (e.g. requirements; thematic classes or features needed)**	**Spatial resolution (& vertical if important)**	**Time points, year(s)**
Gridded emissions	NOx, SOx, PM2.5, VOCs, PMco, CO, NH_3	At least 1x1 km^2 for the three cities	Yearly

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9.6 Hydrological modelling

Model/Service/Mapping product name: Hydrological modelling

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

Short description of output:

The hydrological model will produce time series of flow in either storm drains or open channels. The model may be distributed and produce gridded outputs, or lumped and produce flows at catchment outlet locations. Note, the outputs will also feed into the water quality Questor model input nodes as well as providing understanding on how NBS affect river flows in test catchments.

Methods

***Model background*:** Model TBC as discussions evolve in project. Either lumped or distributed. Requires analysis of available data from ULL.

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.
- 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.

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. I do not think the model will be suitable for the scale of a single park.

Basic information on map/model output

Scale of extent (e.g. single park, city centre or part of city, whole city, small area but up-scale to whole city)	"Part of city" including areas with NBS and within a hydrological catchment
Approximate spatial resolution of output (e.g. metres, city block)	Catchments with land cover at minimum 50m and catchment from 1km^2
Temporal resolution (time points) of output (if relevant)	Hourly

Data table for input requirements

Data type	**Other information (e.g. requirements; thematic classes or features needed)**	**Spatial resolution (& vertical if important)**	**Time points, year(s)**
Land-cover	Gridded land cover map – showing greenspace and other NBS	10 m	2020
DEM		5m,(1m)	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
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 minute

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9.7 Traffic noise mitigation

Model/Service/Mapping product name: Traffic Noise mitigation provided by trees

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

Short description of output:

The output is a raster depiction of noise attenuation due to trees, with units in dBA, typically with a horizontal resolution of 10 m. This can be interrogated, using shapefiles of residential dwellings, to quantify, for each dwelling, the mitigation received.

Methods

Background:

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 account for the effect of tree. Furthermore, traditional noise modelling approaches are very 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 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:

1) Create Matrix 1, where the cost for moving is 100 units per metre, for all transitions.
2) 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.

3) 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.

4) 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 shapefile.

5) Calculate the minimum anisotropic accumulated cost surface from the origin points. This output allows us to calculate, for each cell coincident with the trees shapefile 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).

6) 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.

7) 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.

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:

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

Basic information on map/model output

Scale of extent (e.g. single park, city centre or part of city, whole city, small area but up-scale to whole city)	Whole city
Approximate spatial resolution of output (e.g. metres, city block)	10 m horizontal resolution
Temporal resolution (time points) of output (if relevant)	NA

Data table for input requirements

Data type	Other information (e.g. requirements; thematic classes or features needed)	Spatial resolution (& vertical if important)	Time points, year(s)
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 shapefile, 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 shapefile	To include those roads used in the traffic noise modelling	These should be accurate and match the trees data, spatially	Most recent available

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9.8 Heat mitigation

Model/Service/Mapping product name: Heat Mitigation

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

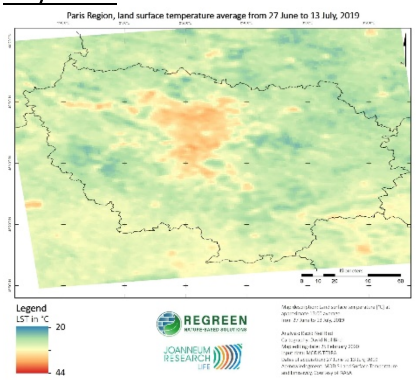
Short description of output:

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

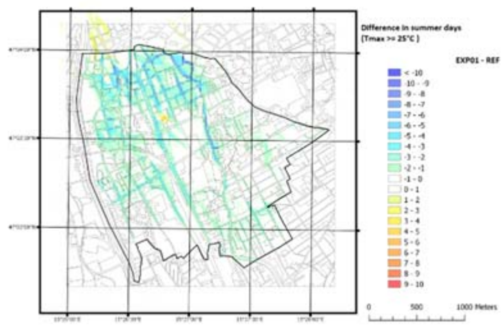
The scale will depend on the needs of the ULL. For example:

<u>City-scale</u>



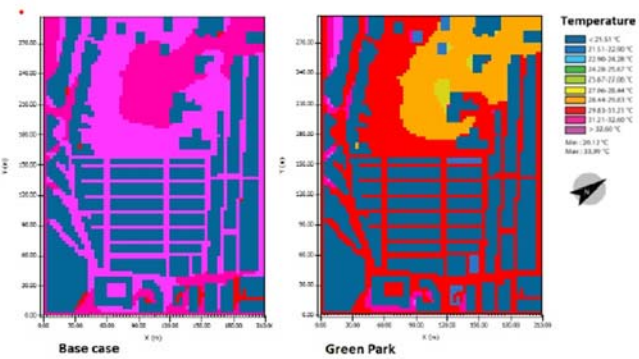
Example: Ile de France, July 12 2019, 14:00

<u>District scale</u>



Example: A district in Graz (modelled impact of adding 30,000 trees)

<u>Local scale</u>



The impact of a green park in the inner city of Avola, Italy at 13:00. From Evola GA et al., 2017. UHI effects and strategies to improve outdoor thermal comfort in dense and old neighbourhoods. Energy Procedia 134:692–701.

Methods

<u>Historical mapping of the UHI and the estimation of value and impacts of NBS</u> will be based on land surface temperature (LST) from satellite data (MODIS and / or LANDSAT 8). 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 or ENVI-met depending on the scale of the action.

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 (16-day repeat). 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 NHS:
  - 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
  - Model selection (MUKLIMO-3 or ENVI-met) depending on the scale and extent of the NBS project
  - Collection of data and modelling

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:

a) deriving relationships of changes in historical UHI to one (or more) indicators of NBS; and/or
b) 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 downscalable. Modelled urban heat island changes due to a specific action by the ULL will not be upscalable.

Basic information on map/model output

Scale of extent	
Satellite based LST	
MODIS	City or district scale
LANDSAT	All scales (city, district, local)
Modelling	
MUKLIMO-3	All scales (city, district, local)
ENVI-met	Local
Approximate spatial resolution of output	
Satellite based LST	
MODIS	1,000m x 1,000m
LANDSAT	30m x 30m
Modelling	
MUKLIMO-3	model defined (30 - 100m grid)
ENVI-met	3m x 3m
Temporal resolution (time points) of output (if relevant)	
Satellite based LST	
MODIS	2 times daily
LANDSAT	Once every 16 days
Modelling	
MUKLIMO-3	Annual averages
ENVI-met	A single day

Data table for input requirements

Data type	Other information (e.g. requirements; thematic classes or features needed)	Spatial resolution (& vertical if important)	Time points, year(s)
LST from satellite data MODIS LANDSAT	NBS indicators Ground temperature	See above vertical resolution not important	See above
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	See above Vertical resolution is necessary (variable from 10 – 50)	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	See above Vertical resolution is necessary (variable from 10 – 50)	Daily meteorological measurements

Note: MODIS and LANDSAT satellite data must not be acquired by the ULLs.

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9.9 List of most common acronyms

As used in: Fact sheets for mapping & modelling ES

Acronym	Meaning
ACTM	Atmospheric chemistry transport model
CIR	Colorinfrared photography (older versions without ortho-rectification – the near-infrared is captured which is essential to calculate any vegetation indices)
CVM	Classified vegetation metabolism
dBA	A-weighted decibel
DEM	Digital elevation model
DOP	Digital orthophotos (recently most common, including orthorectifiction)
DSM	Digital surface model (mostly captured by LiDAR techniques; LiDAR= light detection and ranging)
DTM	Digital terrain model
EC	Elemental carbon
EMEP	European Monitoring and Evaluation Programme
EMEP-WRF	EMEP MSC-W model coupled with the WRF model
MSC-W	Meteorological Synthetizing Centre - west
ENVI-met	Commercial climate simulation software
GEE	Google Earth Engine
LA1018	Noise metric calculated as the arithmetic mean noise level in dB(A) (sound levels weighted for human hearing) which are exceeded for 10% of each hour over the 18-hour period 06:00 - 24:00 hours
Lden	Sound pressure level day evening night
LNight	Sound pressure level night
LST	Land Surface Temperature
MUKLIMO-3	Small-scale atmospheric flow model with thermodynamic extensions
NCF	Non-commutative function
nDSM	Normalised digital surface model
OBIA	Object-based image analysis
PM10	Particulate matter at the size of <10 µm
PM2.5	Particulate matter at the size of <2.5 µm
PMco	Particulate matter at the size between of 2.5 and 10 µm
QUESTOR	Quality Evaluation and Simulation Tool for River Systems
SIA	Secondary inorganic aerosols
SOA	Secondary organic aerosols
SuDS	Sustainable Urban Drainage System
UHI	Urban heat island
VOCs	Volatile organic compounds
WRF	Weather and Research Forecast model

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