REGREEN
NATURE-BASED SOLUTIONS

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

Deliverable **N°2.1.**

WP N°2 Challenges

REPORT ON ASSESSMENT OF DRIVERS AND PRESSURES LEADING TO URBAN CHALLENGES, ACROSS THE ULLS, INCLUDING SPATIAL AND TEMPORAL COMPONENTS

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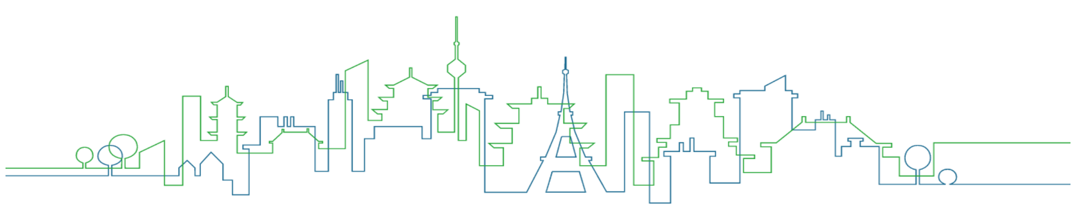

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EXECUTIVE SUMMARY

This document forms part of the context-setting for the REGREEN project, and describes the main drivers and pressures associated with urbanization which are the focus of the Urban Living Labs (ULLs) within the project. The pressures are primarily environmental, but shaped by social and economic factors. The report illustrates how social factors interact with green, blue and grey infrastructure to shape the opportunities for implementing NBS to address these challenges.

Contributors to this report come from WP2 (challenges), WP3 (mapping and modelling) and all six ULLs: Paris, Aarhus, Velika Gorica, Shanghai, Beijing and Ningbo.

Each ULL ranks and describes the main pressures facing them. Air pollution, noise and heat are the top three pressures in Beijing and Velika Gorica. In Aarhus and Paris, the top three are biodiversity loss, water quality and flooding. In the other two Chinese ULLs, Ningbo and Shanghai, the top three issues are air pollution, water quality and flooding. These pressures are explored in more detail, including the health and societal impacts they cause.

Urban sprawl is separately addressed as a pressure, illustrated by a historical analysis of the rate of change in urban extent in all six ULLs since 1985. The expansion of urban area in the Chinese ULLs is substantially greater than any of the European ULLs.

Social and economic factors, which influence vulnerability and exposure to pressures, are also discussed. The literature suggests that age is the main risk factor for negative health impacts from high-temperatures, while deprivation is a risk factor for $PM_{2.5}$ associated health impacts.

The report discusses the important role of spatial and temporal variability in pressures and in the potential of NBS to address these pressures. This highlights the importance of capturing spatial and temporal variation in data representing the pressures, but also that it is critical to have appropriate contextual data, particularly those data relating to people (e.g. sociodemographic and socioeconomic data) in order to provide useful spatially and temporally explicit representations of the challenges that are produced in urban environments.

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PURPOSE OF THE DOCUMENT

The purpose of this document is to explore the way that drivers and pressures associated with urbanization, lead to challenges that affect the wellbeing of city dwellers. We provide contextual information on each of the urban living labs (ULLs), including their prioritisation of the pressures/challenges they face.

This document forms part of the context-setting for the REGREEN project and helps define the drivers and pressures in relation to the wider societal benefits that can be provided by NBS, which we aim to better quantify in this project. While the detail is focused on the ULLs in the REGREEN project, the principles are readily transferable to cities of different sizes and other parts of the world.

Contributors to this report come from WP2 (challenges), WP3 (mapping and modelling) and all six ULLs: Paris, Aarhus, Velika Gorica, Shanghai, Beijing and Ningbo.

SCOPE OF THE DOCUMENT

This document covers the main drivers and pressures relevant to REGREEN (air, noise and water pollution, heat, flooding, lack of accessible greenspace, land use change, urban expansion). It includes a brief assessment of the pressures in all six ULLs, although greater focus is provided on the three European ULLs, and an assessment of social and economic factors associated with increased risk of adverse effects.

STRUCTURE OF THE DOCUMENT

The structure of the report is as follows:

- We first introduce some recent thinking on drivers and pressures in an urban context.
- We then introduce a conceptual framework describing how drivers and pressures interact with other contextual factors, which has a bearing on how to identify opportunities for NBS.
- We provide context around the priority pressures/challenges for each of the REGREEN ULLs, and discuss the factors that influence vulnerability and exposure to pressures, which in turn affects the demand for NBS.
- We discuss less-studied aspects around spatial and temporal variation in drivers, pressures and the benefits that NBS can provide. For an example ULL, we analyse and map the variability in service provided by one type of NBS, with consideration of spatial and temporal factors.
- Finally, we provide a synthesis of the results relating it to the context in the ULL cities.

1 INTRODUCTION

Although the rate of global population growth is now slowing, there is a massive rural to urban migration trend, which seems set to continue to strengthen (Sanyal, 2011). Approximately half of the world population currently live in cities, with this proportion projected to reach 60% by 2030 (Montgomery, 2007). As the existing urban fabric struggles to accommodate this influx, towns and cities expand and/or densify. By-products of these increases in urban population, and the corresponding expansion of urban infrastructure, include increased air, water and noise pollution (e.g. from traffic, domestic waste and industry), increased anthropogenic heat outputs, as well as increased absorption of solar radiation and decreased emission of longwave energy (i.e. Urban Heat Island, UHI, effects - Mirzaei, 2015). Nature Based Solutions (NBS) can help avoid or reduce the impacts of these pressures. One goal of the REGREEN project is to better understand how to enhance the benefits derived from NBS, by planning and managing the NBS themselves or the way people use and perceive them.

For the purposes of this report, we define what is meant for some key concepts:

Nature Based Solutions (NBS): encompass green and blue space in cities, but have many definitions, and different interpretations in the current literature. The EU defines NBS as solutions to societal challenges that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions (EC, 2016; Faivre et al., 2017). Lately, the EU has added to the definition of NBS: nature-based solutions must benefit biodiversity and support the delivery of a range of ecosystem services.

As a working definition for the purposes of this report, NBS are taken to mean all types of green and blue space (and hybrids with existing grey infrastructure), which provide either a direct, or an indirect benefit to city dwellers through the provision of a range of ecosystem services.

Driver: the impetus behind the shift in states/conditions that can manifest as pressures, drivers can be global, regional or local. For example, urbanisation as a process is an underlying direct or indirect driver which leads to specific pressures on city dwellers and on the environment. Climate change, acting at a broader scale, can also be considered a strong driver of a number of the pressures felt in urban areas, the effects of which are exacerbated by the velocity and direction of changes in land cover and the greater number of people living in cities. Climate is not a direct focus of the project, but is mentioned because of its direct and indirect roles in influencing hazards.

Pressure: external or internal factors, resulting from Drivers, that exert a negative impact on the liveability of cities, encompassing effects on people (health and well-being), environment and man-made property/infrastructure. In the context of this project, pressures include:

- High temperatures
- Air, noise & water pollution
- Flooding
- Availability of and access to green and blue space
- Change in urban extent and morphology
- Increasing population, and contextual determinants of risk such as poverty, education & other socio-economic factors

Both pressures and the management interventions implemented to alleviate them, can have direct and indirect effects on the liveability of cities, which encompass the following end-points:

- Human health and well-being
- Biodiversity, integrity and function of urban ecosystems (green and blue space)

Demand: Demand can also be seen as the 'need' to reduce the impacts of pressures, and where NBS may help to provide some or part of a solution.

2 FRAMEWORK DESCRIBING HOW DRIVERS, PRESSURES, GREEN AND BLUE SPACE AND DEMAND COMBINE TO FORM OPPORTUNITY FOR NBS

2.1 Conceptual framework for NBS opportunity

'Ecosystem Service' (ES) is an anthropocentric term. It is increasingly recognised in socio-ecological system frameworks (e.g. Sarukhán et al., 2005; Reyers et al., 2013) that ES only exists when, and where, there is demand for, or use by, a stakeholder (Paetzold et al., 2010; Jones et al. 2016).

The combination of pressure and contextual factors can be conceptualised simply in a framework that combines supply and demand, to identify opportunities for NBS creation (Figure 1). In risk analysis, Risk is the product of Hazard, Exposure and Vulnerability. Here we rename Risk as 'demand' and rename Hazard as 'pressure' but the meaning remains the same.

This diagram represents the urban context as an integrated social-ecological system. It addresses the importance of considering multiple aspects in order to most efficiently plan and design where NBS will provide most benefit. These aspects are the demand (from people – direct and indirect), and the varying potential for the ecological + urban infrastructure components to provide benefit. Both of these will vary depending on contextual factors.

The right hand side of the diagram shows the social side of the system. This illustrates how pressure, exposure and vulnerability combine to form demand for the mitigation of a pressure. Demand can therefore be high due to any combination of high population, a large vulnerable sector of the population, or high levels of pressure, but crucially the spatial context is important and is defined by exposure. So demand is higher where a large or vulnerable population coincide with high levels of pressure. Demand for some services can also be managed by providing additional information or altering infrastructure, accessibility etc, - discussed in more detail in Jones et al. (2016).

The left hand side of the diagram shows the ecological and bio-physical side of the system, with green infrastructure, i.e. green and blue space, together with grey infrastructure (Wang et al. 2018). This green and blue space has potential to supply the NBS benefits. Following the logic that actual supply of ecosystem service benefits does not exist without taking into account the people who benefit, we use the term "potential supply" in this part of the diagram (Jones et al., 2016). Here, spatial context is also important, since the amount of service that particular NBS can potentially provide is not constant, and can vary depending on the level of the pressure, as well as other biophysical factors which have an influence on the type or attributes of the green and blue space that can occur at a given location. Managing the extent and attributes of blue and green space (including biodiversity), as well as its location can all help increase the amount of potential service provided.

In this framework, defining 'Opportunity' must take into account both potential supply and demand, and this relationship is complex. The simplest approach is to identify a mismatch between potential supply and demand. For example, where demand is high and existing levels of appropriate green and blue space are low, there is clear opportunity to provide additional NBS. However, there are other aspects which should be considered to achieve the maximum benefit from NBS. These include any constraints on the type of NBS that is possible to introduce to an area with low existing supply, and the knowledge that the efficiency of NBS also varies according to pressure and location. Opportunity therefore takes into account the mismatch in demand and potential supply and, combined with feasibility, will determine the suitability and effectiveness of locations for the NBS.

Ideally, in an urban planning setting, decision-makers can identify the areas where NBS will provide the greatest potential benefit, at the same time as identifying areas of maximum demand, and taking account of any constraints. This allows decisions to be made between two areas of similar demand, but where the potential amount of service provided may be different due to other factors. It is also worth noting that the best location to provide one kind of ecosystem service benefit, or to mitigate one particular pressure, may not be the same for a different pressure or NBS. A holistic planning approach will therefore take into account the multiple benefits provided by NBS, balanced across multiple needs and pressures.

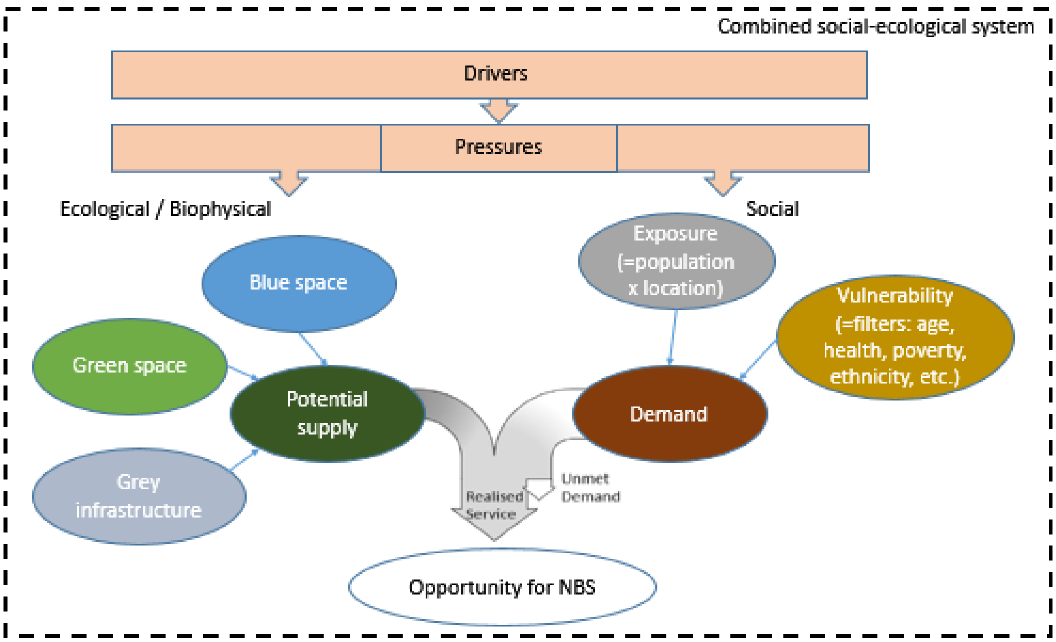

Figure 1: Conceptual approach to deriving opportunity for NBS. This incorporates potential supply of corresponding ES, and the demand for mitigating the effects of a particular pressure. Opportunity can arise from a mismatch between supply and demand, but also can be used to target where potential supply will be most efficient at delivering a service.

2.2 The role of biodiversity

Biodiversity plays multiple roles in an ecosystem services context in urban settings (see e.g. Mace et al., 2012). It is at the same time part of the attributes of green and blue space which helps to deliver the benefit. It can also be an end-point which is affected by pressures. In addition, it is a basic attribute which helps confer resilience of green and blue space to withstand external pressures such as those resulting from climate change.

Biodiversity can help deliver services and benefits to people. For example, natural sounds such as birdsong can promote psychological restoration and reduce stress levels (Payne, 2013; Ratcliffe et al., 2016), and diversity of urban planted meadows increases people's aesthetic appreciation of greenspace, with associated benefits (Southon et al., 2017; 2018). In particular, green areas are essential in cities, as they give humans valuable contact with biodiversity and natural processes that are important for their educational, emotional, and recreational benefits (Banzhaf et al., 2018; De La Barrera et al., 2016). Enhanced biodiversity can contribute to the development of a city, as it can support the creation of a multifunctional green network (Liverpool City Council, 2010). In this way, biodiversity is a highly important quality attribute of green and blue space in governing the ability of these areas to provide potential benefits to the city's inhabitants, as well as being important in an ecological context.

Connectivity between green and blue space is also important, for ecological systems (Matthews et al. 2014), but also for people, and in some cases for ecosystem service provision, where linear ecological features can provide enhanced service provision depending on where they lie in the landscape (Thomas et al. 2020). Urban ecological networks comprise various dimensions from 'stepping stones' to 'green veins' (Ignatieva et al., 2011), displaying considerable diversity in terms of scale, from the neighbourhood scale (with its depictions of green roofs, Williams et al., 2014), through local and regional storm water management (Ahern, 2007), to large national ecological networks (Weber and Allen, 2010). When addressing biodiversity in landscape and urban planning, the main opportunities lie around habitat creation or expansion and improved management or restoration (Poll et al. 2016).

3 OVERVIEW OF PRESSURES IN ULLS

Representatives from each of the six ULLs (Aarhus, Denmark; Beijing, China; Ningbo, China; Paris region, France; Shanghai, China; Velika Gorica, Croatia) listed the current environmental challenges within their cities. They then prioritised these and provided background information explaining why these challenges are so important. Table 1, below, details the responses from the representatives of the ULLs.

Table 1: ULL stakeholders' prioritisation of challenges. Challenges are ranked in order, with 1 being highest priority. Some challenges are equal ranked.

Environmental and societal challenges/pressures	Aarhus	Beijing	Ningbo	Paris Region	Shanghai	Velika Gorica
Air pollution	6	1	2	3	2	1
Noise	5	2	4	4	7	1
Heat	7	2	5	2	8	2
Water flow/flooding	2	3	1	2	3	3
Water quality	2	5	1	2	1	5
Carbon sequestration	4	3	3	3	6	5
Biodiversity	1	4	6	1	5	5
Lack of accessible green space	3	6	7	3	4	5
Low energy efficiency of buildings	-	-	-	-	-	4
Fossil fuel usage in district heating	-	-	-	-	-	4
Parking space	-	-	-	-	4	-
Other : Stop urban sprawl	-	-	-	3	-	-
Other : Health	-	-	-	2	-	-
Other: Afforestation	1	-	-	-	-	-

3.1 Aarhus

In Aarhus, the blue and green agenda is considered very important, which is why biodiversity and afforestation are ranked as number one and water flow/flooding, water quality as number two. Rapid city growth is putting a pressure on nature, biodiversity, water quality and recreational areas in and around Aarhus. At the same time the climatic changes necessitate an adaptation of the city to mitigate future risk of flooding.

The city government has set an ambitious goal of reaching 8000 ha of forest on both public and private land, before 2030. The city government has also set a goal of reaching 4000 ha of nature areas, before 2030. The purpose is to increase natural areas, increase the storage of carbon in the ground and at the same time create attractive green, recreation areas for citizens. Carbon sequestration, coupled with creation of nature, forests and climate adaption projects, are part of a new upcoming goal, and will probably be raised to a higher level in the coming years. Furthermore, there are pressures on the water quality – both concerning drinking water and the surface water environment. Clean drinking water is under pressure from the use of pesticides in agriculture and in private gardening. This issue has been increasingly visible during the last couple of years and action plans for improving the quality of the drinking water have been implemented in specific locations in Aarhus. The municipality and the municipal water utility company, Aarhus Water, are continuously working together on improving the quality of the surface water in lakes, watercourses and in the sea, by improving the wastewater and rainwater management. At the same time, there is a need for many different stakeholders - including the municipality, Aarhus Water and private developers - to cooperate to adapt the city and protect it from flooding as a consequence of climatic changes.

Lack of accessible green spaces are also of high concern because the city is growing rapidly and the issue of city densification has been of high priority in the last couple of years. It means that more and more open space in the city is being built upon and paved, and that opportunities for citizens to access green spaces are under pressure.

3.2 Beijing

Smog has been the number one air pollution problem in Beijing in the last decade (Gao et al., 2015). In recent years, through rigorous enforcement of regulations to cut emissions, the smog problem has been alleviated significantly (Zhang et al., 2020). Nevertheless, ozone pollution has emerged as a new problem. The rising number of cars is an important source of nitrous oxides, which are the precursor of ozone (Xiang et al., 2020). Other than air pollution, the urban heat island (UHI) intensity in Beijing has been increasing over recent decades (Peng et al., 2020). The UHI magnifies the warm and humid summer climate in Beijing and poses a health risk, especially to vulnerable groups such as the elderly. The problem will get more significant because it is predicted that Beijing will become warmer due to climate change (He et al., 2020). Climate change will also intensify another problem; urban flooding. The rapid urbanization in Beijing has increased impervious surface coverage in the urban part of Beijing. One consequence is that urban flooding events occur more frequently. In some events, significant damage to property and loss of lives have occurred (Su et al., 2015). The urban runoff also carries pollutants into the rivers and lakes. Beijing has taken a “sponge city” approach that integrates many engineering and non-engineering measures to control urban flooding (Zhang et al., 2018). As a city that has more than five million privately owned cars and various other vehicles that serve the daily needs of twenty million people, road noise is a severe issue in many parts of Beijing. The annual average noise level in the built area was 53.7 dB (Beijing Municipal Bureau of Ecology and Environment, 2020), higher than the 50 dB limit recommend by the World Health Organization (World

Health Organization, 2020). Other than challenges from environmental problems, Beijing is also facing the challenge of maintaining biodiversity. For example, Beijing is located on the East Asian-Australasian Flyway for migrating birds. Each Spring and Fall, large flocks of migrating birds choose Beijing as an important stop-over site. Studies have shown that many bird species have disappeared from Beijing as the city has continued to grow (Chouteau et al., 2012). Therefore, an important task faced by Beijing residents is to share the space with wildlife.

3.3 Ningbo

Meishan Island (Urban Living Lab) is located in the east of Ningbo, China, which is the part of Ningbo-Zhoushan Port. It aims to become a distinctive bonded port, a recreational and liveable ecological island and a vibrant harbour city. With the advent of the era of economic globalization, ports have become a window and platform for information and goods exchange between countries around the world (An, 2020). Heavy urbanization across the east coast of China (following the conventional engineering-driven approach of constructing ports, dams, bridges, roads and buildings) has brought about major water issues for Ningbo, relating to both quality and quantity, various port activities are the likely cause for poor water quality inside the port area (Fang, 2011; Jahan and Strezov, 2017). In order to develop the tourism economy of port cities, artificial beaches and lakes have been built in the Meishan Island. However, the occurrence of harmful algal blooms in the artificial lagoon has been seen as an increasingly critical challenge, as it poses the greatest threat to water quality and ecosystem services, with negative effects on public sport and recreation on the waterbody (O'Neill et al., 2015; Padmakumar et al., 2012; Tiling and Proffitt, 2017). The concrete dams have limited water flow and nutrient transportation beyond the artificial lagoon, creating highly favourable conditions in which harmful algal blooms can occur, most often during the summer season (Li et al., 2011). Excessive artificial intervention on the near coast will reduce the biodiversity of the near coast, increase engineering noise, and reduce the green space in the island (Ahmed and Yeom, 2014; An, 2020; Chatzinikolaou et al., 2018). In addition, the Meishan Island still suffered the air pollution, which is mainly caused by dust pollution, including material loading and unloading dust, road dust, and wind erosion dust from stockpile, bare soil (Liu et al., 2013). Meishan Island needs to pay attention to the solutions that contribute to the release of carbon and increasing its sequestration, without compromising currently ordered vernacular ecosystems, are required, especially for small territories. Increasing the resilience of small islands to these losses, including spatial management to prevent and adapt to climate change while preserving biodiversity (Vergilio et al., 2016). More importantly, future predictions show that nutrient concentrations could increase, as urban runoff during the monsoon storm season can contribute substantially to non-point sources of pollutants and the area of impervious surface across Ningbo is increasing rapidly, through heavy urbanization, with the development of conventional grey infrastructure. The urban heat island effects in Ningbo are not obvious in the city centre, but in the industrial land, with high energy consumption. The old urban area has obvious heat island effect compared with the new urban area. As it is a coastal city, extreme heat is not obvious. At present, a certain amount of noise pollution exists in Ningbo, mainly from industrial noise, such as heavy vehicle transportation. However, there is a certain distance between the areas producing the noise and residential areas, and roadside trees or other measures have been taken to block noise. There are many urban green spaces in the main urban areas, but only some low trees or shrubs in the industrial areas, which lack green spaces. With the heat emitted by industry and less green space, especially in summer, the temperature of Ningbo industrial zone will be significantly higher than other functional areas.

3.4 Paris Region

Concentrations of several air pollutants are problematic in the Paris region, particularly fine particles (PM), nitrogen dioxide (NOx) and ozone (O_3). All of these pollutants can cause serious health effects, thus air quality constitutes a public health emergency. The health of Paris Region inhabitants is mainly impacted by chronic air pollution. This situation is largely attributable to the transport sector. Road traffic is responsible for more than 50% of nitrogen oxide emissions and 25% of fine particle emissions. Residential and commercial sectors, economic activities and agriculture also release air pollutants. Despite recent reductions in atmospheric concentrations of all but ozone, the World Health Organisation (WHO) recommendations are still largely exceeded. For instance, 4% of Paris Region residents are potentially exposed to excessive (i.e. greater than WHO recommendations) NO_2 levels, 75% of the population is exposed to excessive PM_{10} levels, more than 90% of the population is exposed to excessive $PM_{2.5}$ levels, and in 2019, ozone levels exceeded the WHO threshold value for the protection of human health, particularly in urban areas.

Within the densely populated zone of Ile-de-France, nearly 90% of the more than 9 million, inhabitants are exposed to noise levels that exceed those recommended by the World Health Organisation to avoid the health effects of noise. Road traffic is the main cause, with 10.8% of inhabitants exposed to excessive road traffic noise. Exposure to noise levels exceeding guidelines for aircraft and rail traffic is down (respectively 3.7% and 0.5%), but these two types of nuisance have proportionally higher health risks due to their event-related nature (succession of noise peaks).

According to Météo-France, climate change will result in an increase in overall global temperatures, an effect which will be particularly noticeable during the summer months especially in built up areas affected by the phenomenon of Urban Heat Islands (green space per inhabitant is very scarce within Paris and around the capital). The “Institut Paris Région” has assessed urban heat island effects at the scale of blocks, termed “islets”. In the Paris Region, high and medium urban heat island effects characterize 11% and 3% of islets, respectively. Approximately one inhabitant in three (c. 3.7 million) inhabitants - including 800,000 old people (7% of the population) – live in an islet characterized by a high or medium urban heat island effects.

In Paris Region, one of the most important risk factors is flooding. There have been significant floods in Paris Region in the last few years, which are caused by extreme weather conditions and waterproofing of soils. In the Paris region, 23% of the territory is in urban usage, with 16% impermeable surfaces – this being concentrated around Paris city. Moreover, 840 hectares of rural areas are consumed each year by urbanisation. Areas around large rivers (Seine, Oise, Marne, Yonne) and areas exposed to runoff are most sensitive to flooding. Val-de-Marne is the most vulnerable department of Paris Region, followed by Paris and Hauts-de-Seine.

Agricultural, industrial, and urban activities are leading sources of water pollution, and have several negative impacts on biodiversity, hydromorphology and functioning of river ecosystems. The majority of streams (81%) in the Paris Region have poor ecological status and 64% have poor chemical status. Only 15% of the groundwater bodies have good chemical status, whereas 92% of them have good quantitative status. The whole of Paris Region is classified as a vulnerable zone under the nitrates Directive of December 1991 (91/676/EEC). Nitrate concentrations in Paris Region rivers has increased by 25% between 1992 and 2020. In 2020, all the rivers were found to be contaminated with pesticides despite 67 % of cities in Île-de-France having completely stopped using pesticides since 2017. Most likely because pesticide use for agriculture has increased by 22% between 2008 and 2018.

For the Paris region, the main challenge is preserving existing wetlands and related flood-prone areas (wetland meadows, riparian forests) of all sizes (especially ponds and marshy forests), as well as placing limits on overly intensive management of these areas. Wetlands represent around 2.8% of the region's surface area (compared to 5% nationally). Over 50% of wetland areas have been lost in the last century, and a significant portion of those that have survived are around artificial bodies of water.

For Paris region, the amount of surface area covered by forest in Paris region is 23%, which in relative terms is not far off the national average of 26%. The main challenge is to prioritise management methods that respect biodiversity and climate change. The region emits 3% of the nation's agricultural greenhouse gases from only 1.8% of the country's total farmland; however, it is possible to reinforce carbon storage in soil via agro-ecological methods.

Biodiversity loss in Paris Region rarely causes extinction of species, but the decline of local population species. Île-de-France has lost one-fifth of birds' populations in 13 years (Muratet, 2016) and between 25% and 40 % species are threatened (Zucca et al., 2019). All of these changes have significant implications for the functioning of ecosystems, their ability to provide goods and services (on which human well-being depends), and their ability to deal with changing circumstances, especially climate. For Paris region, the main challenge is preserving biodiversity to answer the environmental challenges (air and water quality, flood risk, carbon capture and storage).

Green space per inhabitant is very scarce within Paris and around the capital. At the regional scale 51% of residents live in an area including less than 10 m² of green space per individual (minimum recommended by WHO), 31 % citizens do not have access to a "nearby green space"[3] and 8 % do not have access to a "weekend green space"[4] located within 30 minutes by bike, walk, or by public transport. Since 2000, despite a political objective of creating new green spaces, the lack of accessible green space has increased, especially in urban areas. The causes of this are population growth, residential intensification, and urban sprawl. Since 2017, Paris Region in has launched a program to create new parks, with the goal of allowing every citizen having green spaces nearby less than 15 minutes' walk away.

Heat waves, air pollution, Urban Heat Island effect, flooding, lack of accessible green space, biodiversity loss, and climate change have a negative impact on health and the quality of life in urban areas. The health effects of these disruptions include increased respiratory and cardiovascular disease, injuries and premature deaths related to extreme weather events, and other infectious diseases, and threats to mental health. In Paris Region, significant relationships between air pollution and health have been proven (ORS, 2013, 2016).

3.5 Shanghai

Compared with the northern cities of China, Shanghai, located at the mouth of the Yangtze River, should naturally be relatively water-rich. However, due to the large population and the pollution of industrial cities along the middle and lower reaches of the Yangtze River, Shanghai has water shortage issues, as well as water quality issues. For these reasons, water-related challenges are the most critical environmental issues for the people and government of Shanghai. The attention of China's big cities to air quality has long been very important, which is reflected in the adoption of $PM_{2.5}$ as one of the key indices of weather forecasts and reports. As typhoons and rainstorms often occur during the

[3] Green spaces with a minimum size of 1000 m² or linear parks of at least 5 km.

[4] Green spaces or wood spaces with a minimum size of 30 hectares

summer months in Shanghai, flooding is a substantial threat in Shanghai. It is a seasonal environmental problem, so it ranks below the water and air-related challenges. In such a large city, where space is at a premium, an increasing population means that per capita allocations of space are often insufficient. In addition, the demand for ecological space (non-built-up areas) and the increase of the number of private cars make the incongruity more and more obvious. In the traditional consciousness, the function of a metropolis is different from that of countryside and wild space, therefore, few people might pay attention to urban biodiversity. However, the public awareness of environmental protection has increased in recent years. In particular, due to the impact of the covid-19 epidemic, people pay more attention to urban biodiversity than ever before. For instance, scientists informed the public that COVID-19 is a zoonosis (a human disease of animal origin), which is likely to have its ancestral origins in a bat species, but it probably reached humans through an intermediary species, for example pangolins. This involves numerous wild animals, making people feel that direct contact with wild animals will lead to an outbreak of unknown epidemic, especially in urban areas. This not only enhances people's understanding of biodiversity, but also promotes the improvement of wildlife protection laws. Carbon sequestration is not considered by most people to be a function of the urban areas. However, because Shanghai is located in an estuary, an area representing a huge carbon sink, the concept of carbon sequestration in Shanghai is paid more attention by all parties. Due to the legislation and management of urban noise in Shanghai, the public does not currently view it as a priority issue. According to the national standard of China, the noise in residential areas should not exceed 50 dB during the day, and should be lower than 45 dB at night. The standard attainment rate is 97.2% during the day and 65.7% at night. The heat is regarded as a typical climatic characteristic of Shanghai, so people hope to get a more pleasant environment through other improvements. (More information, see: Annual report on resources and environment of Shanghai 2020 https://www.pishu.com.cn/skwx_ps/bookdetail?SiteID=14&ID=11550381)

3.6 Velika Gorica

Air quality in Velika Gorica is not satisfactory. There were multiple instances of registered air pollution beyond legislative limits, for particles $PM_{2.5}$ and PM_{10}, and for NOx. Therefore, the city administration had to bring the Action plan for improvement of air quality with respect to $PM_{2.5}$ suspended particles, for the area of the City of Velika Gorica (further: Action plan). During the winter 2017/2018, indicative air quality measurements were made as a basis for passing the Program for protection of air, ozone layer, climate change mitigation and adaptation to climate change for the area of the City of Velika Gorica for the period from 2019 to 2022 (further: Program). During the four indicative measurements, which were made at four different locations within the duration of one week each, PM_{10} and NOx values were found to be higher than the legislative limits. The problem of air quality in Velika Gorica mostly derives from: road traffic – cars, trucks, busses, especially diesel engines; air traffic – the vicinity of Zagreb Airport Dr. Franjo Tudjman; railway traffic; combustion of biomass – in individual houses for heating and domestic hot water production, especially during winter time; combustion of heating oil – in district heating boilers; cultivation of agricultural land – around the city; city of Zagreb waste disposal site, Prudinec-Jakuševec (this is a particular problem in the village of Mičevec). Measures foreseen in the Program and Action plan for the mitigation of air pollution problems are not currently implemented to a satisfactory extent, due to lack of money and dedicated staff in the city's administration, which will hopefully change during the following years, through the implementation of the European Green Deal. Noise is the second most relevant problem, due to the vicinity of Zagreb Airport Dr. Franjo Tudjman, intersection of main roads and railways (which gives Velika Gorica the favourable position for business) and the traffic inside the city's urban area. The city's administration has thus ordered the noise pollution maps to be made for the railway and road traffic (https://geoportal.zagreb.hr/Karta), and the Airport has its legal obligations to measure the noise pollution from the air traffic. Noise pollution mitigation activities are mostly limited to building of standard noise barriers around the roads where citizens ask for its implementation. Urban heat island (UHI) effect is one of the city's urban area challenges which has not been met properly during the last few years, when many new apartment buildings were built with concrete or asphalt paved parking lots around them and very little, if not none at all, greenery at the building plots. This will pose a problem during in the coming years when occupants start living in these houses, because they will have high energy demand for cooling during the summer period. The city will have to change this, using better building permits policy and awareness-raising and education methods for the public on the problem of heat island effect and importance of green spaces for shade and biodiversity in the urban area. Luckily, the rural areas around the city still hold the high biodiversity potential, which could penetrate the urban fabric if properly organized green corridors and oases were made.

4 DESCRIPTION OF PRESSURES AND THEIR IMPACTS

In this section, we describe the pressures in more detail, and some of the impacts they have on liveability of cities.

4.1 Air pollution - $PM_{2.5}$

Air pollution is a major cause of mortality worldwide, with fine particulate matter ($PM_{2.5}$) responsible for the greatest health impacts. High concentrations of $PM_{2.5}$ air pollution are closely associated with urban areas (Tsapakis et al., 2002; Park et al., 2002; Pinto et al., 2004). In China, dust, secondary sulphates and nitrates, coal, diesel and petroleum combustion are all substantial contributors to $PM_{2.5}$ air pollution (Zheng et al., 2005). Elevated $PM_{2.5}$ concentrations are closely associated with a variety of negative health impacts, including premature death, lung cancer, pulmonary inflammation, altered cardiac function, and acute stroke mortality (Hong et al., 2002; Pope et al., 2002; Pope et al., 2004).

4.2 Heat

Against a background of global temperature increases, many of the manmade materials that comprise the urban fabric (i.e. buildings, roads, pavements, etc.) possess thermal properties that lead to the exacerbation of heat extremes in already hot summer conditions. Urban areas contain a number of sources of additional heat energy, e.g. domestic heating, air conditioning and refrigeration, internal combustion engines, industrial manufacturing, cooking, electronic equipment etc. These factors, and others, contribute to produce a phenomenon known as Urban Heat Island (UHI) effect, where urban areas can experience significantly higher temperature extremes than surrounding rural areas. The UHI effect can cause severe heat extremes in built-up areas. For instance, a study in Athens found a difference in air temperature of up to 13 °C between built up areas and greener areas (Zoulia et al., 2009). Elevated temperatures can place significant stress on the human body, with extremes leading to heat syncope, cardiovascular stress, thermal exhaustion or heat stroke (Kleerekoper et al., 2012). The severity of these conditions range from discomfort, impairment of physical and cognitive functions, to increases in morbidity and mortality rates. High temperatures in urban areas can also lead to increased ground-level ozone, which can have an antagonistic effect on cardio-respiratory conditions (WHO, 2004).

4.3 Lack of accessible public open space

Physical inactivity is associated with a range of health issues, including type II diabetes, heart disease, back and joint issues. Lack of physical activity has been implicated in c. 1.9 million deaths per year, globally (WHO, 2004), and accounts for 3.7% and 15% of annual healthcare expenditure in Canada and China, respectively (Janssen, 2012; Zhang & Chaaban, 2013). It cost (INT$) 53.8 billion worldwide in 2013, with the majority of this being paid by the public sector (Ding, et al., 2016). This is often seen as a product of increasingly sedentary lifestyles, coupled with a lack of free time and suitable public spaces in which to exercise or simply spend leisure time. Increased incidence of psychosis and clinical depression, and decreased life satisfaction have all been connected to high levels of urbanisation, high population density and low levels of local-area urban green space (Sundquist et al., 2004; Chen et al., 2015; Cox et al., 2018; Houlden et al., 2018). As well as proximity to public open space, it should be both accessible to the public, and minimise aspects which may lead to inequality of access.

4.4 Noise

Noise pollution is pervasive, particularly in urban environments where sources of noise are numerous (e.g. traffic, overhead aircraft, construction works, etc.). Exposure to noise pollution can result in reduction in sleep quality and quantity, elevated prevalence of stress and mental health-related conditions, and increased risk of cardio-vascular disease (Hammer et al., 2014; Munzel et al. 2014; Munzel et al. 2016; Hammer et al., 2018). The World Health Organisation (WHO, 2011) estimated that a minimum of one million healthy years of life lost (YLL) annually because of traffic noise, in the western part of Europe alone.

4.5 Flooding & Water quality

Widespread impermeable surfaces and management of water-courses influence surface run-off and modify flow regimes, often leading to water quality issues and elevated flood risks. Climate change is already increasing the risk of flooding and water quality issues in many cities. Increases in traffic, industrial activity and residential dwellings in turn come with increased outputs of potentially harmful by-products. For instance, in urbanised areas, road networks are a major source of particulate air pollutants and petro-chemicals, which not only end up in watercourses via surface runoff but also intensify storm rainfall rates while they are in the air (Fan et al., 2015). The hydrological properties (e.g. permeability, conductivity, etc.) of the manmade materials used to construct the urban fabric also cause problems with water flow. These problems can manifest in the form of highly destructive flooding. The flooding of urban areas poses a substantial challenge to human safety and to the economy (Miller & Hutchins, 2017). The magnitude of this challenge is exemplified by the estimated costs of the 2015 flooding in the UK; exceeding £5bn (KPGM, 2015). In addition to the monetary costs, flooding can also have a negative impact on mental health (Fernandez et al., 2015).

4.6 Urban expansion, and change in morphology

Urban expansion and change in morphology (including densification) are key elements of the aforementioned trend of urbanisation. These changes can be traced back for each ULL in REGREEN, either by historic documents or time series analysis by means of remote sensing data (e.g. GAUD and GAIA global data sets on urbanisation processes). Metrics such as the total population within a given urban area, the differentiated allocation of population densities and the respective variations in the areas of built-up surfaces can be used to express the stages of this process to visualise over time. The process of urbanisation replaces natural landscapes and their ecosystems by human-induced developments and thus leads to a variety of pressures. It may, for instance, lead to the decrease or even vanishing of much needed ecosystem services such as carbon sequestration, air pollution removal, microclimate regulation and water management, which are essential in urban landscapes (Wei et al., 2016).

Economic and societal change are the main drivers leading to pressures around urban expansion, and dynamics within the existing urban area, such as changing morphology and shape of the urban structure. Urban sprawl, or changes in urban morphology, can exacerbate other pressures. For example, by either opening up spaces, or enclosing them with buildings and public infrastructure, pressures such as the urban heat island effect and reduced air circulation that influence the urban microclimate are triggered (Guo et al., 2016; Wei et al., 2016; Privitera et al., 2018). Taking those effects into account when planning new construction sites and creating open spaces in cities can reduce pressures at neighbourhood or urban scale and thus contribute towards a more sustainable urban development.

4.6.1 Assessment of historical urban change in the ULLs

Urban land use and land cover changes are the drivers that are connected with population growth, their physical expression may lead to adverse processes and pressures on the environment. To gain an understanding of the historical urbanisation developments of all six Urban Living Labs in REGREEN, we first considered the urban land cover products GAIA (global artificial impervious area) (Gong et al. 2020) and GAUD (global annual urban dynamics (Liu et al. 2020). Both approaches are founded on available global research (i.e. the Global Human Settlement Layer, the Global Urban Footprint, the Global Urban Land) which they pull together in a distinct set of data. To detect the urbanisation extent, annual time series are calculated that have the year 1985 as baseline and continue to monitor the urban dynamics until 2018. All annual changes in the urban extent are mapped at 30 m ground resolution, thus relating to the Landsat satellite sensor system. The consistent database is generated on the platform Google Earth Engine (GEE).

Figures 2-7 illustrate the dynamic urban expansion of the six ULLs in their various expressions. All information is aggregated to a spatial resolution of 100 m to ease reading. For the European ULLs, it is striking that there is only some urban expansion in Aarhus (Fig. 2), mainly in the western and northern part. This is down to a political choice of limiting urban sprawl and accommodate the growing population through densification. A radial urban dynamic following the lines of transport infrastructure is monitored for Paris Region (Fig. 3) that reaches far into the surrounding rural area of the region. For Velika Gorica (Fig. 4), the urban land cover expands the urban core area, further extends towards the Zagreb airport in the north, and along the main transport lines.

The monitoring result for the Chinese ULLs shows quite a different picture, which encompasses a much more intensive dimension in terms of velocity of change and coverage of land take: Beijing (Fig. 5) expands intensively from the core area (baseline 1985). Due to its geo-topography with mountainous ranges from west to north and northeast, further land cover expansion shows a dispersal pattern severely occupying the plains towards the southwest and southern region. The utmost urbanisation process is exhibited by Shanghai (Fig. 6), with highest density development patterns now reaching into the distant Chongming Island. Since it is a planned new city expanding from what was previously a small fishing town, Ningbo (Fig. 7) has considerably extended its urbanised area with a networking character, changing the urban land cover towards a connection with the neighbouring cities.

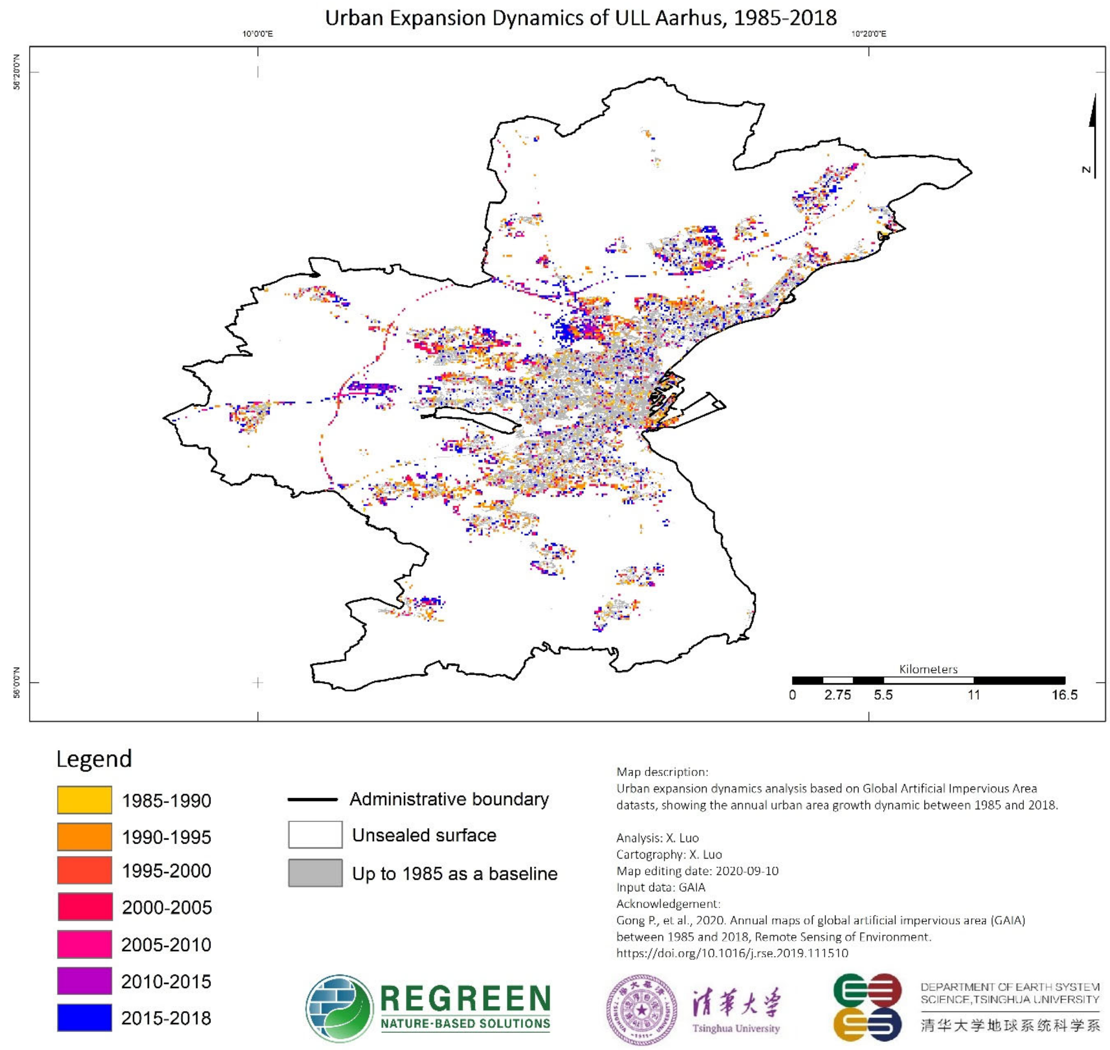

Figure 2: Dynamic urban land cover expansion of the ULL Aarhus between 1985 and 2018.

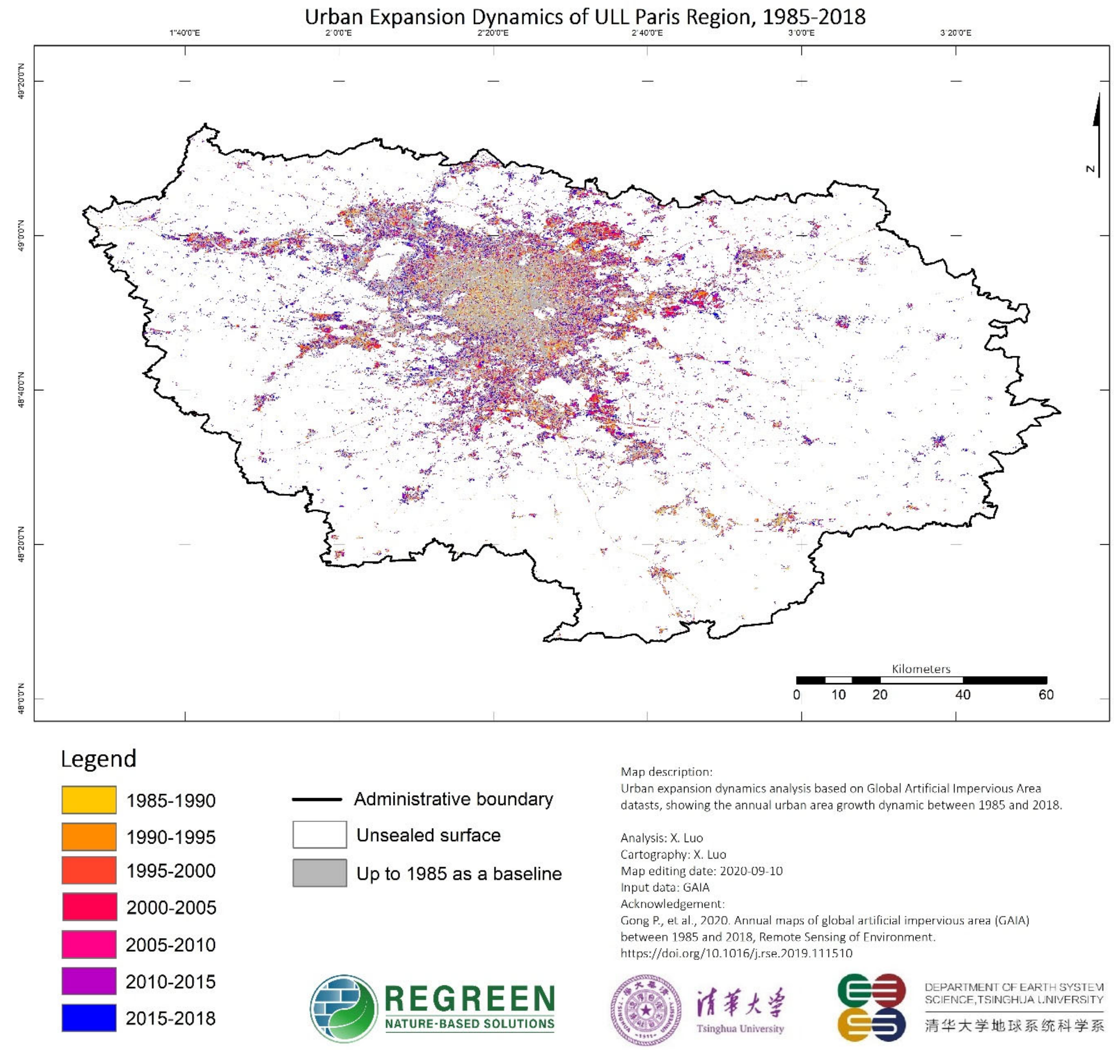

Figure 3: Dynamic urban land cover expansion of the ULL Paris Region between 1985 and 2018.

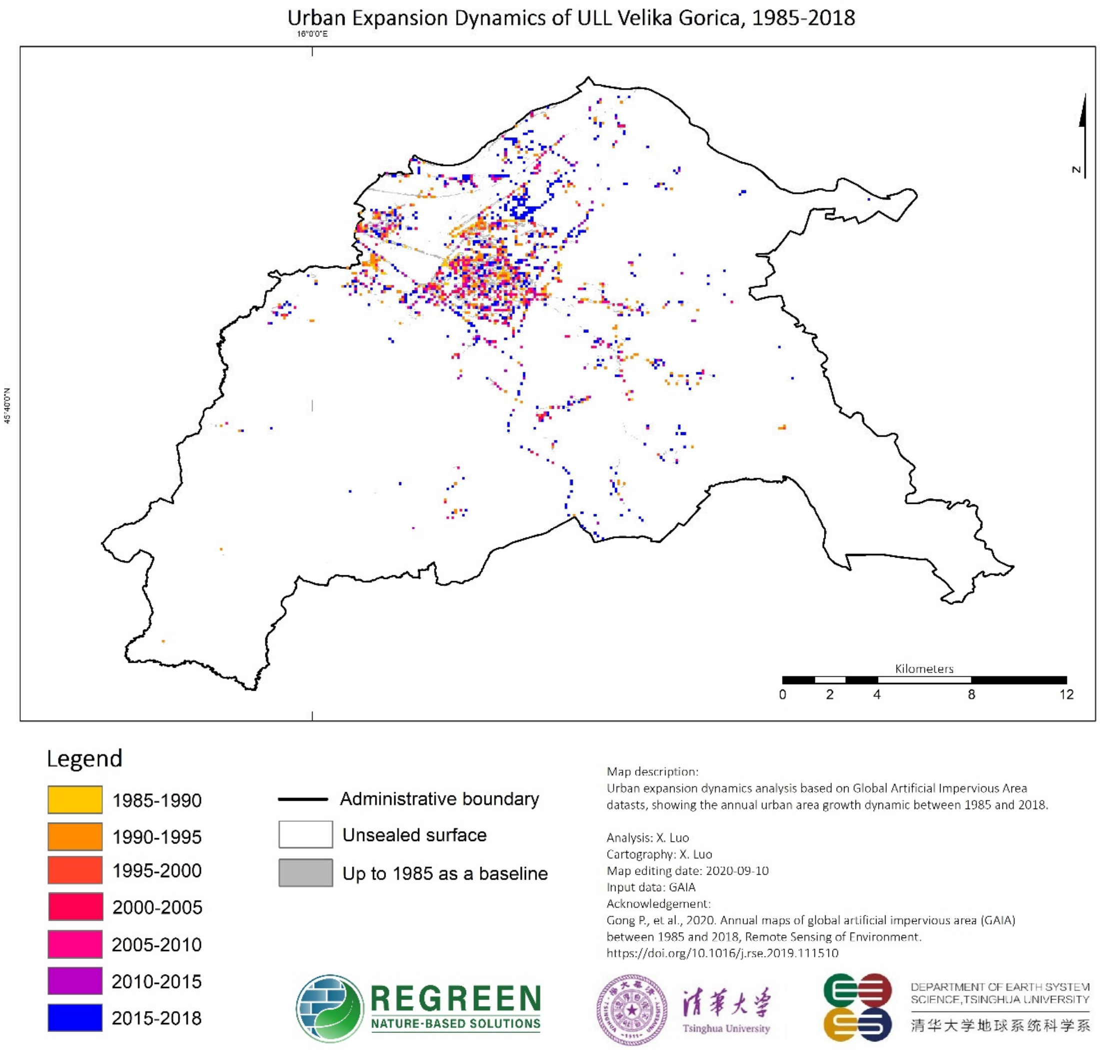

Figure 4: Dynamic urban land cover expansion of the ULL Velika Gorica between 1985 and 2018.

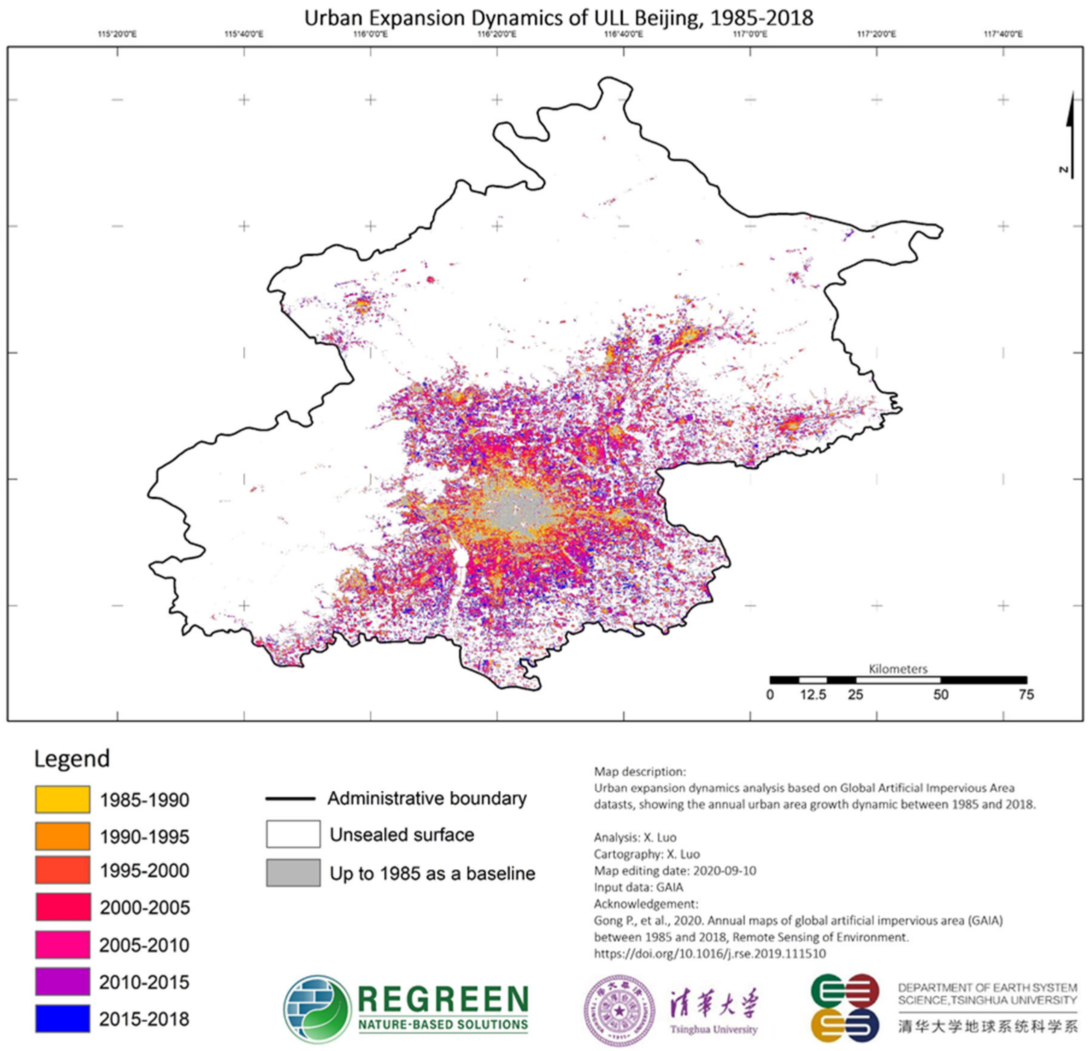

Figure 5: Dynamic urban land cover expansion of the ULL Beijing between 1985 and 2018.

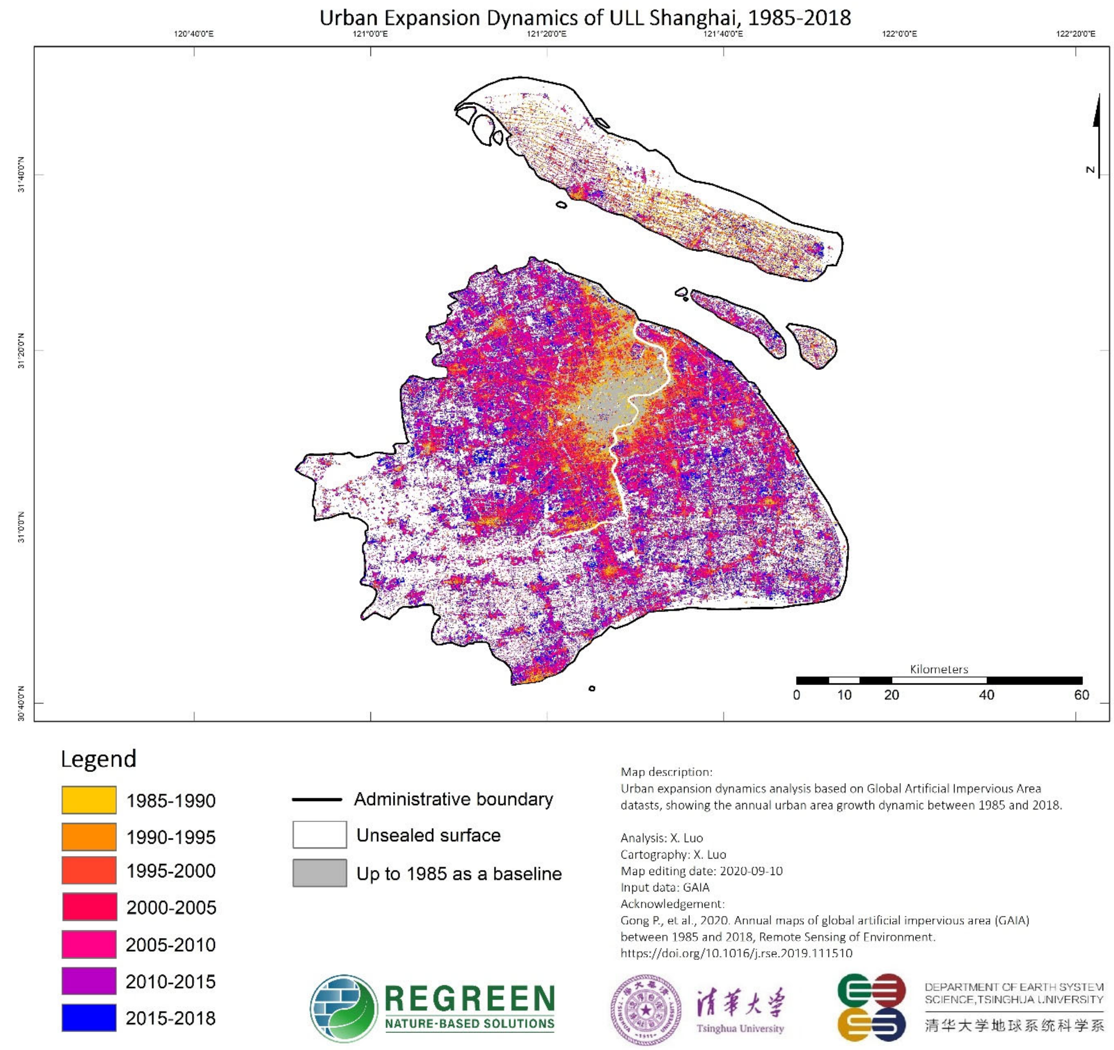

Figure 6: Dynamic urban land cover expansion of the ULL Shanghai between 1985 and 2018.

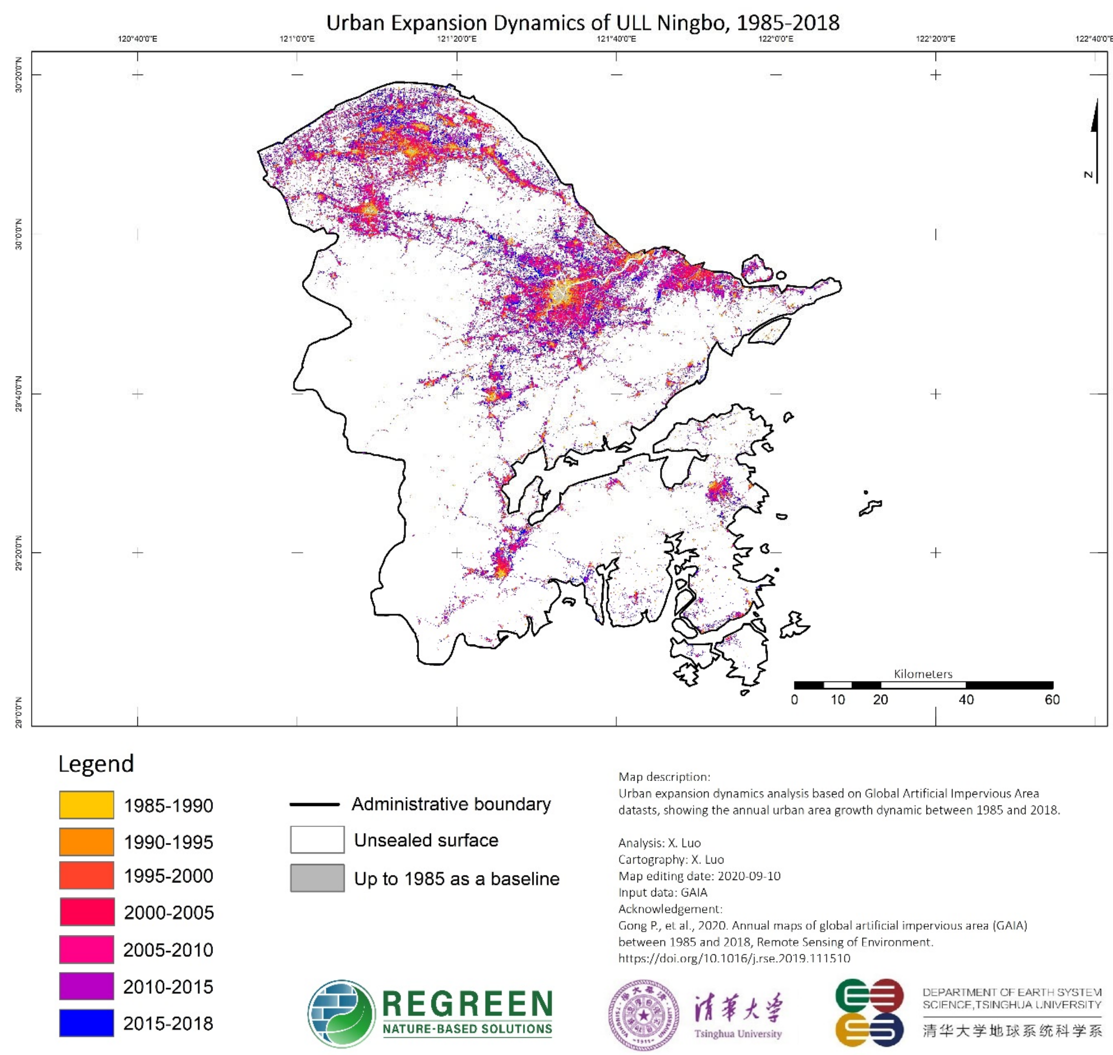

Figure 7: *Dynamic urban land cover expansion of the ULL Ningbo between 1985 and 2018.*

5 BETTER UNDERSTANDING THE ROLE OF VULNERABILITY AND EXPOSURE IN SHAPING DEMAND FOR NBS

5.1 The role of spatial context in social vulnerability and exposure

The pressures detailed in section 0 are framed as challenges to the health or well-being of people, or the liveability of the city. The severity of the impact of the pressures is a function of the numbers exposed or affected and their relative vulnerability and capacity to adapt to or avoid harm. For instance, high $PM_{2.5}$ concentrations at a location with low population density will have a lower impact than equally high concentrations at a location where there is high population density, by virtue of the fact that more people are exposed to it. In a similar vein, different sub-groups of the population may have higher or lower vulnerability to certain pressures. For instance, people on lower incomes are often at higher risk of exposure and lack the means to respond, or adapt, to a number of these urbanisation-related pressures (Pearce, 2013). A recent study in the city of Birmingham (UK), investigating social deprivation in relation to Urban Heat Island effects, showed that areas with higher levels of deprivation were situated in the warmest parts of the city (Macintyre et al., 2018). Rosenthal (2010) found significant positive associations between heat-related mortality rates and both poverty levels and poor housing conditions in New York City, USA. Neidell (2004) observed greater exposure and effects of air pollution on asthmatic children of lower socio-economic status (SES) in California, USA (the authors cite affordability of relocating to areas with cleaner air as a factor). Children are particularly vulnerable to some of these pressures and exposure to them can result in life-long impacts (Salthammer et al., 2016), not only in terms of health and well-being (e.g. $PM_{2.5}$-related impaired lung development, increased respiratory symptoms, increased prevalence of childhood asthma – Gauderman et al., 2005; McConnell et al., 2010), but also in terms of social mobility. For instance, studies have shown that increased temperatures in education environments can have negative impacts on learning ability (Wargocki & Wyon, 2007) and similar impacts of elevated $PM_{2.5}$ air pollution on educational attainment have also been observed (e.g. Sunyer et al., 2015). The text below summarises the main modifying factors presented in the literature for the challenges relevant to REGREEN.

5.2 Age as a modifier of extreme high temperature-associated risk

Armstrong et al. (2011) estimated the relationship between temperature and the number of all-cause deaths, between 1993 and 2006, throughout summer months (i.e. excluding cold-related deaths, by using only the four warmest months, Jun-Sept) in England and Wales. They found that there was a temperature threshold - 93rd centile (95% CI: 92nd, 95th) of year-round temperatures, over which adverse effects started. This same threshold was also a good predictor for the slope of the relationship of % mortality per °C increase, beyond the threshold temperature itself:

$$\text{Slope} = -0.1284 + 0.0074 * (\text{mean summer temperature}) \quad (1)$$

Gasparrini et al. (2012), when looking at data for the same period and locations, observed increases in relative risk (RR) with increasing age groups (i.e. 0-64, 65-74, 75-84, >84) for all categories of main causes (CVD, Respiratory, Other), including aggregated (i.e. all-cause) data. The age-specific RR ranged from 1.3% (in ages 0-64), to 3.0% (in ages 85+). However, their main conclusion was that heat-related mortality is not strongly cause-specific, so a focus solely on age as the main risk factor is appropriate.

5.3 Deprivation as a modifier of $PM_{2.5}$-associated risk

Deprivation was found to be the principal modifier of air pollution associated risk. The generalised dose-response function for Relative Risk (RR), in terms of mortality rates associated with $PM_{2.5}$ exposure, is defined as 1.064 (95% CI: 1.043; 1.085) for a 10 μg/m^3 increase (Ostro, 2004). However, Cesaroni et al. (2013) refined this further, calculating the hazard ratio (equivalent to RR) for three classes of socioeconomic position – high, medium and low, 1.04 (95% CI: 1.02; 1.06), 1.018 (95% CI: 0.99; 1.04), 1.05 (95% CI: 1.03; 1.07). Their results also suggest that people over the age of 60 are at less risk than those aged below 60.

6 SPATIAL AND TEMPORAL VARIATION IN NBS BENEFITS

6.1 Variation in potential supply of ES

There can be variation in both time and space in the potential of these NBS to provide ES. For instance, deciduous trees shed their leaves in autumn, which substantially reduces their potential for removing particulate air pollution from the atmosphere as a result (Beckett et al., 2000), giving temporal variability in this service. Equally, the quantity of pollution removed is partly dependent on pollution concentrations, so trees located in areas with the greatest atmospheric concentrations of pollutant will remove the most and perform the greatest potential service. Other factors also vary substantially over a year (e.g. seasonal temperature changes, monthly or seasonal average rainfall totals), or even a 24hr period (e.g. diurnal temperature changes). ES are often quantified using annual mean values (e.g. Kroll et al., 2012; Kandziora et al., 2013; Schmalz et al., 2015), despite the possible presence of substantial intra-annual variation of critical factors. In climates where evapotranspiration varies seasonally, the potential for urban greenspace to reduce flood volumes also varies seasonally (e.g. Stovin et al., 2012), as evapotranspiration is the main mechanism by which the water storage capacity of green areas is recharged between rainfall events. This potential is also linked with the duration between events, as even in the summer, a rapid succession of significant storms may fill the water storage capacity more quickly than it is emptied by evapotranspiration. A similar principle also applies to NBS that provide temporary water storage, such as detention basins/ponds, although capacity recharge in temporary water storage NBS is normally controlled by physical/structural properties of the flow outlet.

Temporal scale can also be an important consideration here, particularly where climatic cycles may operate at scales of years. For example, European extreme heatwaves are projected to occur biennially (Stocker et al., 2014) and changes from flood-poor to flood-rich periods in northwest Europe (and the opposite in eastern and southern Europe) coincide with turning points in the North Atlantic Oscillation (Lun et al., 2020). Convective rainfall has been observed to follow weekly signals in many parts of the world (Colliquat et al., 2012; Marani, 2010; Simmonds & Keay, 1997). Level of urbanization, as well as specific urban footprint geometry, both of which change over time, are also linked to thunderstorm formation (Ashley, Bentley & Stallins, 2012; Haberlie, Ashley & Pingel, 2015). Some spatial variation may be linked to urban form or morphology, which can interact with pressures such as heat, air pollution or flooding.

This co-variation in both space and time means that identifying mismatches in potential supply and demand are critically important in attempting to maximise the efficiency of NBS, through planning the location and type of NBS.

6.2 Variation in demand

Exposure and vulnerability also vary temporally and spatially. Some factors are less likely to change over short periods than others are, e.g. the age profile of neighbourhoods may not shift enormously from year to year. Similarly, the resident population of an area is unlikely to vary substantially from one year to the next, but can vary within the space of a few years, especially in rapidly growing cities. One exception to both of these is where particular social groups make up a large part of the population, for example students or seasonal workers. Tourism can also be strongly seasonal and may influence the numbers of people exposed to, or affected by some pressures.

Variability in exposure and vulnerability are harder to quantify over shorter time-scales, e.g. intra-annual variation. Exposure can vary within populations according to factors such as occupation, commute route and type of vehicle used. For example, if we consider exposure to air pollution; a road-worker works outside in close proximity to traffic, whereas an office worker might work in an out-of-town business park, in the leafy suburbs. Cycling can represent higher exposure to air pollution than driving, and a longer commute on busy roads would mean exposure for longer, to higher concentrations. Data on such factors are not widely available, socioeconomic contextual data are often collected at census tract level every few years and give a static snapshot, typically based on residential addresses and there are few comprehensive data sources on behaviours such as commuting. Nonetheless, data available for some pressures do reflect both temporal and spatial variability. For example, $PM_{2.5}$ is monitored at numerous stations across many cities throughout the day. Earth observation data, can be obtained from satellites with revisit times of less than a day (e.g. the MODIS, TIR sensor), providing the basis for calculation of realistic temporal fluctuations in demand and supply (e.g. for cooling).

One implication of not appropriately accounting for temporal variation of important factors, which determine demand and supply of ES, is that resulting estimates may not accurately reflect reality, or that planning decisions may not be based on the best available information. For example, where particulate air pollution removal is strongly influenced by leaf area of vegetation (Beckett et al., 2000), annual estimates will need to account for seasonal variation in this factor, i.e. for deciduous trees, timing of onset of foliar senescence and emergence will be pertinent (Przybysz et al., 2019). However, as pollution removal is also influenced by the ambient atmospheric concentration of pollutant (i.e. severity of the Pressure), variation in this factor should also be accounted for. Because both of these factors independently vary over time and combine to determine the quantity of particulate air pollution removed, it is necessary to account for this covariance in any generalisations (e.g. average values) in order to make appropriate estimates of the pollution removal from the atmosphere. Similarly, because the quantification of ES provided is influenced by its demand (or use) by stakeholders, variations in this demand is also pertinent. The factor of vulnerability will also play a role and can change over time, e.g. shifts in age demographics, or seasonal variations in population density.

Spatial scale and extent are also important considerations in mapping and modelling of ES, and the location and type of NBS may dictate, for both of these factors, what is appropriate. There is often spatial disparity between green infrastructure/capital location and ES beneficiary location, e.g. for water-related ES the benefits may occur in different areas to where the NBS are located. For noise mitigation, the benefits are implicitly underpinned by direction and proximity, relative to noise source and mitigation infrastructure. For ES that function via direct physical interaction, e.g. use of a park for recreational activities like exercise, the area of interest for the purpose of estimating ES provision may not extend much beyond the park itself, however, it would be necessary to also include source areas of potential users, where supply and demand were being considered, i.e. where the people live who use that particular park. Thus, scale and context are important and the relevant scale at which the challenge is considered varies according to the nature of the challenge itself. For example, the entire catchment area (potentially thousands of km^2) can influence the flood risk of a given neighbourhood, or locality.

6.3 Case study exploring spatial and temporal variation: Removal of $PM_{2.5}$ by trees in Paris City

This case study illustrates some aspects of how taking account of spatial and temporal variation can lead to better planning of NBS. We use an example for the service of pollution removal by vegetation, in this case trees, in Paris City. Detailed mapping of $PM_{2.5}$ concentrations by Paris authorities shows how the pressure from air pollution varies spatially across the city (Figure 8). For the same part of Paris, we show the land cover, mapped at 10 m pixel resolution, with separate classes for deciduous and evergreen trees (Figure 9). Using methods described in Jones et al. (2019) and Fletcher et al. (in review), we calculated the quantity of $PM_{2.5}$ removed by trees over a period of one year without differentiating between evergreen and deciduous trees. This rate is not constant and varies according to the concentration of $PM_{2.5}$. Figure 10 shows how there is greater removal by trees alongside roads and in the bottom right part of the image, where pollution concentrations are greater. In Figure 11, we further differentiate between removal rates for deciduous and evergreen trees, which takes into account variation in the amount of service provided through the year. This illustrates both the spatial and temporal variation in the service, but could also aid urban planning. For example, if exposure to pressures has a seasonal basis which means that service provision during a particular part of the year is more relevant than looking at a yearly total or average level of service.

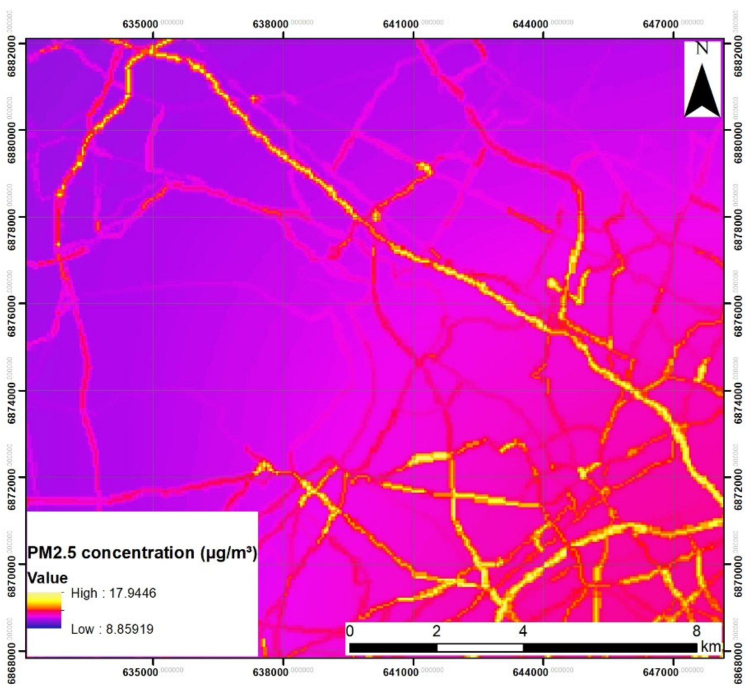

Figure 8: $PM_{2.5}$ atmospheric concentration for an example area of interest in Paris.

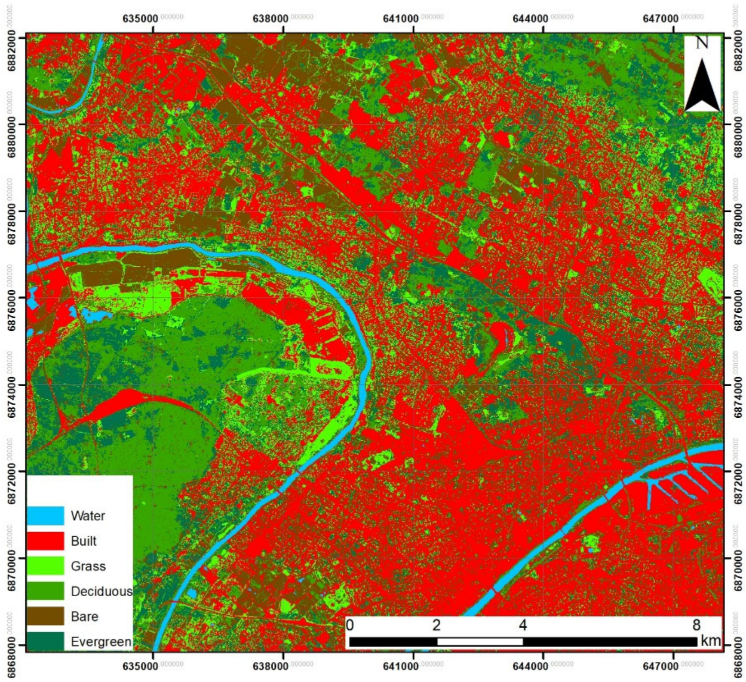

Figure 9: Land Cover classification, with six classes, including differentiated deciduous and evergreen trees, for an example area of interest in Paris.

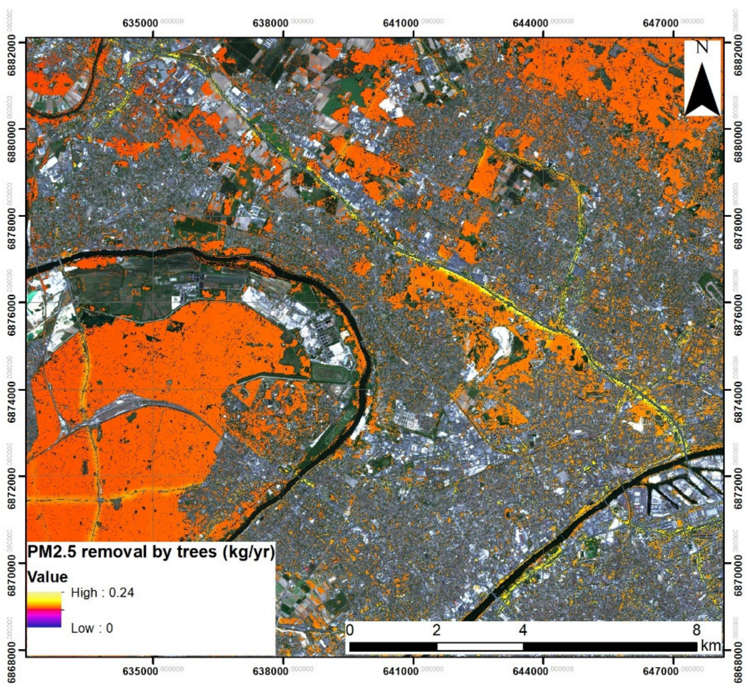

Figure 10: Modelled $PM_{2.5}$ removal by trees, with deciduous and evergreen types not differentiated, overlaid on satellite imagery.

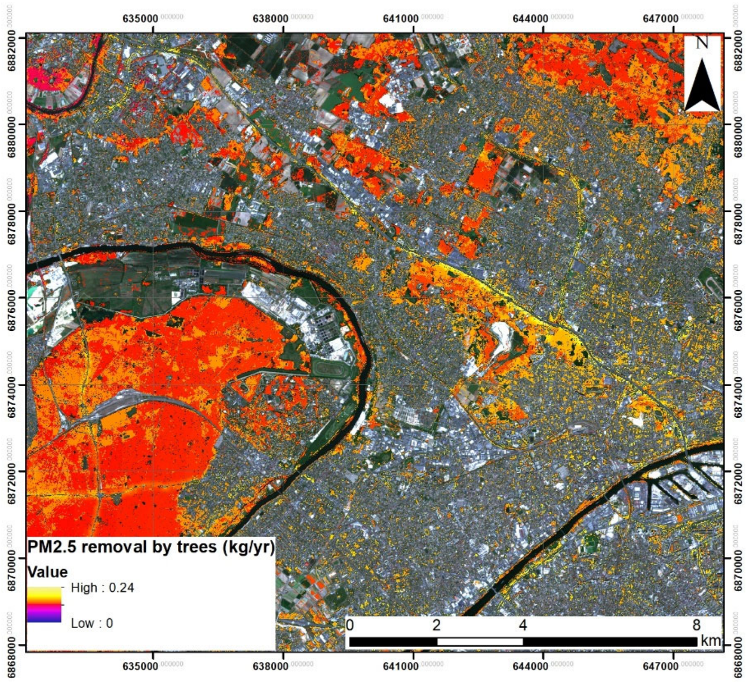

Figure 11: Modelled $PM_{2.5}$ removal by trees, with deciduous and evergreen types differentiated, overlaid on satellite imagery.

7 CONCLUSIONS

Through the process of compiling this report, we have improved our understanding of how drivers and pressures interact with contextual factors to produce a variety of impacts. This has highlighted the importance of capturing spatial and temporal variation in data representing the pressures, but also that it is critical to have appropriate contextual data, particularly those data relating to people (e.g. sociodemographic and socioeconomic data) in order to provide useful spatially and temporally explicit representations of the challenges that are produced in urban environments.

Achievements have been made to map the urban expansion for the six ULLs from 1985, as initial year, to 2018 based on global land cover data. By undertaking this effort, the direction and velocity of urbanisation processes could be visualised and quantified. Further achievements relate to priority setting of pressures to each ULL for a deeper understanding of the respective needs for tailored ES models and for a pinpointed communication with targeted stakeholders. Advances in the ES modelling allow more refined spatial application of the models. In particular, an improved conceptual understanding of how demand and potential supply interact will allow us to better use the models and data available within REGREEN to plan and design improved NBS.

In the next step, we will collate socio-demographic and socio-economic data for each ULL, we will then allocate this quantitative information to the urbanised areas and overlay with land-cover mapping to set local priorities for ES modelling. Moreover, at the neighbourhood scale we have started to map the urban morphology, first for the ULL Aarhus to undertake fine-scale mapping. This fine-scale mapping can help underpin models for UHI and noise, flooding and water quality, and for biodiversity.

It is necessary to take account of spatial and temporal variation in pressure, potential service and demand to guide effective planning of holistic multi-functional NBS. For instance, we know that trees are better than grass at removing $PM_{2.5}$ air pollutants and for cooling, but if we plant an entire large area with trees, it may not provide optimal health and wellbeing benefits from use of the space for socialising, recreation and exercise. Add to this that stakeholder preference should be included in planning, as ongoing support and use will be impacted by this – stakeholders are less likely to engage with and use NBS that they don’t prefer or see as useful/wanted.

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