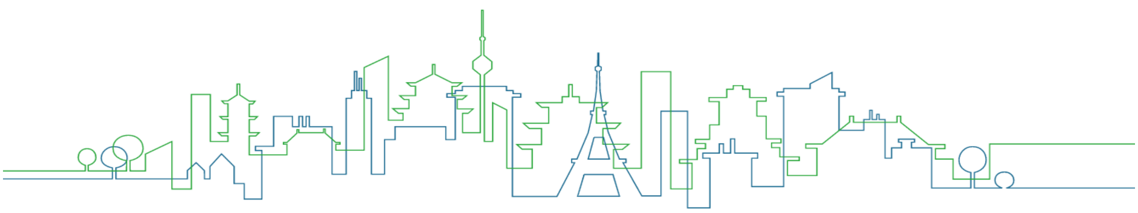
Fostering nature-based solutions for smart, green and healthy urban transitions in Europe and China

Deliverable **N°3.2.**

WP N°3 Mapping and modelling ecosystem

GUIDELINES FOR A "DEPAVING" AND "RE-GREENING" STRATEGY IN CITIES

Author(s): **Gwendoline Grandin (IPR), Gaëtane Deboeuf De Los Rios (IPR), Marc Barra (IPR)**



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

DOCUMENT INFORMATION

GRANT AGREEMENT No.	**821016**
DOCUMENT TYPE[1]	**R**
WORKPACKAGE No. /TITLE	**WP3 / Mapping and modelling ecosystem services**
LEAD CONTRACTOR	**IPR**
AUTHOR(S)	**Gwendoline Grandin (IPR), Gaëtane Deboeuf De Los Rios (IPR), Marc Barra (IPR)**
REVIEWED BY	**Åsa Ode Sang (SLU), Marianne Zandersen (AU)**
PLANNED DELIVERY DATE	**28.2.2022**
ACTUAL DELIVERY DATE	**28.2.2022**
DISSEMINATION LEVEL[2]	**PU**

[1] Type: P: Prototype; R: Report; D: Demonstrator; O: Other.
[2] Security Class: PU: Public; PP: Restricted to other programme participants (including the Commission); RE: Restricted to a group defined by the consortium (including the Commission); CO: Confidential, only for members of the consortium (including the Commission).

Copyright Statement

EXECUTIVE SUMMARY

The loss of soil functions and ecosystem services is one of the major environmental challenges Europe is facing. Despite a reduction in the last decade, land take in EU28 still amounted to 539km^2/year between 2012-2018. Since the mid-1950s, the total surface area of cities in the EU has increased by 78% while the population has grown by just 33% [1]. Population growth can also drive land take, but built-up areas are expanding more quickly than populations are growing. Urban sprawl often continues even where populations are decreasing. In France, the rate of land take in France is the highest in Europe, occurring 4 times faster than population growth. This phenomenon is now foremost among the drivers of rapid climate change and the erosion of biodiversity [2].

To address this global problem, the European Commission has proposed in the EU Environment Action Programme to 2020 (7th EAP) to achieve 'no net land take' by 2050. Sealing agricultural land and open spaces should be avoided as far as possible and the focus should be on building on land that has already been sealed. In France, the national objective dubbed *Zéro Artificialisation Nette* (Net Zero Land Take) marks a turning point in strategies designed to slow urban sprawl as it places the emphasis on urban renewal and densification. It also introduces a renaturing goal that involves "giving back to nature" an amount of land equivalent to that consumed by urban growth. For example, unused land could be returned to cultivation or renaturalised so that it can once again provide the ecosystem services of unsealed soils. The implementation of the Net Zero Land Take goal, however necessary it may be, may nevertheless result in even greater urban densification in cities that are already suffering from climate change and dwindling biodiversity. Moreover, the estimated cost and complexity of a renaturing operation above all presuppose the avoidance of any additional land take.

In this context, slowing urban growth and renaturing urban environments have become key strategies. They are all the more relevant as biodiversity is declining significantly in urban areas, the effects of climate change (runoff, flooding, urban heat islands, etc.) are intensifying and the health and wellbeing of city-dwellers are deteriorating. Renaturing makes it possible to adapt cities to climate change and to make them more permeable to wildlife by developing nature-based solutions. Our cities are full of areas that have been concreted or asphalted over and where nature could return and flourish. The Paris Region, especially the Greater Paris area, is particularly affected by the consequences of urbanisation and density. The purpose of this guide is to propose a method that will help local authorities to target urban areas where renaturing represents a key strategy to restore biodiversity, adapt to climate change and improve people's health. Based on feedback from respondents in the field, it provides recommendations on how to implement projects in the best possible conditions.

This guide is part of the European project titled Horizon 2020 REGREEN on nature-based solutions in urban environments. The term "nature-based solutions" refers to initiatives aimed at the conservation, management and restoration of ecosystems. Their aim is to attenuate climate change (e.g. via carbon capture and storage) and to facilitate adaptation to climate change (e.g. via protection against storms, flooding and landslides). These solutions have proved their effectiveness and can complement or replace the grey infrastructure traditionally used in regional development. The advantage of nature-based solutions is that they are multi-functional whereas grey solutions only solve one problem at a time. As well as benefiting climate and biodiversity, they have the advantage of helping to improve the living environment and health of city-dwellers at lower cost to local authorities. Nature-based solutions apply to all environments on all scales (farmland, woodland, aquatic and urban environments) and help enhance the resilience of local regions to global change. Renaturing is a way of rolling out nature-based solutions in areas that have been subject to land take and ground sealing.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 WHAT IS "RENATURING"?

The term renaturing encompasses many different approaches and visions whose terms are constantly evolving within the scientific community. The word, for which it would be pointless to attempt to give a single, universally accepted definition, refers to the general idea of a "returning ecosystems that have been degraded, damaged or destroyed by human activity to their natural or semi-natural state" (*Aronson, 2004*)**.** Originally associated with the restoration of degraded natural areas, the concept has been gaining ground in the urban environment since the advent of the Net Zero Land Take goal. It remains open to different interpretations depending on the stakeholders involved, be they ecologists, developers, planners or landscapers. It thus seems vital to return to the source of this idea and the different approaches it encompasses. Understanding the goals of renaturing facilitates dialogue between urban stakeholders and makes it possible to propose a common interpretive framework for the implementation of these kinds of projects.

1.1 Meanings and approaches

1.1.1 Natural renaturing

Renaturing is traditionally associated with processes by which nature returns to an area that has been subjected to land take or anthropic disturbance. Simply putting an end to human interference allows the environment to be recolonised in a passive or spontaneous way. This process has been described as leading to a state of "ferality": in other words, ecosystems return to the wild state when human exploitation ceases (*Génot and Schnitzler, 2012*). Ferality is close to the idea of rewilding, which means the recolonisation of an environment by wildlife (with or without human intervention) when anthropic activities have been abandoned or halted.

In France, the idea of rewilding is being supported and implemented for example by the Association pour la Protection des Animaux Sauvages (ASPAS) in the Vercors National Park and recently by the association set up by Françis Hallé, a botanist involved in a 700-hectare rewilding project in the Vosges mountains. Naturalists and rewilding specialists Gilbert Cochet and Béatrice Kremer-Cochet recently published "L'Europe réensauvagée, vers un autre monde" (*Actes Sud, 2020*), an essay that draws on their experience to demonstrate the value of these wild areas in restoring biodiversity. According to Edward O. Wilson (2017), 50% of the planet must be given back to wildlife in order to halt the mass extinction of living organisms. Recently, researchers suggested that ensuring the biodiversity intactness would entail restoring 23.9 million km2, or 18.1% of the global land surface, based on a novel environmental limit from the planetary boundary concept (*DeClerck et al., 2021*). In France, protected areas where human intervention is at a minimum account for a mere 1.8% of land, and for 0,59% in the Paris Region [3].

This type of renaturing, which allows nature to take its course, relies on elements already present in or near the area (*Grubb and Hopkins, 1986; Powers et al, 2009*) and thus involves no financial or environmental cost. Moreover, renatured ecosystems function as open-air laboratories, adapting over time to new uses and climate change. This type of renaturing is especially useful when the project can take place over a long period of time and when ecological connectivity is sufficient to allow animal and plant species to recolonise the site (*Prach et al, 2015; Chazdon & Guariguata, 2016*). In certain cases, it can even be used in significantly disturbed areas such as abandoned quarries or mines, although the process is then slower (*Prach & Hobbs, 2008*).

In urban areas, the idea of spontaneous colonisation is still uncommon as it is often associated with neglect and abandonment. This type of trajectory can, however, already be observed in urban brownfield sites, although the latter are sometimes perceived negatively. Several scientists have shown that sites that have been allowed to become overgrown have real potential for the conservation of urban biodiversity (*Bonthoux et al, 2014*). In the Paris Region, the diversity of plants, birds and butterflies in brownfield sites is higher than in any other "natural" urban areas (parks, gardens, cemeteries, and so on) (*Baude et al, 2011*). Because they do not harbour exactly the same species as managed areas, brownfield sites also act as a refuge for so-called "urban avoiders" (Great mullein, Welted Thistle, whitethroat, wall lizard), which struggle to adapt to urban conditions. Last but not least, these freely evolving environments also contribute to the ecological continuity of local areas by allowing species to travel across the urban matrix (*Muratet et al, 2019*).

BROWNFIELDS AS A REFUGE FOR WILDLIFE

A study by the Paris Region Institute has identified over 2,700 brownfield sites covering a total of 4,200 hectares in the Paris Region. This work has fuelled the revision of the region's development master plan (Schéma Directeur de la Région Île-de-France: SDRIF) which began in 2020 and aims to earmark available sites for densification and urban renewal. Given their ecological potential, many such sites should be seen as natural areas in their own right and protected from urban development.

Brownfield sites are an example of spontaneous renaturing without human intervention ©École d'Urbanisme in Paris

By the same token, any project that aims to redefine brownfield sites, however "green" it may be (converting them into parks or gardens, urban farming initiatives, etc.) can ultimately lead to a reduction in the ecological potential of these areas where unimpeded natural development and the absence of management ensure a high level of biological diversity. Improving knowledge of brownfield sites via ecological inventories carried out at an early stage is thus vital to all ecological planning initiatives, as is recognising the status of such sites as natural areas.

This process of spontaneous colonisation has been studied in particular detail in Germany via the work of Ingo Kowarik on spontaneous urban woodland in Berlin. Some of the city's emblematic parks are the result of this process, for example the *Natur-Park Schöneberg Südgelande*, which is the result of renaturing a former railway marshalling yard. This 18-hectare area remained inaccessible for almost 50 years before opening to the public in 2000. Existing trees have been retained with no additional planting. Maintenance is minimal and restricted to the footpaths. An inventory in the 2010s identified 366 different species of ferns and flowering plants, 49 species of mushroom, 49 bird species, 14 grasshopper and cricket species, 57 spider species and 95 bee species, 60 of which are endangered.

In 2000, the Natur-Park Südgelände in Berlin opened to the public after almost 50 years of unhindered evolution. ©City of Berlin

Miyawaki forests: renaturation or just a fad?

In the past years, urban tiny forests, also called "Miyawaki forests" have multiplied all over Europe. Founded by the Japanese botanist Akira Miyawaki, this method consists of dense plantations of various tree species (3 to 7 per square meter), generally on an area of less than 1 hectare. It was originally inspired by the spontaneous dynamics observed in forests. Several companies and associations have specialized in the creation of these tiny forests. According to them, these new forests would "grow 10 times faster", "host 20 times more biodiversity" and be "30 times denser" than natural forests [4]. Proposed as a miracle solution for biodiversity or urban cooling, they are nevertheless criticized by the scientific community. Firstly, the marketing argument ("10, 20, 30 times more...") is rarely substantiated. A "10 times faster" growth, but in relation to what reference? To reach which objectives? A mature forest requires an old forest soil, develops over a long period of time (more than 200 years) and hosts the maximum of its biodiversity (lichens, fungi, insects) in the old and senescent stages (*Génot, 2020*). Moreover, planting at a high density, "30 times higher" than natural forests, can lead to significant mortality due to competition between trees. One of the few studies carried out in Europe on the subject reports mortality ranging from 61 to 84% (*Schirone et al., 2011*). As for the benefits on biodiversity or cooling, they are still poorly evaluated. Biodiversity is mainly measured by the number of newly planted species (plant richness). The only study evaluating the benefits on fauna, indicating a "20-fold increase" in biodiversity, was conducted in the Netherlands, 2 years after planting and lacks scientific rigor (unprotocated surveys, absence of reference ecosystem) (*Ottburg et al., 2018*). More scientific monitoring and studies are needed to objectify the benefits.

Among the recommendations issued by companies and associations specializing in the creation of "Miyawaki" tiny forests, some management methods can be unsustainable, such as the uprooting of unwanted plant species or the frequent watering of seedlings in the first 3 years after planting. In addition to resource requirements, the selection of plants is based only on their competitiveness, and not on their ability to resist to drought episodes, which are known to increase in both frequency and duration. Adaptations to the traditional method seem necessary, for example by reducing the density of plants in the case of arid/semi-arid conditions (*Schirone et al., 2011*). Finally, taking into account the initial state of the soil is also important. A poor or polluted soil can constrain the development of plants. In this context, the importance of plant succession, in particular the establishment of pioneer plants and their role in the preparation of degraded soils, cannot be overlooked.

Urban micro-forestry projects are an attractive and motivating approach for citizens, and they may have their place in a pletophora of actions to bring nature back into the city. However, today they seem to be more of an electoral slogan or marketing argument where biodiversity is measured by the number of trees planted rapidly. This type of operation cannot be standardized but must be related in the local context, and can thus take various forms: multilayered hedges, afforestation or grove, extension of a relictual forest, etc. It is important to consider its sustainability and the resources required for its implementation and finally the waste produced (this type of project often involves the removal of rubble, followed by a phase of preparation of the soil by means of external fertile soil). Regarding the growing need for immediacy (creating forests in 30 years), Jean-Claude Génot reminds us that for a forest to reach its ecological maturity, it must go through different stages of development where different species follow one another. He urges cities to take inspiration in brownfields, which for him corresponds to wild urban woodlands, which require no human intervention, cost nothing and can become a mature forest over time and through plant succession (*Génot, 2021*).

1.1.2 Ecological restoration and engineering

In most cases, renaturing involves human intervention, however minimal. This is referred to as ecological restoration, a discipline formally established in the 1980s with the creation of the *Society for Ecological Restoration* in the USA. This group of scientists defines ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed in order to re-establish the former ecosystem with respect to its specific composition, its ecological functions, the ability of the physical environment to support living organisms and its connectivity with the surrounding landscape. In recent years, ecological restoration has developed in particular in natural, especially aquatic environments (rivers and wetlands) but has also been used to restore sites and soils contaminated by former industrial activity (*Tobias et al, 2018*).

Ecological restoration initiatives can take very varied forms and involve varying degrees of human intervention. While some interventions require heavy equipment (construction site machinery, etc.), others use alternatives to traditional civil engineering. This is true of ecological engineering, which leverages a wide range of expertise and tools based on living organisms and an understanding of the mechanisms that govern ecosystems. According to the researchers who initiated the movement, ecological engineering is broadly defined as "*the management of environments and the design of sustainable, adaptable, multi-functional developments inspired by, or based on, the mechanisms that govern ecological systems (self-organisation, diversity, heterogeneous structures, resilience)*" (*Abbadie et al., 2015*). Ecological engineering is applied in the context of the rehabilitation of damaged ecosystems; the restoration of functional communities; the reintroduction of species; the treatment of pollution using living organisms; the restoration and reinforcement of ecosystem services; and the design of new materials that minimise the destruction of the environment.

Ecological restoration has been particularly developed within the framework of the rehabilitation of aquatic environments (rivers and wetlands), here the Bièvre restored at Igny © Hervé CARDINAL, SIAVB

One of the objectives of ecological engineering is to limit the use of non-renewable resources and inputs, instead using renewable natural resources with low ecological impacts. Ecological engineers use an array of techniques inspired by the living world. For instance, it is possible to use species referred to as ecosystem engineers, whose presence and activity alone significantly modify their environment (mycorrhizae, earthworms, phytoremedial plants, harvester ants, beavers, rustic herbivores, etc.). Unlike civil engineering, ecological engineering has a small ecological footprint and takes its cue from the context in which it is applied, providing greater chances of success. However, restoration initiatives usually combine civil and ecological engineering, given that they often rely on the prior decontamination of the sites concerned and require the destruction of man-made structures such as buildings, concrete infrastructure, channels, embankments, dams and so on.

REFERENCE STATES IN RESTORATION ECOLOGY

Restoration ecology uses the notion of the reference state, which means establishing the condition a site was in before it was damaged. This method of defining an initial state is often used in projects aimed at the restoration of natural or semi-natural ecosystems, but it is difficult if not impossible to carry out in urban environments. Renaturing in urban settings more often involves rehabilitation, reclamation or natural regeneration without necessarily aiming to return to an original state whose very existence is open to debate within the scientific community**.** However, it is always interesting to carry out historical research in the early stages of a restoration project and to seek to restore certain functions of the target ecosystem (if not its biotic integrity), as is the case with renaturing operations focusing on former wetlands, streams that have been channelled or covered over, relictual woodland, former meadows, or riverbanks that have deteriorated over time. Where reassignment and natural regeneration are concerned, no historical references are required as renaturing leads to a new ecosystem with different functions and a different structure.

1.2 Urban renaturing: beyond landscaping

1.2.1 From regreening to renaturing

In urban settings, renaturing is still often perceived as an approach to landscaping (*Pech, 2015*) whose main aim is to create a green decor that makes the city more attractive. In France, this kind of greening developed under the influence of formal landscaping whose legacy has been a highly controlled ornamental approach to nature focusing mainly on plants and ignoring other species as well as ecological functionality.

Unlike ecological engineering, greening often takes place with no connection to the climatic or geographical context, uses ill-adapted horticultural species and requires numerous inputs (topsoil, fertiliser, energy, irrigation, etc.), which means that these areas are not self-sufficient and are reliant on intensive management. Greening operations often start from scratch by eliminating existing vegetation and replacing the existing soil with topsoil—which is becoming scarce in agricultural environments. Greening is often organised on the scale of the site alone whereas renaturing takes a range of different scales into account, following the principles of landscape ecology. The archetypes of greening are, for example, the French-style formal garden, lawns, monospecific planting, modular living walls, raised planters, flower meadows sown with non-local species, etc.

"Saving the bees" requires first and foremost to protect and restore a diversity of pollinator-friendly habitats (urban meadows, hedgerows, terricultural environments, etc.). In dense urban areas, the multiplication of beehives in cities is similar to a breeding method and can lead to an overdensity of the honeybee (Apis mellifera), to the detriment of wild pollinators, through competition for access to floral resources (*Ropars et al., 2019*). Similarly, creating substitute habitats for species such as insect hotels or other wildlife shelters can prove to be unrelated to the needs of the targeted species. In this way, although these operations can contribute to nature education, they are not always effective facilities for the recovery of biodiversity.

Conversely, renaturing via ecological engineering relies on knowledge of the living world and takes each level of biodiversity (genetic, specific and ecological) into account. Its primary aim is not to beautify but instead to maintain ecological functionalities by targeting relevant flora and fauna, by taking soil quality into account, by using minimum resources and by minimising the need for future management.

BLANDSCAPING: THE STANDARDISATION OF NATURE IN CITIES

Some greening systems, such as these pre-cultivated sedum mats for green roofs, are often "copied and pasted" from one city to another. ©Marc Barra

The growing interest in nature in urban environments goes hand in hand with a form of standardisation, for example beehives or insect hotels set up to the detriment of habitats for wild pollinators, “ready-to-use” systems for living roofs or planted façades disconnected from local requirements, and alluringly marketed urban micro-forests that do nothing to protect and regenerate brownfield sites and existing urban woodland. This phenomenon, which certain researchers have dubbed “blandscaping” (*Connop, 2018*), involves solutions that use the same design approaches and often the same species, and are rolled out in different urban areas across the world. Such solutions are generally developed industrially so that they can be commercialised in the form of standardised or ready-to-use products. The living world depends above all on local realities, however. Although commercial supply streams are necessary (e.g. for seeds, plants and materials), initiatives aimed at developing nature in cities and renaturing projects can only be conceived on an ad hoc basis, taking account of specific regional characteristics; they can hardly be developed industrially as this would inevitably lead to standardisation. Applying the principles of ecological engineering makes it possible to avoid this pitfall by offering one-off solutions that are relevant to the local context, whose design focuses on the requirements, life patterns and intrinsic needs of species (size of habitat, connectivity, complexity of trophic networks), and which make use of local resources (reclaimed land, wild seeds collected nearby, species already present on site, etc.). In France, the Végétal Local® label, which makes it possible to commercialise plants that are specifically suited to different regions, has opened the way for projects that take full account of local ecological realities.

The transition from greening to ecological engineering requires active collaboration between ecologists and landscapers. Many landscape designers, such as Michel Clément, have opened up a new era where the world of landscaping and the world of scientific ecology meet. They rely on landscape ecology, which takes the scale of the landscape into consideration in the spatial organisation of ecosystems, considering its composition and configuration as key elements that influence ecological processes (*Bourgeois, 2015*). It uses different methods and models to study past, present and future forms of the landscape, and has contributed to both ecological knowledge and the implementation of ecological connectivity in cities. Urban ecology cannot do without landscape ecology as the disciplines are necessarily complementary in the framework of urban renaturing projects. More and more ecological restoration projects are being developed on the scale of the landscape rather than on that of individual habitats alone. Some landscape architects use the "dynamic vegetation design" concept as a tool to create and work with systems through management over time. Indeed, it is pointless, from the standpoint of biodiversity, to attempt to restore an ecosystem disconnected from the gene flows necessary for the long-term survival of the species that live in it. The ecological restoration of landscapes can be conceptualised via the restoration of green and blue grids, making it possible to connect isolated environments in landscape matrices that do not lend themselves to species movement.

1.2.2 Ecological engineering in urban environments

In recent years ecological engineering has significantly developed in cities, in particular, in France, under the name plant-based engineering techniques ("genie vegetal" in French), which comprises an array of techniques based on the use of plants and their structural functions (as stabilisers, anchors, etc.) to combat soil erosion, to stabilise embankments, or to restore riverbanks, rivers or urban wetlands (cf. examples in Chapter 2). In these kinds of operations, vegetation does not merely play a supplementary role (that of "greening"); instead plants are perceived as living construction materials in their own right, which can be used alone or in association with inert materials (*Schiechtl, 1992*). As well as plants, the use of living things can take a variety of forms in cities and serve a range of applications designed to restore ecological functionalities or entirely renature degraded environments: using plants to purify greywater (phytopurification) or to capture urban pollutants; flood management; reducing urban heat islands; and so on. In any case, biodiversity is central to these operations: it is both a means and an end where renaturing is concerned.

The principles of ecological engineering can thus be applied to a multitude of urban projects, whether they involve renaturing or the management or creation of new ecosystems. New techniques combining ecological and civil engineering have also emerged, in particular regarding the restoration of soils containing materials left over from demolition programmes ("technosoils"). Although some human intervention is required, ecological engineering is often synonymous with active renaturing. The principles and steps involved in implementing ecological engineering in the framework of a renaturing project are laid out in Part 3.

Ecological engineering techniques used to restore the banks in order to protect them from erosion, stabilise them and allow them to regenerate. ©Gilles Lecuir

1.2.3 Natural regeneration or ecological engineering? Combining approaches

The different approaches to renaturing in natural and urban environments are not incompatible; on the contrary, they can complement one another within an area or on a single site, for example applying natural regeneration goals in some sectors and human-assisted restoration in others. Whether renaturing is passive or active, all these approaches converge towards the natural process of ecosystem recovery though they differ in terms of how much human intervention is involved. In all cases, they require continuous adaptive management and close monitoring until the ecosystem has recovered. Objectives vary from one project to the next: we can attempt to restore all the components of biodiversity, from genes to species to landscapes; we can focus on the functionality of ecosystems, in other words not only the functions that are necessary for ecosystems to work but also the functions that provide humans with "ecosystem services"; we can also try to make ecosystems "wilder". The final goal is to restore ecological functionality, to make environments better able to maintain themselves and to ensure that natural carbon, water and nitrogen cycles are functional by mimicking the characteristics of natural systems.

DESEALING IS NOT RENATURING

Drainage pavements or permeable asphalt, which are legitimately useful on certain surfaces to improve stormwater management, do not correspond to renaturation. ©Gilles Lecuir (on the left) ©Commune de Narbonne (on the right)

Renaturing is sometimes confused with desealing, which merely entails restoring permeability to the upper layer of the soil, often by using porous ground covering materials that facilitate drainage. Desealing is a necessary but not sufficient condition for the restoration of the soil's ecological functions. Moreover, alternative systems for managing rainwater have prompted cities to partially deseal certain areas without necessarily going ahead with a complete renaturing programme. Renaturing presupposes a return to an open ground, in other words desealing and, where necessary, other soil restructuring work (decompaction, creation of soil horizons, amendment, etc.) in order to restore a living soil that is continuous with the geological subsoil. In urban environments, this excludes above-ground solutions (green roofs, raised beds, planted slabs, modular living walls, etc.). Where green spaces are concerned, it may be of value to distinguish relatively unnatural areas (lawns, flower gardens, etc.) whose ecological quality is low but which can be easily improved (by applying ecological management principles, for example) from very natural green spaces that must be preserved and protected in planning documents (waste ground, relictual woodland, old meadows). In absolute terms, most urban areas, even green spaces, could be renatured. However, the degree of land take and the amount of harm done to soil functions varies significantly from one area to the next and sealed areas (covered with buildings, asphalt or bitumen) are a priority in a renaturing strategy given the potential benefits.

Figure 1: Classification of urban spaces that can be renatured, restored, covered with vegetation or protected

Table 1: Comparison between desealing, greening and renaturing

	DESEALING	GREENING OR "LANDSCAPING APPROACH"	RENATURING OR ECOLOGICAL APPROACH TO THE LANDSCAPE
Goals and purposes	Restoring the water cycle by making the soil permeable, limiting runoff and flooding.	Using plants to make the urban environment more attractive, ornamentation.	Restoring ecological functionalities, creating viable habitats in relation to the green and blue grid, water management, adapting to climate change.
Associated skills and professions	Engineers, hydrologists	Landscape architects	Ecologists, engineers, naturalists, eco-landscapers
Scales taken into account	Site, runoff zone or catchment	Site or landscape	Nested scales with respect to the landscape and ecological networks
Monitoring	Relating to the quality and dynamics of water	Not systematic	Evaluation of biodiversity before and after using standardised protocols
3 levels of biodiversity taken into account?	No	No, limited to plants or planted areas	Yes: gene flows, species and interactions
Examples of application	Alternative systems for managing rainwater, permeable surfaces	Swales, flowerbeds, raised containers	Marshland, meadows, green and blue grids, creation of habitats focusing on the needs of species
Adapted to local environmental context?	Yes, in relation to the water cycle	Not necessarily (inappropriate choice of species, massive input), but often take the social context into account	Yes: coherent selection of species within the desired ecological trajectory
Management	Extensive to intensive	Extensive to intensive	Extensive to free natural evolution
Prior environmental information required	Hydrology, soil permeability	Not necessarily	Ecological analysis of initial state of the site

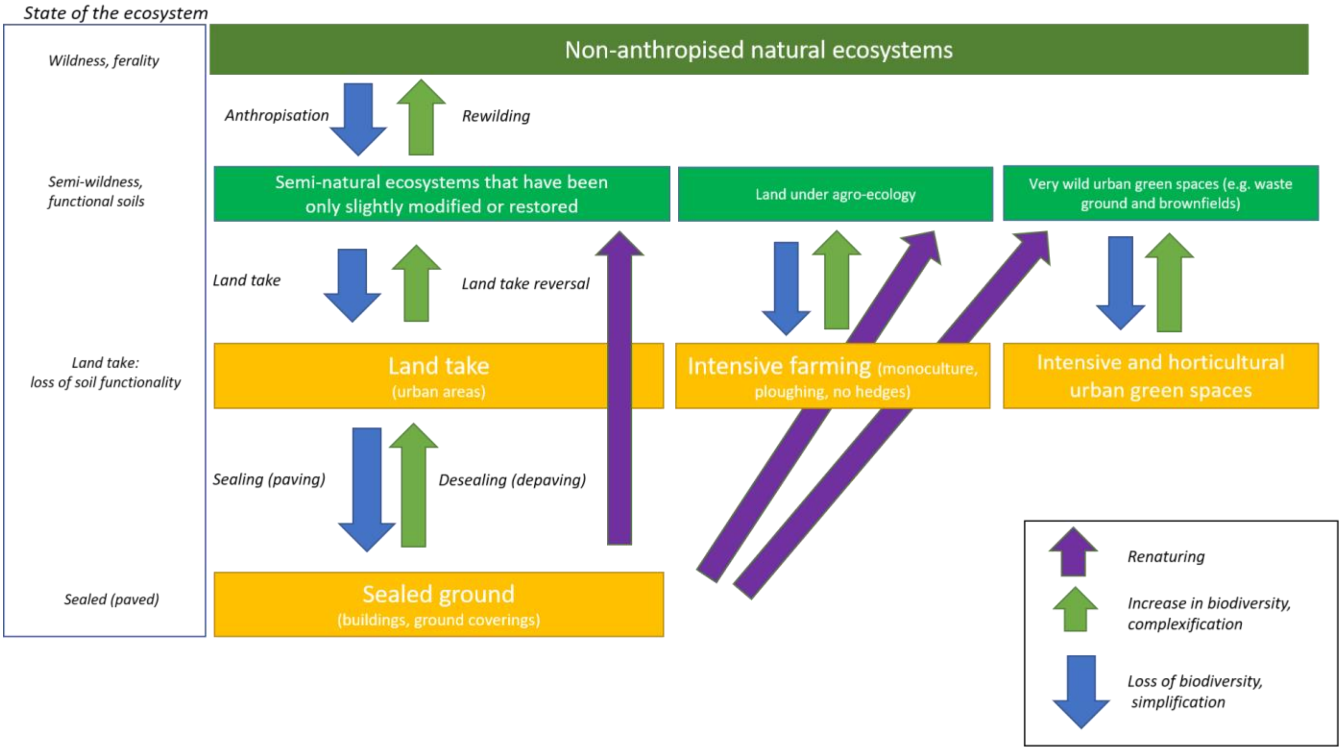
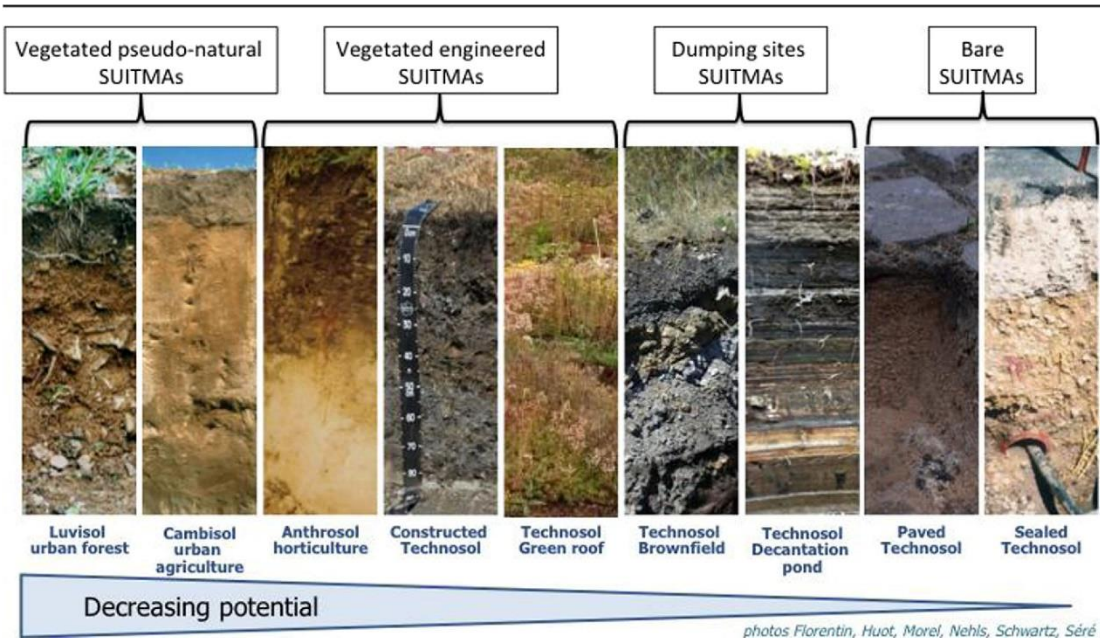


Figure 2: Summary of concepts and human activity influencing ecosystems depending on their degree of wildness. The green arrows indicate potential benefit to biodiversity, the blue arrows a potential loss. Renaturing means restoring sealed ground to make it into a natural or semi-natural area. It can also involve agro-ecology or restoring relatively "wild" urban areas (waste ground, wooded areas, urban meadows). Some agricultural areas, due to intensive farming (monoculture, deep ploughing), can be termed "land take" in the sense that their soil functions are impaired, as can certain urban green spaces that are hardly "wild" at all (lawns, intensive horticultural gardens). They cannot, however, be placed in the same category as urbanised areas as their soil functions can be restored more rapidly.

1.3 Soil: central to urban renaturing challenges

Although soil is home to 25% of the world's terrestrial biodiversity (*IPBES, 2019*), it is still poorly understood and has long been neglected and seen as a mere physical medium. The soil is, however, a fully-fledged component of biodiversity, providing a habitat for countless living organisms (microfauna, mesofauna and macrofauna) and acting as a medium for fundamental ecological processes such as biogeochemical cycles and the water cycle. Renaturing cannot be implemented without taking into account the state of the soil and its ecological functionality.

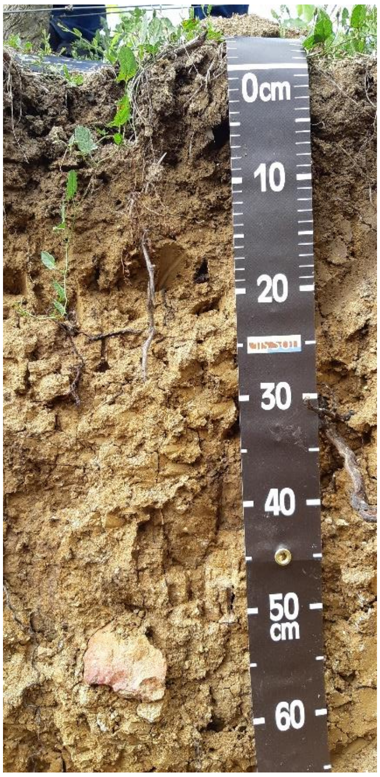
Urban soils are in most cases significantly modified and degraded (pollution, compaction, disturbed soil horizons) or even rendered impermeable when they are covered with non-porous materials (roads, car parks, etc.) or by a building. Sealing prevents water from entering the soil and compromises its function as a medium for plants. Urban soils are also generally contaminated with heavy metals and hydrocarbons. In the Paris Region, soil concentrations of cadmium, lead and copper content are 8 times higher in urban woodland than in rural woodland (*Foti, 2017*). In cities, soils are also fragmented by infrastructure, which breaks up ecological continuity and partially or totally isolates biodiversity reservoirs.



Proposition of groups of SUITMAs (soils of urban, sensu stricto, industrial, traffic, mining, and military areas) according to their potential as vegetation support systems. ©Florentin, Huot, Morel, Nehls, Schwartz, Séré.

Renaturing in urban environments has to focus on restoring soil functions rather than replacing them. Today, most planting projects in urban environments use topsoil removed from farmland or volcanic soil. This is a major problem that merely transfers impacts to other environments. To put an end to this "soil-trafficking", more and more actors are choosing to reuse urban by-products (compost from green waste, crushed concrete or brick, excavated earth) collected on site. These circular economy approaches can be combined with techniques of ecological engineering (reintroduction of earthworms, mycorrhization, inoculation of micro-organisms). The restoration of fertile soils or "technosoils" has been the focus of several recent research programmes and seems to be a viable solution for urban renaturing in the future (see 3.3.2 "Restoring the soil"). Renaturing must also focus on restoring continuity between soil compartments, both vertically and horizontally ("brown grid").

1.3.1 "Open ground": a notion that is hard to define but essential for renaturing



More and more local authorities in France are seeking to improve representation of soil-related issues in their planning documents and are taking an interest in protecting what is termed "*la pleine terre*", which may be translated approximately as "open ground" or "natural soil" (*planter en pleine terre* means to plant directly in the ground and not in a pot or container). The notion of open ground does not have a universally accepted definition, nor is there scientific consensus regarding its precise meaning. A study carried out by the Paris Region Institute (*Cornet et al, 2021*) looked at 25 local urban development plans and highlighted the fact that no definition of open ground was provided in 20% of the documents. Where such a definition was provided, local authorities used different criteria to define what open ground means, such as "[the soil's] ability to let water in, the absence of constructions on and under the surface (though the presence of underground utility networks does not necessarily disqualify it), or its ability to provide a medium for plants". Such attempts at definition reflect how difficult it is to establish a binary classification given the significant variability of urban soils. Because of this, it seems more appropriate to talk in terms of an open ground" gradient, referring to several criteria including: surface covering, vertical continuity and depth, horizontal continuity (the "brown grid"), physical, chemical and biological soil quality, compaction and permeability.

(1) Surface covering (paving/sealing)

An obvious distinction can be made between sealed urban soils and soils that are not sealed or paved. This is not, however, sufficient to qualify a soil as an open ground.

(2) Vertical continuity and depth

For pedologists (soil ecology specialists) it is tempting to equate open ground areas with natural soils where there is continuity between soil horizons[3] and the water table or the geological subsoil. However, this situation hardly ever arises in densely built-up urban areas, where the subsoil is occupied by utility networks, tunnels, underground transport networks, sewers, car parks, basements, etc.). An overly strict definition would risk excluding degraded or modified soil that can be rapidly restored and requires protection. An excessively loose definition (accepting, for example, shallow soil depth) risks encouraging developers to lay out green spaces on concrete plazas. In certain sectors (for example dense city centre areas), it may thus be acceptable to refer to "substitute open ground", or "artificial soil" while defining a minimum soil depth.

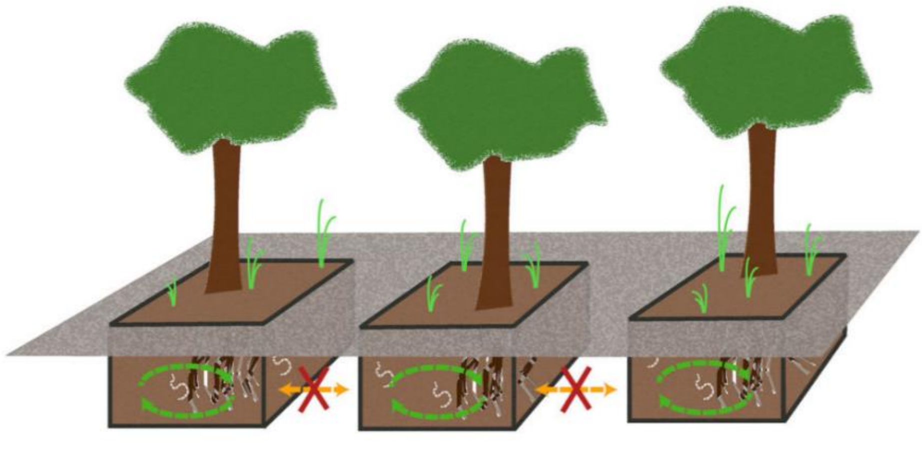
This could be determined by the depth and volume of soil required for plants, especially trees and shrubs, to grow. The depth to which the roots of trees and shrubs penetrate the soil is very variable as the architecture of root systems is primarily determined by the genetics of different species (*Atger*

[3] Pedologists in France have defined over 70 types of horizons (called "reference horizons"), which are listed in the *Référenciel Pédologique* (Pédologique, R, 2008). A distinction is generally made between: the organic horizon (Horizon O) which results from the transformation of plant debris that accumulates on the surface of the soil into organic material; Horizon A, which contains both organic and non-organic material and is the result of the work of living organisms in the soil (worms and insects); Horizon B, enriched with a range of organic and non-organic materials (clay, iron, organic material, calcium carbonate, etc.) resulting from the transformation of primary minerals from the bedrock; Horizon C is the substratum of weathered bedrock; and Horizon R or M is the layer of bedrock (R for hard rock (granite, sandstone, limestone) and M for loose material (sand, marl, etc.)).

& Edelin, 1994). According to some authors, the anchorage strength of adult trees (older than 50 years and over 20 metres tall) primarily resides in the upper layer of soil (to a depth of 60 cm) (*Drénou, 2006*) although depending on species and soil parameters, plants may reach down to different depths (*Gouedard, 2014*). In certain natural environments, bedrock lies near the surface (at a depth of 1.5 - 2.5 m) and constitutes a boundary beyond which roots cannot develop. As well as depth, the volume of soil available to a tree in an urban environment is an equally important parameter. In urban environments it is much lower than the volume naturally used by roots in unconstrained settings (*Lucot, 1992 in Gillig, 2008*), and the conditions of urbanised environments are all too often incompatible with the needs of trees (*Gouedard, 2014*). Given these different root strategies and depending on the urban context, it may be possible to determine, in certain urban areas, a minimum depth for soil to qualify as an open ground, which would correspond to the depth and volume required for trees to flourish. This approach must nevertheless be strictly limited to areas where it is no longer possible to ensure continuity with the water table and subsoil, and should not encourage the development of green spaces on concrete slabs.

(3) Horizontal continuity or "brown grid"

The "brown grid" is a concept based on the model of the Green and Blue Grid applied to connectivity between soils. Pedologists refer to "lateral horizons" stretching from a metre to a kilometre. Species present in the soil also need to move from one place to another (*Mathieu, 2015*) in order to complete their life cycle, to reproduce, to escape occasional changes in their environment, to recolonise an area after an episode of mortality, etc. (*Chalot, 2016*). When looking for open ground one must ensure that there are as few fragmenting elements as possible in the ground (concrete tanks, drainage pipes, etc.). In cities, certain areas where the soil is fragmented are no longer considered to be open ground especially places where there are isolated trees planted in individual trenches, compared to areas where rows of trees stand in adjacent trenches sharing the same mass of soil. The volume of such trenches in urban environments is seldom more than 4-9 cubic metres—though it can be up to 12 or even 24 cu.m. when financial resources allow (*Gouedard, 2014*). Using brown grids to ensure soil continuity would increase the volume of soil available for trees and facilitate rainwater permeation [5].



Soil fragmentation in urban areas © Romain Sordello (d'après Chalot, 2016). From [6]

(4) The physical, chemical and biological quality of the soil

Another dimension concerns the biological quality of the soil relative to its level of biodiversity. Several thousand animal species and several tens or even hundreds of thousands of bacterial and fungal species cohabit in just a few square metres of soil or humus (debris decomposing on the surface), all to a very shallow depth (sometimes less than a metre). In urban areas, several indicators can be used to assess the state of soil fauna and define the ecological quality of the soil (see Part 3). Degraded soils of low ecological quality or whose horizons have deteriorated may nevertheless be restored and referred to as “degraded open ground”

(5) Permeability

The last dimension concerns the permeability of urban soils, as an open ground has to allow permeation. Depending on the compaction constraints to which urban soils may be subject, this criterion could make it possible to distinguish open-ground soils that have retained satisfactory permeability from degraded open-ground soils that require restoration action.

Taking these criteria into account makes it possible to distinguish several different degrees of open ground, namely: **open ground** (natural urban soil); **degraded open ground**; **artificial soil (or substitute open ground)** and **absence of open ground (see table below).** This classification is offered as an indication. This type of approach requires in-depth knowledge of the soil and the use of cartographic tools to evaluate the state of the soil with regard to this gradient. This would help to improve representation of the soil in planning documents and facilitate soil protection or renaturing using objective criteria.

Table 2: Degrees of open ground

	Open ground	**Degraded open ground**	**Artificial soil (Substitute open ground)**	**Absence of open ground**
Vertical continuity (depth)	Yes, as far as the water table	Yes	No: minimum depth to be adapted according to volume of soil necessary for tree stratum	No
Permeability	Reference permeability by soil type	Low permeability, high compaction stress	Permeability possible if surfaces are not compacted	Lack of soil permeability
Horizontal continuity – brown grid	Across the whole site	Partial	Partial	No
Ground covering	No	No	No	Yes
Theoretical ecological quality (to be confirmed)	Good	Moderate to poor	Moderate to good	None
Integration in urban planning documents	Protection	Restoration then protection	Restricted to areas where the subsoil is already occupied by infrastructure	Renaturation

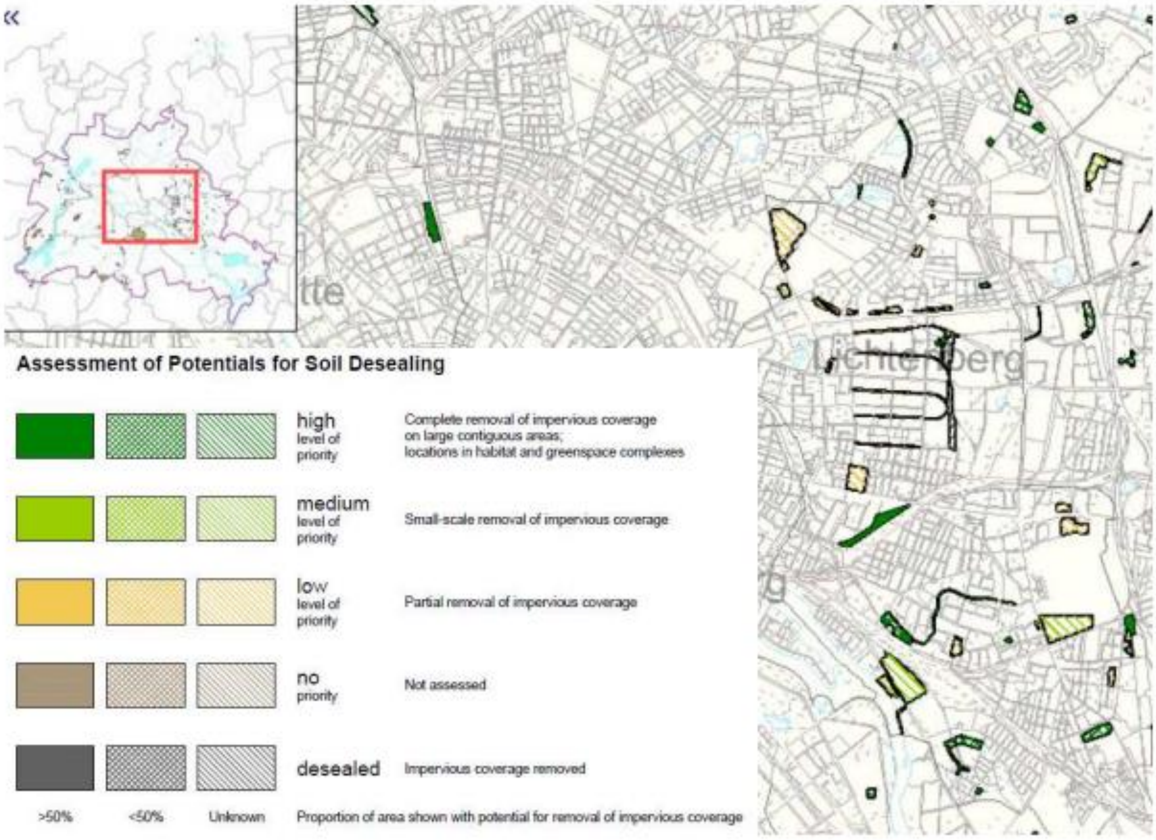
1.3.2 The need to renature sealed ground

Scientific and technical literature on renaturing sealed areas is still scarce. Several local authorities are increasingly removing sealed surfaces or buildings in the framework of compensatory measures (*Adobati et al., 2020*). Such approaches have also been adopted in Wallonia (2005), with the application of the Net Zero Land Take goal set by the European Union in 2016. Germany also has significant experience in this field (*Pileri, 2007*) with several desealing projects at regional level (Bade-Wurtemberg) and local level (Stuttgart and Berlin). In the 2000s, after the Elbe burst its banks, Dresden City Council defined a planning goal, which stipulates that built plots designed for housing and roads cannot account for more than 40% of total urban space. To achieve this, the council has created a "soil compensation account". In return, new projects on unbuilt plots must implement desealing measures in unused or abandoned areas. This public policy has given rise to a range of interventions including demolition, restoring rivers, rehabilitating contaminated waste ground, destroying farm buildings and removing asphalt from cycle lanes and footpaths in green corridors and green spaces. Since 2010, an average of about 4 hectares of land has been desealed annually in Dresden.

Our cities are full of areas that have been needlessly concreted or asphalted over and where nature could return and flourish. ©Marc Barra

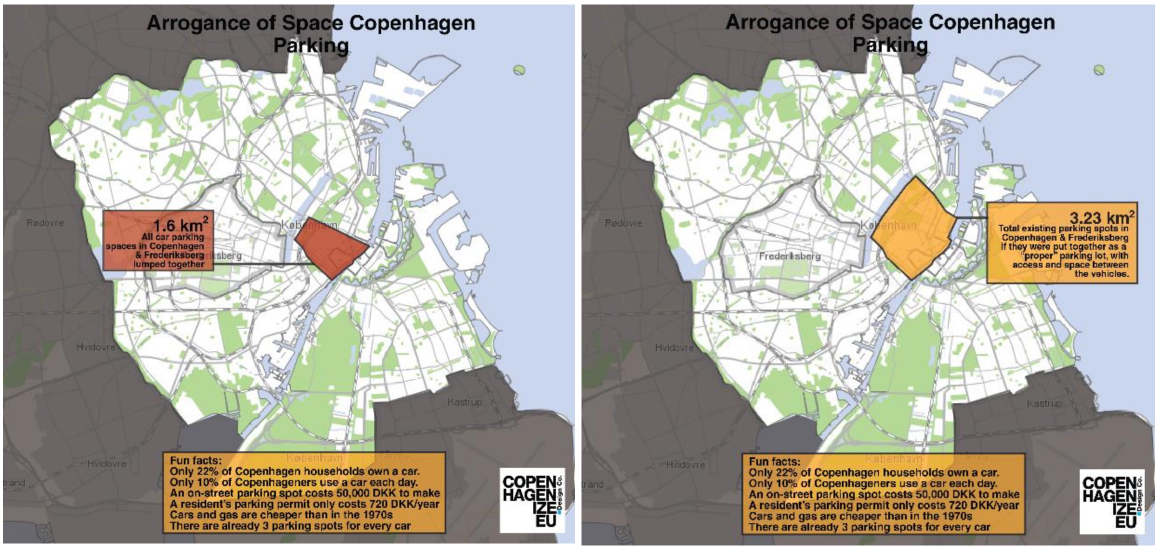
In urban areas, experiments involving the renaturing of sealed land have often taken place in the framework of rehabilitation projects for brownfield sites (*Atkinson et al, 2014*). The region of Emilia-Romagna in Italy introduced the concept of "incongruous buildings" in 2002, giving councils the opportunity to remove these "environmental detractors" that have a negative impact on ecology and the landscape (*Stanghellini 2010*). Other Italian regions have since taken similar steps, although with different objectives. Liguria, for example, has made it possible to demolish buildings to reduce exposure to flood risk and avoid the presence of human activities near rivers.

In Berlin, the local government has rolled out a strategy to identify desealable sites as part of the federal Zero Net Land Take programme. This strategy, titled Potential for the Removal of Impervious Soil Coverage 2020, is similar to the Net Zero Land Take programme rolled out in France and offsets new land take by renaturing sealed areas. It is part of a Soil Quality Atlas developed as a decision-making tool for the city's planners [7]. A survey carried out among council staff and the Forestry Department in Berlin has made it possible to create a database identifying potentially desealable zones. The study went further by classifying each site according to the feasibility and priority of renaturing initiatives. In 2020, of the 179 sites identified, 31 have already been completely desealed and 14 partially desealed.



Maps of areas eligible for de-sealing in the city of Berlin © Umweltatlas Berlin [5]

This work highlights the amount of available sealed areas in cities and the need for tools to characterise them. In Denmark, a cycling association has estimated how much space is taken up by parking spaces and car parks in Copenhagen. Placed side by side, parking spots would occupy a surface area of 1.6 square kilometres. If they were made into a single parking lot with spaces between the cars, it would cover 3.23 square kilometres.



Graphic showing how much space is allocated to car parking in Copenhagen ©Copenhagenize.com by Mikael Colville-Andersen

1.4 Renaturing and Net Zero Land Take

In France between 2006 and 2016, urban growth consumed about 20,000 hectares of land every year, at a rate faster than population growth (*France Stratégie, 2019*). In the Paris Region, despite a slowdown in 2012-2017, land take still consumes an average of 600 - 700 hectares of natural / agricultural soil per year depending on the data used[8].

In response, in 2018 the French government decided to set a Net Zero Land Take goal. This principle, which is written into the Climate and Resilience Act (Loi Climat et Résilience, August 2021), states that there must be a goal for reducing land take by the year 2031 and that Net Zero Land Take must be achieved by 2050. This goal must be written into regional planning documents before being applied to smaller administrative areas (*communes* and groups of *communes*: i.e. towns and villages). The implementation of the Net Zero Land Take goal requires a complex strategy that involves reducing urban sprawl by encouraging urban renewal and densification and using renaturing initiatives to restore land consumed by urban growth. Although achieving "net" zero land take implies a degree of flexibility, many authors stress that renaturing remains a significant technical and financial challenge and that the priority must be to avoid new land take by making do with what already exists (*Levrel et al, 2021*). Approved 25 years ago, the Paris Region Master Plan (SDRIF 1994) is currently under review. Net Zero Land Take is a unique opportunity to construct a new, more frugal model for land use that protects existing natural areas and encourages renaturing.

The question of which sites can be renatured remains; answering it requires both an assessment of existing sites and the availability of sufficient technical and financial resources. The French Climate and Resilience Act introduced a new definition of land take (*artificialisation* in French), which until then was limited to spaces that were not agricultural, natural or wooded. It stipulates that land take is said to occur "*if the occupation or use of the land durably affects some or all of its ecological functions, in particular biological, hydrological and climatic functions as well as its agronomic potential*" (*French Climate and Resilience Act, 2021*). This new definition lends new significance to green spaces and areas of open ground in urban environments (parks, gardens and areas of waste ground) initially considered as instances of "land take", but adds a new layer of difficulty: that of ensuring that such areas are protected (including in the framework of urban renewal programmes) and avoiding the pitfall of densification which can, in practice, lead to land take.

This new definition also reduces the scope of what constitutes land take to areas whose occupation or use has a significant impact on soil functions. Consequently, sealed areas covered with buildings, concrete or asphalt emerge as ripe for renaturing. This is consistent with recommendations from scientists to target areas with little or no greenery where renaturing would be of significant benefit, both in terms of bringing nature into the city and in terms of adapting to climate change and improving public wellbeing.

This is what lies behind the methodology described in this guide, which provides a tool for identifying sealed sites in urban areas, not randomly but in areas that present one or more key challenges to which renaturing is able to respond (e.g. adapting to climate change, improving the living environment or preserving biodiversity). On the scale of the Paris Region and in the framework of the SDRIF master plan review process, this work may make a valuable contribution to conversations on how to prioritise sectors for renaturing. While the regional scope of the master plan makes it possible to define large areas, the more local scale of the *département* and the *commune* seems more relevant when developing a renaturing strategy and building it into planning documents. Ideally it could be applied to regulatory zoning in the framework of local planning documents and guidelines by identifying "preferential renaturing zones" that would stand alongside guidelines relating to the green and blue grid.

2 IDENTIFYING AREAS WITH HIGH RENATURING POTENTIAL

2.1 Methodology

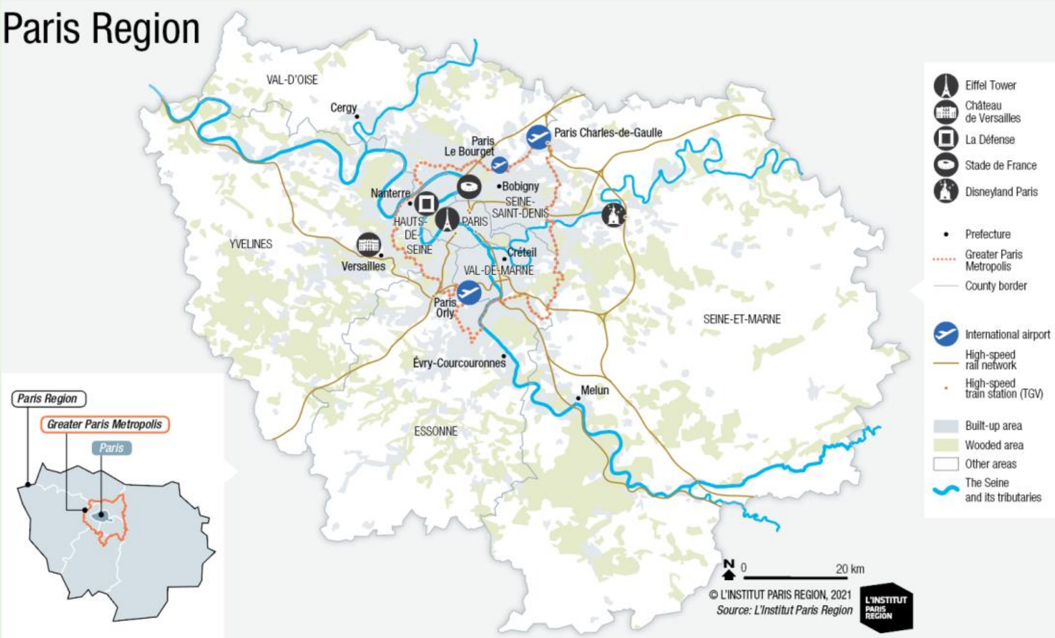
Whether they are striving to achieve Net Zero Land Take goals or carrying out voluntary renaturing strategies, local authorities first need to identify areas with high renaturing potential. The method described in this guide is based on 3 key challenges that make it possible to locate these urban areas:

- **Restoring biodiversity** on targets areas that are deficient in terms of biodiversity, by studying the size of green spaces; the type of plant cover; the presence of rare habitats; and ecological connectivity.
- **Adapting to climate change** on targets areas exposed to climate risk: river flooding, runoff and urban heat islands.
- **Improving health and the living environment** on targets areas that are vulnerable because of lack of green spaces, air pollution and health problems relating to urban heat islands.

This methodology was carried out using a GIS approach (the flowcharts in Appendices 6-10 outline the analytical steps carried out). In order to carry out this analysis, the Paris Region was divided into 125 m x 125 m cells (cell size compatible with the data and studies of the Paris Region Institute). For each challenge (biodiversity, climate change and health), criteria were selected based on advice from experts and available data on the region.

The state of each cell is analysed and converted into a score. For example, a cell exposed more or less significantly to air pollution is given a score that reflects this. A score is thus attributed to each criterion, and then an overall score is given to each challenge. The attribution of overall scores corresponds to the sum total of individual scores for criteria, and the criteria are not weighted in any way. The thresholds that make it possible to attribute scores were based on studies and bibliographical summaries as well as interviews with experts. The results are summarised in Part 2 (tables 4, 6 and 9).

Once the different criteria have been analysed and the overall score attributed, the cells for which the stakes are highest are identified. These are chosen according to their score (a low score reflects high stakes) and also according to how many of them there are (having too many cells might highlight an entire area and prevent prioritisation). This first step makes it possible to identify sectors where potential for renaturing is high, but it does not pinpoint sealed sites that could be renatured. To do this, potentially desealable / renaturable sites (school playgrounds, car parks, areas of waste ground, public squares, etc.) were listed based on the land use classification guidelines laid out in the *Mode d'Occupation du Sol* (MOS) published by the Paris Region Institute (cf. Part 2.2).



Paris Region, also called "Île-de-France", is a province located in the north-central part of France. It includes the city of Paris and 1,275 municipalities around the capital-city. Paris region is the most populated province of France (12 millions inhabitants, which means 20% of the French population concentrated in only 2% of France area ; 1,022 inhabitants per sq.km.). Twenty-three percent of the territory is covered by urban areas (including 16% totally sealed). The outer parts of the Ile-de-France remain largely rural with agricultural landscapes (51% - mainly intensive open fields) and forests (24 %).

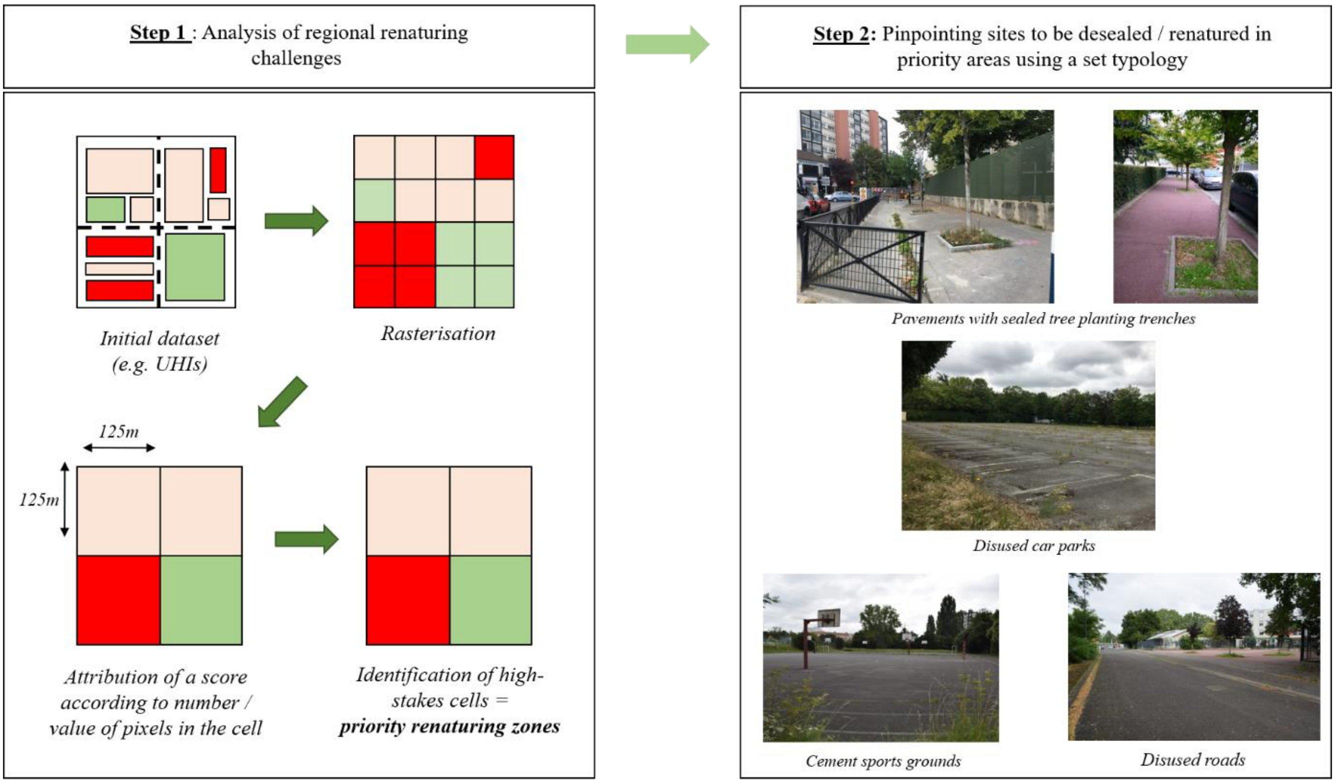


Figure 3: Graphic showing the method of spatial analysis used

2.2 Typology of potentially renaturable sealed areas

The approach outlined here mainly seeks to identify sealed areas, in other words areas covered by buildings, asphalt or concrete and where land take is at its most extreme. These might be oversized car parks, school playgrounds, the courtyards of buildings, riverbanks lined with concrete, residual unused public space that has been needlessly asphalted over, factories, occupied or disused business parks or shopping centres, dilapidated buildings, etc., where renaturing would be of significant ecological benefit.

The typology used here, based on the Land Use Classification Guidelines published by the Paris Region Institute, identifies urban areas containing easily renaturable sealed surfaces (without requiring the demolition of existing buildings). The list is based on available data and is not exhaustive: for example, small areas such as the space at the foot of a wall or the space between two trees planted in trenches cannot be located using this method. It nevertheless targets both small and large areas, making it possible to work on a regional or sub-regional scale.

Table 3: Typology of potentially renaturable sealed areas based on Paris Region Institute Land Use Classification Guidelines

Typology: level of detail 1	Typology: level of detail 2	Typology: level of detail 3
Open spaces where land take has occurred	Public squares	Public squares (pavement, asphalted path, plaza)
	Urban green spaces	Parks or gardens (associated car parks, roads, asphalted paths)
	Open spaces intended for sport	Open-air sports grounds (associated car parks, unused sports grounds, areas around sports grounds that are in use)
		Large-scale sports facilities: golf courses, racecourses (associated car parks, concrete slabs)
	Cemeteries	Cemeteries (concrete slabs, asphalted paths, associated car parks)
	Vacant lots/waste ground	Brownfield sites (concrete slabs, disused buildings)
		Disused facilities: stations, airports, factories (concrete slabs, disused buildings)
Housing	Collective housing	Residential buildings (inner courtyards, concrete slabs, unused car parks, pavements)
	Other	Prisons (yards, areas around sports grounds, car parks)
Roads	Associated structures	Roundabouts
		Cul-de-sacs
		Central reservations
	Roads	1 lane
		2 lanes

		> 2 lanes
	Disused roads	
	Pavements (= sidewalks)	Pavement > 1,40m
		Pavement with row of trees
Transport	Roads	Roads over 25 metres wide (urban freeways, disused roads)
	Car parks	Ground-level car parks (circulation areas, areas separating parking spots, parking spots)
	Stations	Stations (car park, square)
		Edges of tracks
	Railways	Disused tracks
Facilities	Schools and colleges	Primary schools (playgrounds, edges of sports grounds)
		Secondary schools (playgrounds, edges of sports grounds)
		Higher education (edges of sports grounds)
	Hospitals and clinics	Hospitals, clinics (car parks, concrete slabs, plazas)
	Public facilities	Town halls (squares, car parks)
		Conference and exhibition centres (concrete slabs, car parks)
		Cultural/Leisure venues: museums, castles, etc. (car parks)
Activities	Economic and industrial	Water and sewage
		Large industrial facilities (dilapidated areas, car parks, pavements)
		Business parks (dilapidated areas, car parks, pavements)
	Shopping	Shopping centres (car parks, pavements, squares)
Water courses	Covered rivers	Covered rivers
	Rivers	Riverbanks
		Asphalted paths
	Canals	Banks
		Artificial riverbeds
		Asphalted paths

2.3 Renaturing to restore biodiversity

Since the 2000s, biodiversity had declined sharply in towns and cities. In the Paris Region, the abundance of butterflies has fallen 33% and that of birds has fallen 20% in urban areas (*Muratet et al, 2016*). In addition to species decline, the urban environment has also witnessed a process of homogenisation favouring generalist species (e.g. wood pigeons and magpies) to the detriment of specialist species (e.g. swallows and swifts). The population abundance of these specialist birds adapted to buildings fell by 41% between 2004 and 2017 (*Muratet et al, 2016*). These trends, which are sharper than the national average, reflect high population density (1,022 inhabitants per sq.km.) and the lack of greenery in the region's urban environments whereas they only represent 23% of its total surface area.

To identify the urban areas to be renatured in order to restore biodiversity, it is important first to locate zones where biodiversity is lowest and where renaturing would offer high ecological gains. Our methodology relies on several criteria drawn from scientific literature and is inspired in particular by *Making Nature's City (Spotswood et al, 2019)*. In accordance with the data available on the Paris Region, 4 criteria were selected: the planted surface areas; the type of plant cover; the presence of rare habitats; and ecological connectivity.

2.3.1 Selected criteria for locating areas of low biodiversity

Table 4: Criteria, thresholds and bibliographical resources used to identify areas of low biodiversity

Criteria	Thresholds	Score	Source
Surface area of planted areas	Absent	0	*Vega & Küffer, 2021; Spotswood et al, 2019; Beninde et al, 2015*
	≤ 4.4 ha	1	
	> 4.4 ha – < 53.3 ha	2	
	≥ 53.3 ha	3	
Plant cover (%)	< 25 %	0	*Threlfall et al, 2017; Szulczewska et al, 2014*
	> 25 % – < 45 %	1	
	≥ 45 %	2	
Rare habitats	None	0	
	Notable trees	1	*Spotswood et al, 2019; Stagoll et al, 2012; Le Roux et al, 2015*
	Ponds	1	*Spotswood et al, 2019; Ramsar Convention on Wetlands, 2018; Oertli and Parris, 2019; Alikhani et al, 2021*
	Wetlands	2	
Connectivity	areas of ecological interest under urban pressure	0	*Cornet, 2021*
	No areas of ecological interest under urban pressure	2	

Continuous planted areas

The size of planted areas is one of the main factors that determine biodiversity in urban settings. The larger a habitat[4], patch[5] or reservoir of biodiversity is, the more likely it is to be home to a diverse range of species (*Strohbach et al, 2013*). In the Paris region, on average, the surface area of green spaces is 16 times larger in the outer suburbs of Paris than in the inner suburbs. This results in a reduction of favourable habitats and thus a reduction in the size of species populations and higher risk of extinction in the densest areas[6].In a study of 75 cities, researchers have shown that to support biodiversity adapted to the urban environment, the minimum size of a habitat is **4.4 ha**. Where more sensitive species that usually stay away from cities are concerned (so-called "urban avoiders"), this rises to **53.3 ha** (*Beninde , 2015*). On the basis of this information, the following types of areas have been identified in urban environments:

- **Micro-patches**: planted areas less than 4.4 ha;
- **Patches**: planted areas measuring 4.4 – 53.3 ha;
- **"Areas of special regional interest" [*réservoirs d'intérêt regional*]**: planted areas larger than 53.3 ha.

For this criterion, the score was applied in the following way: the presence of a micro-patch in a cell gives it a score of 1, a patch gives it a score of 2 and an area of special regional interest earns it 3 points. If there are no green spaces at all, it scores 0. Where 2 green spaces of different sizes are present in the same cell, only the most promising one is taken into account.

GOING FURTHER

Although not included in the analysis, private gardens contribute to the green grid (*Riboulot-Chetrit, M., 2015*) and can serve as refuges and stop-off points for many species, especially if they are ecologically managed (*Goddard et al, 2010*). Adding this data, as well as an ecological quality index for urban green spaces (based on species diversity, plant strata, management methods, etc.) would make it possible to fine-tune the ecological analysis of a region.

---

[4] In ecology, a **habitat** is a set of characteristics and natural resources that constitute an environment allowing a species population to live and reproduce there. A single habitat can meet the needs of several different species. Diverse interconnected habitats form an ecosystem that allows numerous species to thrive and move around.

[5] In ecology, a **patch** is a relatively uniform space that differs from its surroundings. Parks and areas of grass within a built-up area can be considered as patches.

[6] Proceedings of the Natureparif conference, 2016, "ecological continuity in urban environments: results of research and action"

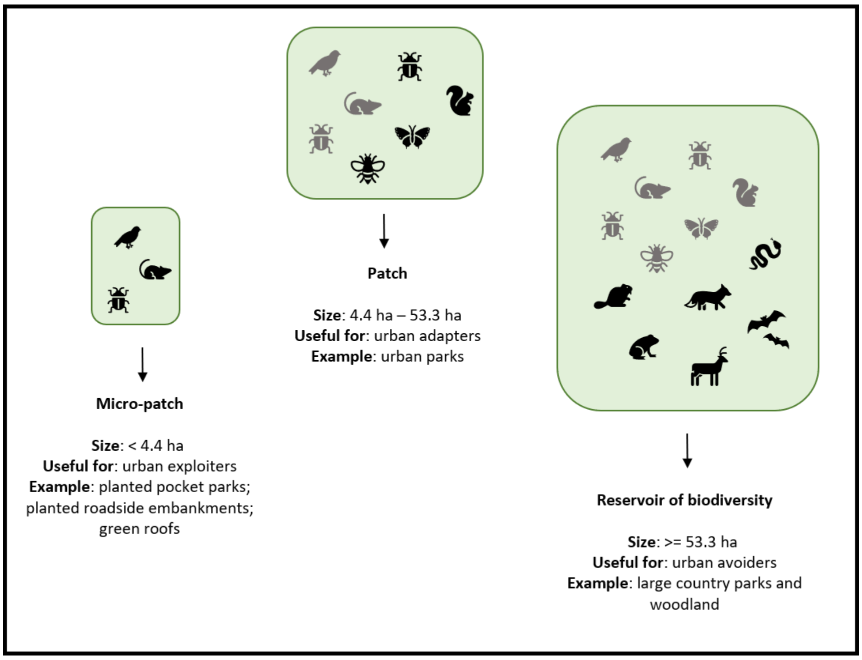


Figure 4: Illustration of the link between size of habitat and specific diversity

Plant cover in the urban matrix[7]

Several studies have highlighted the importance of plant cover and its positive effect on the number of species present in urban areas (*Aronson et al, 2014*). While urban environments are made up of built-up areas with little greenery, they also feature many planted areas (rows of trees, hedges, gardens, waste ground, riverbanks, cemeteries, etc.) that can provide habitats for numerous species. These spaces can be looked at by analysing satellite images that show the surface area occupied by plant cover. It is generally accepted that the more highly developed plant cover is in a particular area, the more able that area will be to host biodiversity (*Threlfall et al, 2017*).

The difficulty lies in the definition of a threshold above which plant cover begins to offer optimum conditions for biodiversity. In a Polish study (*Szulczewska et al, 2014*), researchers suggest that a minimum of 45% of spaces covered in vegetation (RBVA index[8]) is necessary to provide environmental stability on the scale of the local area. Taking this hypothesis into account, 3 thresholds were selected for our study: a score of 0 for cells where plant cover is less than 25% of the total area; a score of 1 for plant cover of 25% to less than 45%, and a score of 2 for areas that have 45% plant cover or more.

[7] The urban matrix is here considered to be the set of elements that make up the urban landscape (buildings, roads, etc.), within which can be found patches of greenery that lend themselves to biodiversity. Landscape ecologists also refer to the landscape's ecological matrix, which means the dominant feature of the landscape characterised by a more or less uniform occupation of the land (forest matrix, hedgerow matrix, field matrix, etc.), and in which habitat patches can be discerned.

[8] The study uses the RBVA or Ratio of Biologically Vital Areas, which means the percentage of areas covered in vegetation across a neighbourhood. Different levels of RBVA were compared on the basis of species inventories and calculations of climate-related parameters.

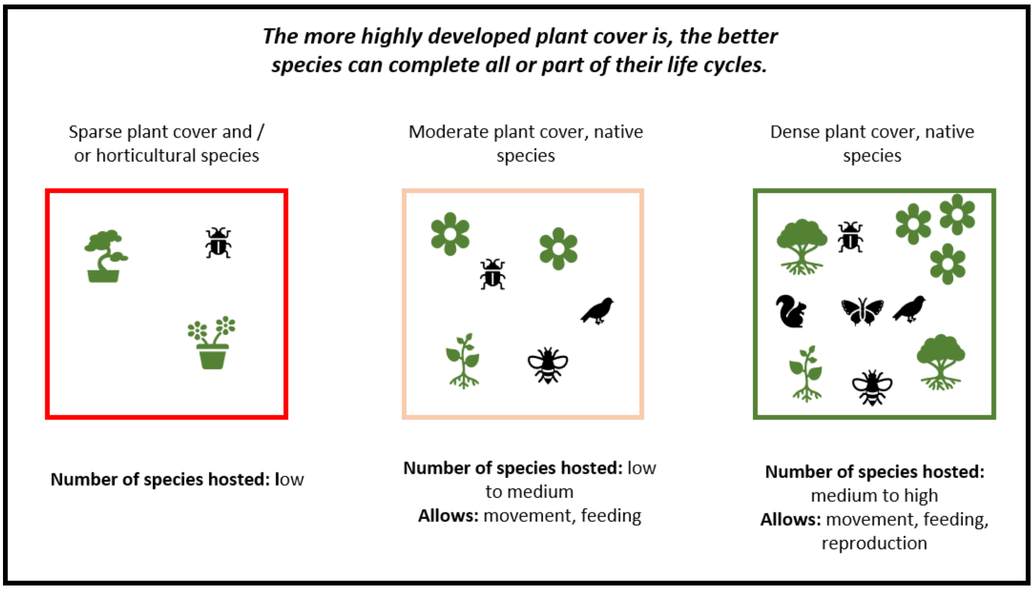


Figure 5: Illustration of the link between plant cover and the presence of species and their life cycles

GOING FURTHER

Percentage of plant cover is only a quantitative criterion, and it has its limitations. A more detailed analysis of different plant strata (herbaceous plants, shrubs and trees) would better reflect the ecological quality of these environments. These strata do not provide the same kinds of habitats and thus do not host the same species. For example, trees correlate positively with the presence of birds, but negatively with the presence of insect pollinators (*Brunbjerg et al., 2018*). It is generally accepted that the presence of all 3 types of strata, made up of local species, maximises biodiversity (*Threlfall et al, 2016; Beninde et al, 2015*). The type of plant species can also influence the ecological quality of an environment. More birds and butterflies and greater species diversity are to be found in areas dominated by native plant species (*Burghardt et al, 2009; Kurylo et al, 2020*). To enrich this analysis, it would be interesting to undertake a study to quantify the different strata and the proportion of native and non-native species in a particular region.

Habitats that are rare in urban settings

Some habitats able to host a high level of biological diversity or specialised species are rarely found in urban areas: for example, wetlands or old trees are ecological niches in which many cohorts of species can thrive (*Stagoll et al, 2012; Hill et al, 2017*). Wetlands (including ponds, lakes, streams, rivers and marshland) play a vital role in terms of the ecological services they provide and also as habitats for many different species (amphibians, Odonata, avifauna) (*Ramsar Convention on Wetlands, 2018; IPBES, 2019*).

In urban areas, these habitats also offer a refuge for more specialised and even rare species (*Oertli et Parris, 2019; Alikhani et al, 2021*). Large old trees also play an essential role in conserving biodiversity in urban environments (*Stagoll et al, 2012*): they host more species than smaller trees and offer more diverse habitats due to their age (holes, dead wood, etc.). They are sometimes the only habitats for very specialised species such as saproxylic insects. In response to the decline in old trees in urban areas, an Australian study recommends prioritising the conservation of large old trees and protecting them for longer than their currently accepted lifespan (*Le Roux et al. 2014*).

The absence of such “rare” habitats in an area can reflect a “biodiversity deficiency” that could be remedied via a renaturing strategy. The method analyses the presence or absence of 3 types of habitats: notable trees[9], ponds, and other wetland areas. A score of 1 is given to cells in which one or more notable trees are to be found (irrespective of the number of notable trees in the cell); 1 point is awarded to cells where there are one or more ponds; 2 points are given to cells where there is a wetland area (marshes, peat bogs, lakes, wetland meadows, marshy woodland). The scores can be accumulated. Natural and semi-natural riverbanks are also considered as “rare habitats” in urban areas. They provide habitats for wild species, unlike sealed riverbanks.

Ecological networks and connectivity

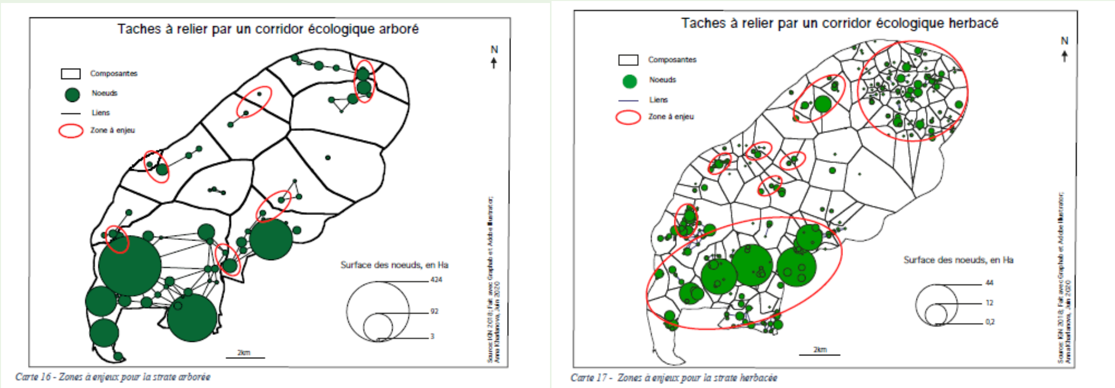
The last criterion selected refers to another fundamental dimension of biodiversity in urban environments: ecological connectivity, whose importance in urban environments has been demonstrated in a number of studies (*Shanahan et al, 2011*). Making it easier for species to move around increases genetic mixing between populations and maintains dynamic, adaptable and resilient ecosystems. On the regional scale, the components of green and blue grids are shown in the framework of the SRCE (Schéma Régional de Cohérence Ecologique/Regional Ecological Coherence Plan), whose aim is to preserve, restore and maintain ecological continuity. However, the SRCE is not sufficiently detailed and precise on the scale of dense urban areas to be used at sub-regional level in renaturing projects.

To take this component into account, data produced in the framework of a study aimed at restoring ecological continuity in urban environments was used (*Cornet, 2021*). This data pinpoints areas of particular ecological interest (because they feature a biodiversity corridor/reservoir or host protected species) that are (or have been) subject to pressure (from urban growth for instance). The cells located on these sites score 0, while the others score 2 points, which reduces the overall score of cells where renaturing would make it possible to restore ecological networks. Renaturing these areas, as well as increasing their overall capacity to host wildlife, would make it possible to help reconnect existing biodiversity reservoirs.

GOING FURTHER

The Environment92 association has produced a map of vegetation in urban areas based on very high-definition aerial photographs taken in the *département* of Hauts-de-Seine. In order to show areas of ecological continuity, graph theory was used as an assessment tool for urban biodiversity in the area studied. The connectivity of ecological networks was studied, based on 4 species (European hedgehog, Myotis bechsteinii (a species of bat), great tit and meadow brown butterfly). This work provides a more detailed overview of urban areas to be renatured with a view to improving the connectivity of ecological networks. It could be built into the methodology for a more precise approach to spaces earmarked for renaturing in order to foster biodiversity.

[9] Notable trees are trees that have been identified for their outstanding features (beauty, age and/or size). Although old trees are not always labelled “notable”, most of those that are have high potential for biodiversity. The data used here comes from notable trees in the Paris Region. Data at sub-regional level would provide this study with an added level of detail.



Maps showing sectors of special value for a connected network of trees and herbaceous plants for the European hedgehog © Environment92

2.3.2 Where should renaturing take place in order to restore biodiversity?

In keeping with the method detailed in section 2.1, low-scoring cells (with a score between 0 and 3) were defined as priority renaturing zones. Spatial analysis reveals that the urban zones with least biodiversity are located in the city of Paris. Where the inner suburbs are concerned, the least favourable zones are generally close to Paris and thus correspond to areas that come under pressure from urbanisation and densification, which have adversely affected biodiversity.

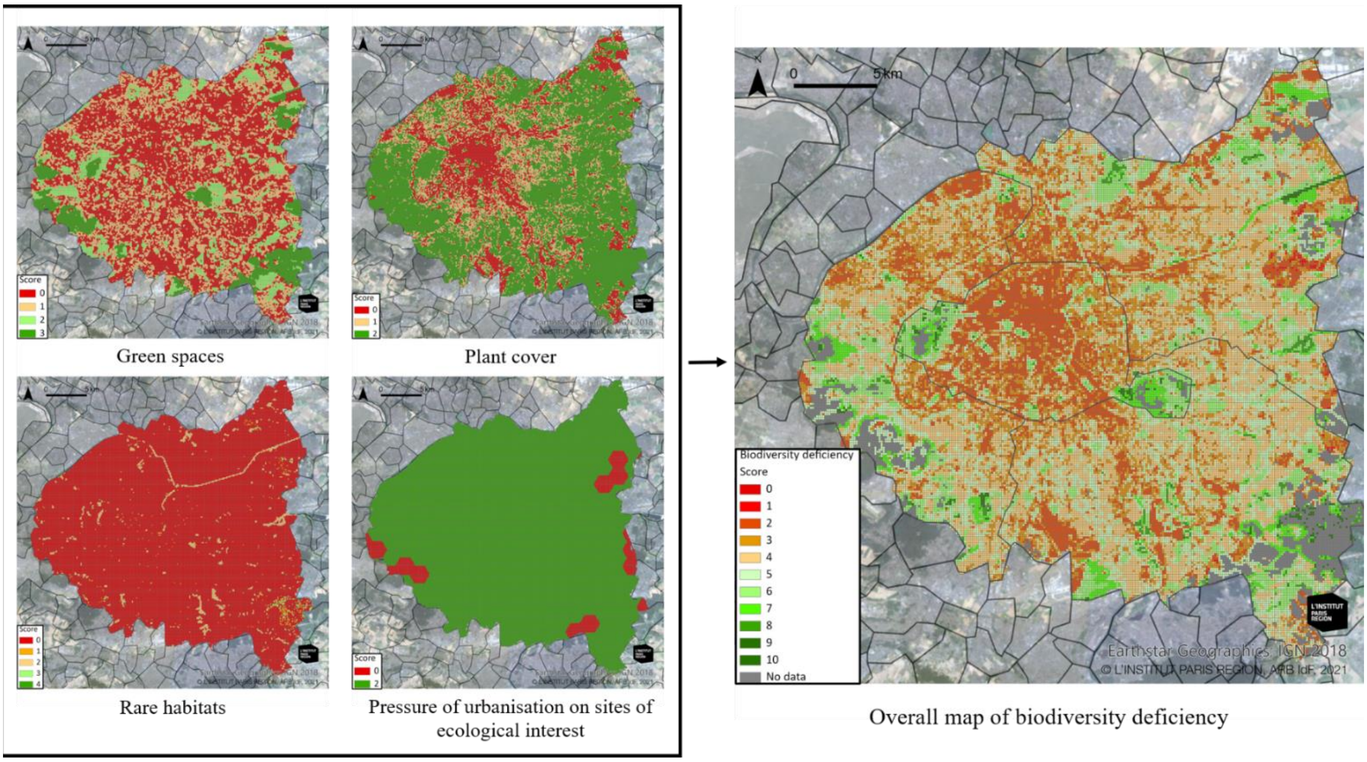
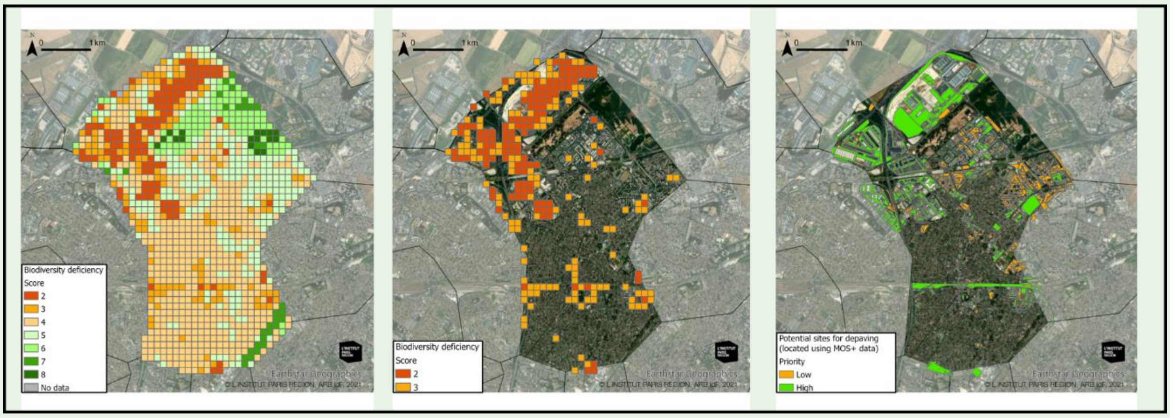


Figure 6: Once the individual criteria had been studied, the points were added up to obtain a final score, resulting in an overall map of biodiversity deficiency

EXEMPLE OF HOW THE METHODOLOGY WAS APPLIED IN THE TOWN OF AULNAY-SOUS-BOIS



Overall map of biodiversity deficiency → Identification of areas with high biodiversity deficiency → Identification of potential sites for desealing to restore biodiversity

Figure 7: Identification of desealable sites in areas most likely to benefit from renaturing to restore biodiversity in Aulnay-sous-Bois (Paris Region, département *of Seine-Saint-Denis)*

Applied to the town of Aulnay-sous-Bois, the analysis reveals a total of 264 highly deficient cells in terms of their biodiversity (scoring 2 or 3). Renaturing needs are mainly concentrated in the northwest of the area, which corresponds to an extensively sealed industrial zone. In terms of biodiversity, this zone has special potential because it is adjacent to the Parc du Sausset (in the northeast of the *commune*), which is remarkable for its biodiversity, classified Natura 2000 and identified as a reservoir of biodiversity in the Ecological Coherence Plan. In the rest of the area, 144 cells suggest high overall quality in terms of biodiversity (scoring 6, 7 or 8). These correspond to the Parc du Sausset and the Parc Robert-Ballanger (in the northeast) and the banks of the Canal de l’Ourcq (in the southeast). 747 cells score 4 or 5, which cannot be interpreted as “high quality” but does not represent a major deficiency.

Aulnay-sous-Bois is a commune in the Seine-Saint-Denis *départment* in the Île-de-France region in the north-eastern suburbs of Paris, France.

2.3.3 Feedback and recommendations

Any renaturing initiative, irrespective of its location, can help to improve biodiversity. However, the benefits can be more or less extensive according to the location of the project. It is thus necessary to contextualise renaturing initiatives and not make general assumptions based on the restoration of a single type of habitat. What can be beneficial to one location might turn out to be inefficient and inappropriate elsewhere. With respect to the criteria selected for this approach, several types of recommendations can be made, in particular:

- Re-establish connections between patches of habitats and existing biodiversity reservoirs
- Extend a reservoir, patch, or area of ecological interest whose size is judged to be inadequate
- (Re)create a habitat or ecological niche for species that are fragile in urban environments or for a community of target species
- Allow waste ground/brownfield sites to evolve or recover freely.

EXAMPLE OF INTERPRETATION OF CARTOGRAPHIC RESULTS OBTAINED FOR BIODIVERSITY DEFICIENCY

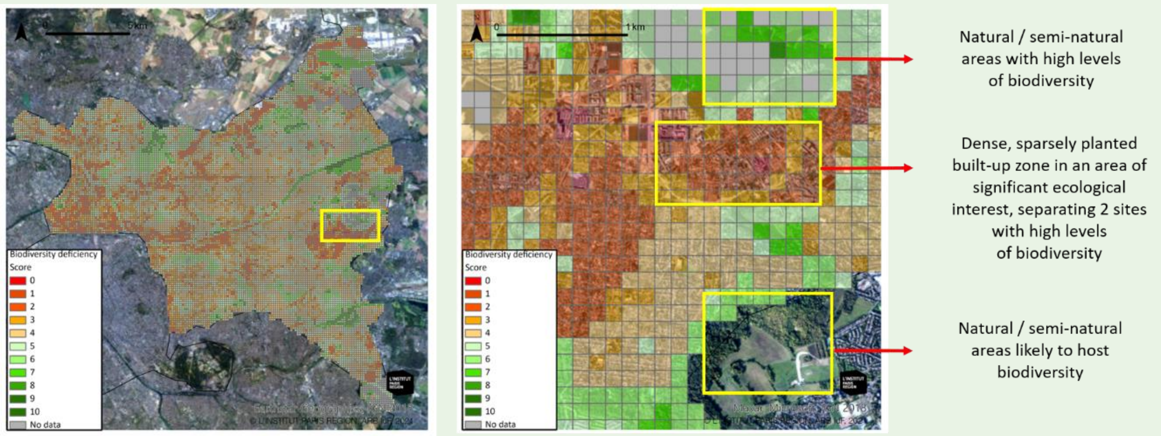


Figure 8: Overall map of biodiversity deficiency in the commune *of Montfermeil and example of interpretation*

The map shows that in the *commune* of Montfermeil there is a sparsely planted urban area with significant biodiversity deficiency. This zone causes a break in continuity between two natural/semi-natural areas. Renaturing part of the identified zone would make it possible to reconnect these two natural areas.

Renaturing to create and/or increase the size of habitats

With this in mind, focusing on extending existing planted areas can help to expand natural spaces in urban environments, in relation to the thresholds presented on figure 4 / appendix 1. The areas to be desealed will be smaller and the newly renatured area will directly benefit species already present in the park or planted area that has been enlarged. Given that there is an existing natural area nearby, the chances of recolonisation will be higher and better suited to so-called “passive” renaturing. Extending an existing natural area may also target the conservation of a specific group of species, based on knowledge of their ecological niche (see table in appendices).

Project 1: rehabilitation of the Kodak factory
In brief: rehabilitation of a brownfield site to turn it into an area of high ecological value.

The former Kodak industrial brownfield was demolished and replaced by a park with a wide variety of habitats ©CDC Biodiversity

Since the demolition and decontamination work at the Kodak factory in Sevran ended, the 13- hectare site has been left untouched, allowing a range of species to reclaim it as their home. In 2015, based on the results of naturalist inventories, the town council decided to preserve the Kodak brownfield site without further intervention: its various environments, coupled with its size and location, make it into a refuge for urban biodiversity and provide an opportunity to reinforce the ecological continuity of a highly urbanised area. In 2017, CDC Biodiversité and Sevran Town Council adopted a plan for the management of the site in the framework of the Nature 2050 programme [9]. This document sets out objectives for maintaining existing habitats and recommends allowing spontaneous evolution in some areas. Among other things it recommends proceeding with the ecological restoration of several wetlands; allowing some areas of grassland to recover spontaneously; allowing 3 hectares of woodland to evolve freely; and setting up scientific monitoring programmes to assess the impact and relevance of each management approach.

KEY TAKEAWAYS

- Biodiversity is richer in brownfield sites than in managed parks and gardens because it is able to develop freely.
- Brownfield sites can function as networks and exchanges for seeds and species. Sites larger than 2,500 m^2 could foster inter-site species exchange, reduce the risk of extinction for plant populations, and supply seeds that could colonise other sites. (*Muratet et al, 2007*)

- 2,700 brownfield sites have been identified in the Paris Region in the framework of the Brownfield Observatory set up by the Paris Region Institute. Those that are of most value in terms of biodiversity, for example because they form part of the urban green grid, should be protected and/or showcased.

Improving or restoring ecological continuity

Making it easier for species to move from place to place increases genetic mixing between populations and maintains dynamic, adaptable and resilient ecosystems. Renaturing in urban areas can also help to reinforce ecological connectivity and restore green, blue, brown or black grids. Carefully chosen sites can resolve lack of continuity between adjacent habitats, enlarge an existing corridor or create an extra habitat that acts as a stepping stone. The varied range of recreated habitats and the management methods adopted will also be decisive factors in ensuring the functionality of the different grids. The proposed methodology offers an initial approach to sectors where renaturing could improve ecological connectivity, although further studies must be carried out locally in order to maximise the likelihood of success for the target species and grids concerned.

Project 2: renaturing brownfield sites in the Maubeuge-Val de Sambre area
In brief: renaturing brownfield sites to reinforce the green and blue grid.

A former power station, the Pantegnies site is now listed as a reservoir of biodiversity in the Val de Sambre Green and Blue Grid Protocol. The site is a corridor and migratory stop-off point for many species © Community d'agglomération Maubeuge Val de Sambre

In a context of large-scale deindustrialisation, the Maubeuge-Val de Sambre Council has engaged with a number of non-profit and institutional partners on renaturing brownfield sites. These are mostly built sites that have been decontaminated, desealed, restored and returned to nature. This approach is even more interesting because the council previously identified and mapped these sites in order to adopt a renaturing strategy that would enhance ecological continuity across the area it administers.For example, creating a marsh and regenerating trees in a wetland meadow on the Pantegnies site earned it classification as a *Réserve Naturelle Régionale* (RNR: Regional Natural Reserve) in 2013. The former CLECIM site, once home to an armaments factory, is now officially listed as an ecological corridor in the Val de Sambre Green and Blue Grid Protocol. It mainly comprises woodland allowed to develop freely.

KEY TAKEAWAYS

- Restoration of ecological continuity in urban environments can entail reconnecting isolated patches of habitat, enlarging existing patches or corridors, or creating "stepping stones"[10] between patches of habitat within an urban matrix.
- Interruptions to continuity (asphalt, infrastructure, fencing, walls, urban furniture, etc.) need to be removed, and in certain cases crossings need to be provided for certain species. Renaturing a network of sites can significantly increase the benefits.

Project 3: buildings deconstruction: an opportunity for renaturing
In brief: study in Cleveland (USA) of the potential of demolishing buildings on vacant land to increase urban biodiversity.

Demolition of buildings in Cleveland and seeding of fescue grasslands ©Perry et al., 2020

In the United States, the city of Cleveland (Ohio) has undergone an industrial and demographic crisis leading to the closure of many factories. Between 2006 and 2010, the city's housing department demolished 5,152 buildings (factories and individual houses), leading to a significant increase of vacant lots. Today, the city has almost 1,400 hectares of wasteland, a large part of which belongs to the municipality. This unprecedented situation has become an opportunity to reimagine the city and study the role of these spaces for urban biodiversity. In a prospective study, several scenarios were proposed to give new uses to the sites freed from construction, such as urban agriculture, water management

[10] Here "stepping stones" refers to a discontinuous ecological corridor made up of intermediate spaces or refuges (ponds, copses on cultivated land, etc.)

through natural spaces (nature-based solutions), the creation of green spaces for the population or the development of renewable energies [10].

Between 2013 and 2019, researchers studied the role of these vacant lots as potential habitats for pollinating insects (*Gardiner et al., 2013; Turo & Gardiner, 2019*). Forty plots were surveyed. Despite their small size, all plots supported large and diverse populations of wild bees. A total of 107 species were inventoried, most of which were native, representing approximately 20% of the total bee species found in Ohio. This research shows that soil newly freed from building cover can become a host site for biodiversity within a few years. The researchers' observations confirmed the importance of pioneer and spontaneous vegetation for wild bees, as well as intentionally planted species for pollinators. On a landscape scale, the combination of these vacant lots and their networked functioning is an important factor in maintaining bee communities. While the deconstruction of buildings is still infrequent in the city and difficult to implement, the case of Cleveland offers an unprecedented example of de-densification of the city and reconstitution of a network of wastelands actively participating in the urban green grid.

Project 4: restoring an urban river and creating a network of ponds
In brief: restoration of a river and creation of a corridor for green toads.

Spontaneous recolonisation of flora in and around the renatured Ostwaldergraben. ©Rémy Gentner

In the 2000s, the Strasbourg Metropolitan Council undertook to resolve ecological discontinuity identified in its Green and Blue Grid Protocol. The project had a twofold aim: to renature the Ostwaldergraben, a river in poor ecological condition, and to create a corridor to allow European green toads (Bufo viridis) to move between two wetlands located upstream and downstream respectively. Several operations were carried out over a period of ten years:

- The riverbed was narrowed and new meanders created to manage its flow.
- Earth bunds installed along the Ostwaldergraben were removed in order to physically reconnect the minor and major beds.
- Under the Ostwald road bridge (a wildlife blackspot), crossing platforms were installed in the water to allow wildlife to cross safely.
- The natural establishment of flora in the new bed made it possible to create new aquatic habitats and to improve water quality.
- Creating a network of ponds along the river reinforced the ecological corridor opening onto the Ostwaldergraben.
- Several nature inventories have demonstrated how successful these developments have been: green toads colonised the site and reproduced the same year the work was carried out.

KEY TAKEAWAYS

- As the notion of connectivity is hard to define and varies from one species to the next, it is possible to rely on average values recorded in scientific studies that can be applied to several groups of species. For example, several studies indicate that a green space located over 300 metres away from another is considered to be "disconnected" for butterflies (*Shwartz et al, 2013*), plants (*Muratet et al, 2008*) and birds (*Hostetler & Holling, 2004*).
  In natural environments, the wider and more continuous corridors are, the more efficient they are and the more likely they are to host numerous species (*Ford et al, 2019*). This principle can also be applied in urban settings by giving preference to wide corridors, for example along watercourses or linear infrastructure. The appropriate size of the corridors varies, however, according to the species being targeted, making it necessary to carry out a preliminary study.
- When urban morphology does not allow the creation of corridors, the presence of numerous interconnected natural areas may be an efficient alternative. A Swiss study shows that areas smaller than 20 sq.m. can provide habitats for several species. Continuity between such areas must be maintained by ensuring they are no more than 50 - 200 metres apart, especially in densely populated areas where large green spaces are scarce (*Vega & Küffer, 2021*).

Project 5: renaturing riverbanks via plant-based engineering techniques
In brief: renaturing and managing the banks of the Seine by a social and work integration association.

Planting carried out by the association Espaces along a 150-metre stretch of the Seine at l'île de Puteaux. ©Association Espaces

The Paris Region has miles of artificial riverbanks (lined with riprap, concrete embankments or sheet piles), especially along the Seine. The decline of natural riverbanks has led to loss of habitats for wildlife. Since 1999, the Espace association has been renaturing the banks of the Seine, restoring ecological corridors and the functions of these ecosystems (by regulating the physical, chemical and hydro-morphological quality of the river). The association uses ecological engineering techniques such as spiling (willow wands woven between upright posts) and planting beds of bog plants to limit riverbank erosion and restore habitats. In some areas, reedbeds or planted rafts have been used. In total, 575 metres of riverbank and 300 metres of embankments have been restored around the île Saint Germain using plant-based engineering techniques. These initiatives improve water quality by increasing phytopurification, boost species diversity (in the 1970s the Seine was home to only four species of fish; today there are about thirty) and protect threatened birds such as kingfishers.

KEY TAKEAWAYS

- Plant-based engineering techniques provide solutions that limit soil erosion. Thanks to its network of roots, the plant stratum protects the soil from subsidence, rain and wind. In riverbank restoration projects, spiling is often followed by sowing adapted plants or planting willow cuttings.
- Renaturing urban riverbanks helps to slow down the flow of the river, to purify the water, to trap sediments and to regulate water temperature.
- While the advantages of natural rivers for biodiversity are undeniable, they also allow species to move along riverbanks as they adapt to climate change.

Project 6: renaturing to restore brown grids
In brief: desealing and renaturing a row of trees to improve rainwater management and restore a brown grid.

Desealing can be used to create ecological networks of living soil in urban areas © City of Caen

To improve rainwater management and reduce urban heat islands, many councils have committed to desealing sections of public areas and uncovering the soil along roads. In 2020 Caen City Council launched an ambitious desealing and planting programme for rows of trees along pavements and roads and plans to remove 4 hectares of asphalt by 2023. The first stage of the work removed almost 5,000 sq.m. of asphalt from several rows of trees. As well as planting, the aim is to restore a continuum of soil ("brown grid") so that surface vegetation (herbaceous plants, trees and shrubs) can benefit from this subterranean continuity not only to share nutrients via their roots but also to interact with the fungal network. These interactions make trees less vulnerable to adverse weather conditions while tree foot greening can improve connectivity for plants and insects.

As well as dealing with asphalt on the surface, it may also be useful to restore the brown grid at a deeper level by removing or reconfiguring individual planting trenches and creating contiguous trenches for the trees. In the framework of the NOS-TREES project (2016-2018), the Canton of Geneva produced a summary of best practices for planting new trees and encourages digging contiguous trenches that are big enough to allow large trees to achieve their potential (ideally 15-100 cu.m. of trench per large tree) to replace smaller individual trenches. This work has shown that the trees are healthier and grow more quickly when individual trenches are not used. It recommends plantings with complex structures (i.e. small and large trees planted at the same time) and combinations of different species with trees planted close to one another in high-quality contiguous trenches.

An experiment in Geneva shows that trees are healthier and grow much faster when individual trenches are not used. ©L. Chabbey, M. Schaller, P. Boivin, HEPIA, Genève

KEY TAKEAWAYS

- The volume of tree planting trenches in urban environments is seldom greater than 4 - 9 cu.m., sometimes 12 or 24 cu.m. when financial resources allow (*Gouedard, 2014)*. Putting in place brown grids providing soil continuity could make it possible to increase the volume of soil available for trees and enlarge the areas around them to improve rainwater permeation.
- Species present in the soil also need to move around (*Mathieu, 2015*) to complete their life cycles, to reproduce, to escape occasional changes in their environment, to recolonise an area following an episode of mortality, etc. (*Chalot, 2016*).
- Desealing and greening the areas at the foot of trees may improve colonisation by wild plants (*Morel, 2010*), which either spread continuously or in a discontinuous fashion in the form of “stepping stones”. (*Pellegrini et al, 2010*).

Renaturing to diversify habitats in the urban matrix

In some cases, renaturing may make it possible to create viable new habitats by targeting specific cohorts or by focusing renaturing on a specific area (urban meadows, woodland, thermophiles, sandy soil, etc.). In all cases, habitat diversification creates a range of different living conditions able to host a wide range of species with different ecological requirements. This work must take place on the scale of the entire administrative area, but it can also be relevant at site level if a range of different habitats is provided. For example, diverse plant strata (herbaceous plants, shrubs and trees) will provide a range of different habitats (*Brunbjerg et al, 2018*). In other cases, it is possible to implement an approach focusing on one or more communities of species in order to prioritise certain groups or a particular environment.

Project 7: renaturing a cemetery in Versailles to improve conditions for wildlife
In brief: renaturing various sealed areas of a cemetery (paths and spaces between graves), planting local species and setting up a monitoring programme via participatory science protocols.

The first cemetery to receive the EcoJardin label (2012), Les Gonards has become an integral part of the urban green grid ©Marie Wagner

In France, cemeteries are very stark environments with little room for spontaneous flora, of which users often disapprove. Rows of marble gravestones and concrete crypts criss-crossed by schist or gravel paths occupy most of the space, to the detriment of vegetation. Herbicides have long been the most practical solution for weed control. With increased anxiety relating to biocides and the prohibition of certain pesticides pursuant to the Labbé Act of 2019, local councils are increasingly inclined to reduce or halt the use of pesticides and to renature cemeteries.

This is the case in Versailles, which in 2009 halted the use of such chemicals in four cemeteries with a total surface area of 18.5 hectares. In the Les Gonards cemetery, the council has renatured several areas where there was no greenery to make the place more wildlife-friendly. Some of the main paths have been desealed, as have the smaller paths and spaces between the graves. Work has been carried out to create areas of open meadow, to plant a range of local species and to monitor wildlife (via the Propage and Florilèges Prairies participatory protocols). These operations have also improved acceptance of ecological management techniques by actively communicating with local residents. The Versailles cemeteries were awarded the EcoJardin label in 2012, reflecting the quality of their ecological management approach.

KEY TAKEAWAYS

- The management of renatured areas is equally essential for restoring and enriching biodiversity. The idea is to adopt an ecological management method or even an unmanaged approach. This decision will depend on the site in question and must go hand in hand with appropriate communication. Not communicating on management practices can result in rejection by local residents.
- Scientific monitoring makes it possible to assess your renaturing project and the impact of its management plan on species. It is possible to set up simplified protocols that do not require extensive naturalist skills, such as those offered by the French Natural History Museum in its participatory science programme “Vigie Nature” (Nature Watch).

Project 6: renaturing soil habitats for pollinators in Lille
In brief: creating a network of nesting sites to aid conservation of wild bees.

Yohan Tison, ecologist at city of Lille, in front of an embankment restored in favour of ground-dwelling hymenoptera ©Denis Lagache, Association Les Blongios

In 2010, Lille City Council became aware of the huge diversity of its wild pollinators thanks to an inventory of wild bees in the Parc de la Citadelle carried out that year. Since then, almost 120 bee taxons have been identified across the city. This group of insects includes species that depend not only on very specific flora but also on special soil qualities. This refers to soil with sparse vegetation that is often poor and heats up quickly (mesotrophic or even oligotrophic soil, loamy, clay or sandy soil, etc.) to reproduce. As well as developing diversified meadows rich in fabaceous plants and increasing areas of host plants for target bee species (goat willow *(Salix caprea),* the red bartsia *(Odontites vernus),* the purple loosestrife *(Lythrum salicaria)*, etc.), the council created a network of nesting sites for species associated with sandy, sandy-and-loamy and clay soils (all oligotrophic and sparsely planted). This network of sites was distributed according to the latest populations identified and mapped onto the main green grid. In total, restoration of these habitats was carried out on eight sites, with volumes of soil ranging from 4 to 20 cu.m. suitable for the plant species necessary for these ground-nesting bees to complete their life cycles (*Odontites rubra, Echium vulgare, Lytrhum salicaria, saules divers, Reseda sp., Lysimachia vulgaris*, etc).

Monitoring the project confirmed the success of these solutions for hymenoptera including bees such as *Andrena vaga* and *Colettes hederae* and several species of ground wasp. Minimum maintenance is planned to remove certain grasses as local rainfall has a high nitrogen content. This initiative draws on in-depth naturalist knowledge and focuses on the ecological needs of wild bee species, the majority of which (70 %) are ground-nesting.

Bee belonging to the genus of andrenes, otherwise known as "sand bee", on one of its habitats
© Denis Lagache, Association Les Blongios

Project 7: renaturing brownfield sites in Hauts de France

In brief: renaturing brownfield sites adopting a naturalist approach resulting in the classification of one of the sites as a natural area in the local planning protocol.

Temporary flower meadow on the Houplines site ©EPF Hauts-de-France

In the Hauts-de-France region, the Etablissement Public Foncier (EPF: public land developer) has for several years been renaturing brownfield sites. Initiated by the development body's resident ecologist Guillaume Lemoine, a number of projects have been launched with the aim of creating temporary or permanent natural areas, guided by a naturalist approach primarily targeting flora and insect populations.

Lens-Van Pelt (3.5 ha) is a site formerly occupied by factories which were demolished by the EPF with a view to urban densification. Over 10 years later, the state of the economy, in particular the property market, had changed and EPF decided instead to create a natural heartland in line with the Regional Forestry Plan, whose target was "1 million trees for Hauts-de-France". The renaturing work made it possible to plant an urban forest of local species, to create a variety of different woodland environments, and to restore dry grassland and habitats for xerothermophilous species. Habitats for chiroptera and sand loving hymenoptera were created using materials available on site. A discovery trail was laid out to allow local residents to explore the newly created ecosystems. Once the project was completed, Lens City Council modified its local planning protocol to classify the site as a natural area and protect it from any form of urbanisation. The EPF regularly carries out wildlife inventories to follow up on the evolution and success of the renaturing initiative.

On the Houplines-Hâcot-Colombier site (2.5 ha), the intervention of the EPF has revitalised the "bord de Lys" industrial belt in the *communes* of Hazebrouck and Houplines. 12 hectares of land are awaiting the development of a new district that will replace a string of brownfields. Meanwhile, the Hâcot-

Colombier site is being temporarily renatured and used for urban agriculture (vegetables and herbs). The EPF has restored the soil and set up biomass cultivation to supply local green spaces with straw mulch. Discussions were initiated with the different stakeholders before the project began in order to define the agricultural trajectory of this "urban third place". Partners specialising in social and therapeutic integration, compost producers and gardeners worked together to outline a programme coordinated on behalf of the local council by the Compagnie des Tiers-Lieux. Renaturing entails demolition work, dealing with concentrated sources of pollution and maintaining a wooded area within the demolition zone to create a future green space before construction work begins. To improve the agronomic quality of the soil, the EPF has sown fabaceous plants, green fertilisers (phacelia) and flower meadows as well as growing hemp to produce biomass that supplies local green spaces with mulch. The latter represents an "economical" way to use an area awaiting development and makes it possible to test technical aspects of hemp growing in urban settings. The remainder of the EPF programme might involve growing complementary crops, setting up a network of hedgerows to produce biomass, or creating a nursery of local trees to supply the entire region.

On the Roubaix-GTI Sodifac site (2.2 ha), timeframes for reviewing local planning protocols and carrying out consultations with developers mean that the land will still be available for several years. As well as "standard" operations to increase biodiversity, improve the living environment and limit urban heat islands, mixtures of cereals and legumes (lucerne and vetch) have been planted to test the value of these areas awaiting development as suppliers of biomass to the city's methanation plant and reduce its reliance on fossil fuels without competing with food crops. A technical partnership with the Lille Agricultural College (JUNIA -ISA) made it possible to determine which combinations to test, to assess the agronomic quality of the soil and to monitor possible contamination of the crops produced. At this stage, the EPF carried out demolition and decontamination work on the site, sowed flower meadows for biodiversity and planted various crop combinations. A similar project is underway on the Lille-Hellemmes-Québecor site (1.5/2 ha), also involving the demolition of a former factory (a concrete and metal recycling works). Most of the trees present on site have been retained, and an on-site nursery has been created to preserve trees and shrubs that had to be uprooted.

KEY TAKEAWAYS

- Sites awaiting development can be temporarily renatured, making it possible to test ecological restoration methods or to experiment with local production (nurseries, cultivated plots, biomass, etc.).
- Some renatured brownfield sites can become habitats for many ground-nesting insect species.
- Discussion with local residents and stakeholders makes it possible to develop locally relevant projects.

Project 8: London's "Beetle Bump"

In brief: renaturing project aimed at recreating the habitat of a species whose former home had been destroyed.

Aerial photo of the Beetle Bump habitat creation at the University of East London, Docklands Campus ©UEL SRI On the left, aerial photo of the Beetle Bump habitat creation at the University of East London, Docklands Campus. On the right, the Beetle Bump (Brachinus sclopeta) © Stuart Connop – Sustainability Research Institute

In the UK, the restoration of a habitat for the bombardier beetle (*Brachinus sclopeta*) is a remarkable example of renaturing focused on a single species. The beetle was associated with brownfield sites in London's Docklands in the East Thames corridor, and its last known habitat had to de destroyed to make way for development. In the framework of compensatory measures supported by Buglife (the Invertebrate Conservation Trust) and the University of East London, discussions led to the creation of the Beetle Bump, a renaturing project that mimics the characteristics of a brownfield site and reproduces the beetle's habitat. The operation involved bringing in a mixture of recycled aggregates poor in nutrients and sowing wild flowers typical of brownfield sites in the region (*Connop et al, 2018*). The bombardier beetles rescued from the construction site were moved to the Beetle Bump. Inventories over the ensuing years have demonstrated the quality of the habitat for the beetles and also for other species. This type of approach to renaturing could usefully improve landscaping practices in urban areas by bringing ecologists and landscape designers together.

KEY TAKEAWAYS

- It is possible to restore habitats targeting a single species or community of species. In this case, it is advisable to enlist the help of naturalist or ecologist organisations.
- Renaturing only makes sense if the restored environments are long-lasting. To ensure that they are, local authorities have a range of tools at their disposal, from land purchase to regulatory protection via their planning protocols.

2.4 Renaturing to facilitate adaptation to climate change

The consequences of climate change are already visible in the Paris Region: higher average temperatures (an average increase of about 2°C since 1950), more frequent heatwaves, less frequent cold snaps and sub-zero temperatures, summer droughts and more intense rainfall (*Vautard et al, 2021*). The frequency, intensity and duration of extreme events (heatwaves, flooding, etc.) have increased. Surface sealing and the preponderance of concrete and stone in cities accelerate the effects of climate change, from rainwater runoff to urban temperatures up to 10°C higher than in rural areas during heatwaves. Although strategies exist to adapt to the effects of climate change, the emphasis should be on nature-based solutions due to their co-benefits in terms of biodiversity and quality of life. Renaturing operations in sealed urban areas can meet these needs by reclaiming natural spaces that mitigate the effects of runoff, reduce flood risk and combat heat islands.

To pinpoint the areas most vulnerable to climate change and maximise the efficiency of renaturing with this aim in mind, exposure to the effects of urban heat islands (UHIs), runoff and river flooding have been analysed.

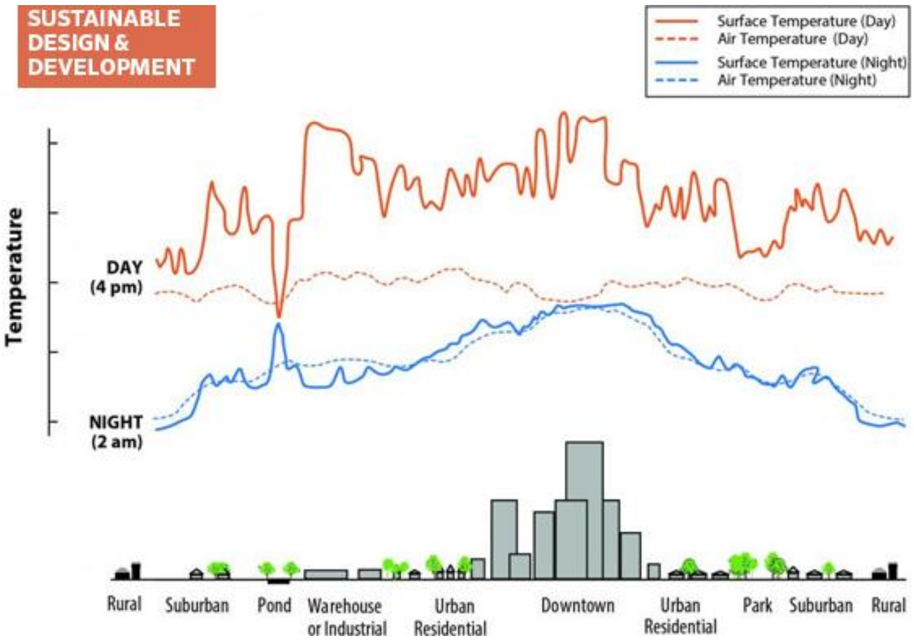
2.4.1 Criteria selected for studying exposure to the effects of climate change

Table 5: Criteria, thresholds and bibliographical resources used to identify urban areas that are most vulnerable to climate change.

Criteria	Thresholds	Score	Source
Exposure to effects of UHIs	High	0	*Cordeau, 2017*
	Medium	1	
	Low	2	
	Cooling	3	
Exposure to runoff	High	0	*Paris Region Institute*
	Medium	1	
	Low	2	
Exposure to flood risk	High	0	*Paris Region Institute*
	Medium	1	
	Low	2	

Exposure to the effects of urban heat islands (UHIs)

In urban areas, sealed surfaces and buildings absorb and reflect the sun's rays, heating the surrounding air. This is one of the many factors contributing to the urban heat island (UHI) effect, resulting in higher temperatures in dense urban areas than in rural areas. The difference in temperature between densely populated areas in the centre of Paris and the Bois de Boulogne and Vincennes is around 4°C in standard summer conditions (summer 2000) but can be much greater in times of extreme heat: 8°C in 2015 and 10°C in 2003 [11]. This phenomenon has many harmful effects on health and wellbeing, energy consumption (air conditioning) and biodiversity (hydric stress and increase in species mortality).



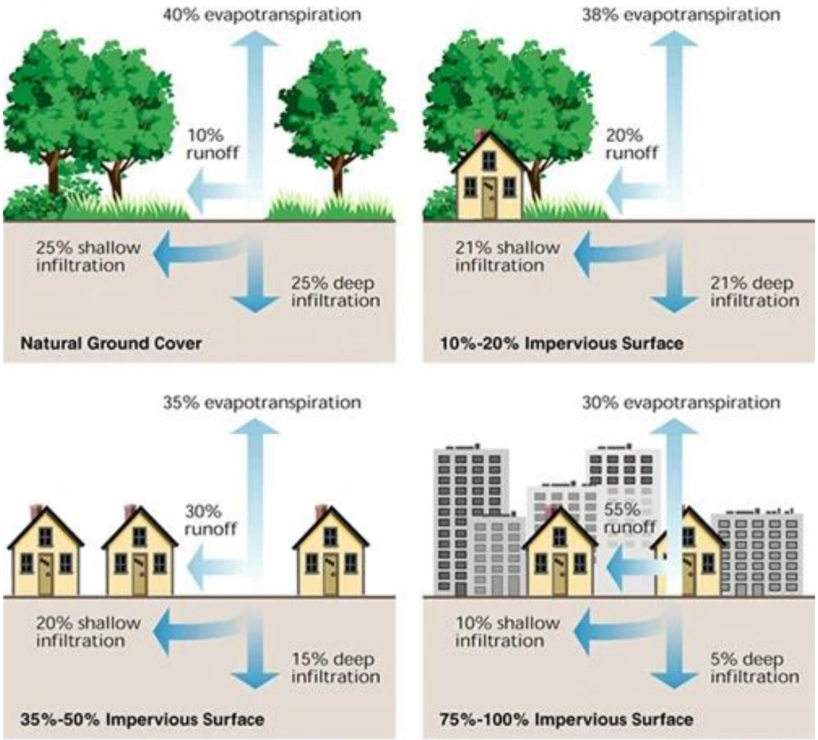
Parks, open land, and bodies of water can create cooler areas within a city because they do not absorb the sun's energy the same way buildings and sealed surfaces do. © U.S. Environmental Protection Agency.

Exposure to UHIs was analysed using the indicator "Aléa jour" [daytime hazard] produced in the framework of the project titled "Adapter l'Île-de-France à la chaleur urbaine"/"Adapting the Paris Region to urban heat" (*Cordeau, 2017*). The effect of UHIs represents a hazard, reflecting the likelihood that heatwaves will worsen locally. The "Aléa jour" indicator is calculated from parameters that generate UHIs: soil sealing, number of built surfaces, ventilation, thermal properties of materials and shade from trees.

According to these parameters, an area will have either potential for the hazard to worsen (increasing the effect of the heatwave) or lessen (e.g. in the case of urban cooling islands). In the framework of the analysis carried out here, a score of 0 is attributed to a cell with a high potential for worsening, a score of 1 for medium potential for worsening, a score of 2 for low potential for worsening and a score of 3 for cooling potential.

Exposure to runoff risk

Runoff in urban environments is likely to occur more frequently due to increasingly heavy rainfall; it consequently amplifies the effect of land take. As well as increasing the risk of flooding, runoff also affects the water quality in rivers and streams. During heavy rain, drainage networks can be saturated and runoff mixes with sewage. Overloading the system that carries sewage to the purification plant can cause polluted water to overflow into natural environments from stormwater overflows, even when rainfall is of average intensity [12].



Impervious cover in a watershed results in increased surface runoff. As little as 10 percent impervious cover can result in stream degradation. ©Green Infrastructure Guidance for Flood Reduction.

Exposure to runoff has been studied based on the runoff index established by the Paris Region Institute. This index compares different datasets such as land use surveys (split into three categories: heavily sealed areas; moderately sealed areas; lightly sealed areas) and the risk of heavy runoff due to local topography (studied by applying three categories of slopes: steep, moderate and gentle). For further details, please see appendix 1.

The values associated with each category are summarised in the table below. Cumulative values are reclassified to obtain a score of 0 to 2 (values in bold) reflecting exposure to runoff risk depending on the slope and the degree of ground sealing. A score is then attributed to the cells according to the principal risk: high exposure to runoff scores 0, medium exposure 1 and low exposure 2.

Table 6: Cross table analysing exposure to runoff depending on slope and degree of sealing.

Sealing \ Slope	Steep (= 0)	Moderate (= 1)	Gentle (= 2)
Heavy (= 0)	0 → **0**	1 → **0**	2 → **1**
Moderate (= 1)	1 → **0**	2 → **1**	3 → **2**
Light (= 2)	2 → **1**	3 → **2**	4 → **2**

Exposure to flood risk

Rises in water level are natural phenomena that may result in flooding. Flooding is a major risk in France, with almost 17 million people exposed to the risk of rivers bursting their banks [13]. In Metropolitan France such events are responsible for most damage due to natural disasters [14]. Increasingly heavy rainfall associated with climate change will amplify this phenomenon (according to some scenarios, a 20% increase in heavy rainfall events is expected by the end of the century) (*Coppola et al, 2021; France, 2020*). Flash floods and extreme rainfall may occur in the Paris Region over the coming years. Rising water levels and flooding are not only due to rainfall but also to the adaptation of catchments, the management of streams and rivers, land use and ground sealing.

To study the cumulative impacts of land take and flood risk, different datasets were compared. Land occupation was divided into three categories: unbuilt areas; open built areas (parks, cemeteries, etc.); and densely built-up areas (housing, business parks, etc.). Flood risk is studied via three categories of hazard: low; high; and very high (for further details, please see appendix 2).

The values associated with each category are summarised in the table below, then reclassified to obtain a score from 0 to 2 (values in bold). This provides information reflecting exposure to flood risk depending on land occupation and potential intensity of flooding. A score is then attributed to the cells according to the principal risk in the cell: high exposure to floods earns a score of 0, moderate exposure 1 and low exposure 2.

Table 7: Cross table analysing exposure to flood risk depending on land use and potential intensity of flooding.

Type of area \ Hazard	Low / Moderate (= 2)	High (= 1)	Very high (= 0)
Unbuilt (= 3)	5 → **2**	4 → **2**	3 → **2**
Open (= 1)	3 → **2**	2 → **1**	1 → **0**
Dense (= 0)	2 → **1**	1→ **0**	0 → **0**

2.4.2 Where should renaturing take place to help a region adapt to climate change?

Following the method described in paragraph 2.1, low-scoring cells (0 - 3) were defined as priority renaturing zones. Applied to the perimeter of the inner suburbs, the analysis shows that the urban areas most exposed to the effects of climate change are in Paris itself, but also more broadly along the Seine and the Marne, where urbanisation leads to high exposure to flood risk. As far as the *départements* of the inner suburbs are concerned, exposure decreases the further one gets from dense urban areas.

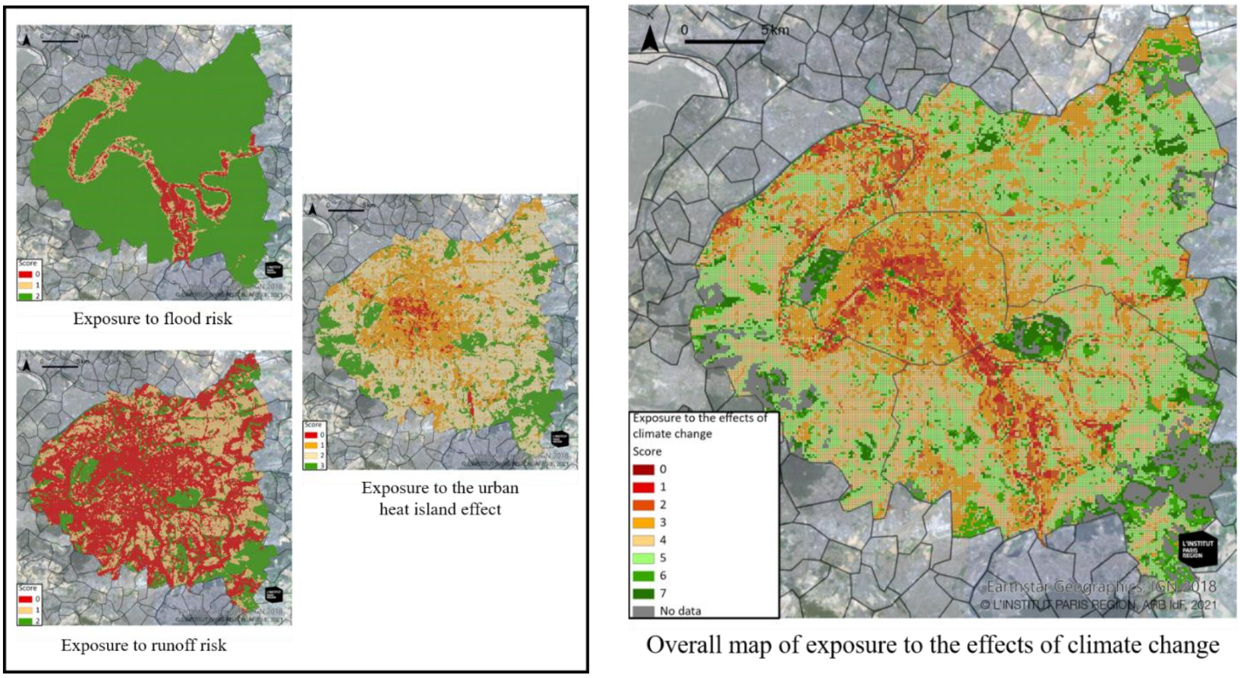


Figure 9: Once the individual criteria had been studied, the points were added up to obtain a final score, resulting in an overall map of exposure to the effects of climate change.

EXAMPLE OF HOW THE METHODOLOGY WAS APPLIED TO THE TOWN OF AULNAY-SOUS-BOIS

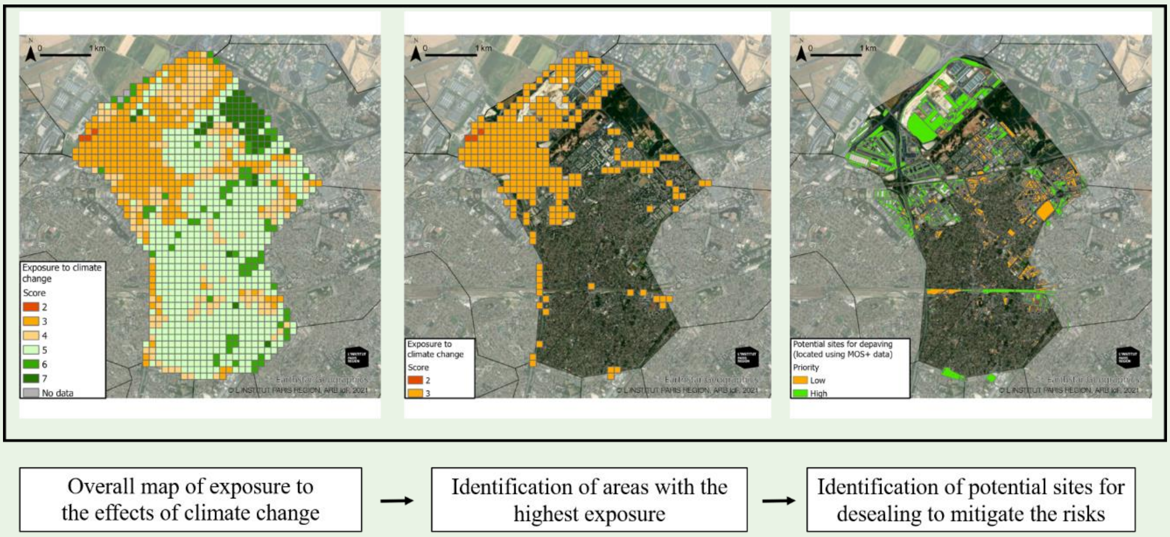


Figure 10: Identification of desealable sites in sectors highly exposed to climate change in Aulnay-sous-Bois (Paris Region, département *of Seine-Saint-Denis)*

The analysis reveals a total of 280 cells highly exposed to the effects of climate change (scoring 2 or 3). Renaturing needs are concentrated in the northwest of the area, which corresponds to an extensively sealed industrial zone exposed to runoff and UHIs. As for the rest of the area, 748 cells have low exposure (scoring 4 or 5). 127 cells have very low exposure (scoring 6 or 7) and are low-priority for renaturing projects targeting adaptation to climate change.

2.4.3 Feedback and recommendations

In terms of adaptation to climate change, renaturing can target several trajectories depending on the area concerned to respond to one or more types of vulnerability that have been identified. Several types of recommendations can be formulated, for example:

- Restoring and remeandering urban rivers and renaturing riverbanks
- Restoring floodplains and other buffer zones to cope with overflow (wetland meadows, networks of ponds, lakes, alluvial woodland)
- Increasing the number of alternative rainwater management systems in previously sealed areas (floodable gardens and parks, networks of ponds, lakes, rain gardens, planted swales, etc.)
- Increasing the density of tree and plant cover in paved streets, in popular public squares and along roads.

EXAMPLE OF INTERPRETATION OF CARTOGRAPHIC RESULTS OBTAINED FOR "ADAPTATION TO CLIMATE CHANGE" SCENARIO

Figure 11: Map of exposure to the effects of climate change in Ivry-sur-Seine and example of interpretation

Spatial analysis for Ivry-sur-Seine reveals a heavily sealed urban area, which is also a floodable area and thus highly exposed to risks of flooding and runoff. The degree of sealing also causes a significant UHI effect. Renaturing would not only protect existing infrastructure from flood risk, it would also limit the impact of heatwaves (with efficiency depending on the size of the renaturing programme).

Renaturing to create floodplains and manage flood risk

In France, most watercourses have been altered by human interventions (rectification, embankment, channeling, covering) which have adversely affected their functionality, leading to an increase in flood risk during heavy rainfall. In parallel, most wetlands and marshes acting as rainwater storage areas in or near towns and cities have been drained or sealed. Rivers are often deprived of their annexes (floodable meadows and floodplains) which used to act as overflows during storms. For example, in the inner suburbs of Paris, the areas surrounding major riverbeds are almost all urbanised, compared to 30% in the outer suburbs. Renaturing existing watercourses, remeandering them, or in some cases restoring them entirely, can improve their flow and increase their storage capacity. Ecosystems associated with rivers such as riparian woodland also help to maintain riverbanks and slow down river flow. Faced with increased risk of flooding, more and more local authorities are planning to restore floodable wetlands next to large rivers and to restore urban watercourses.

Project 1: the Vignois floodplain
In brief: creation of a biodiversity-friendly floodplain.

Permanent and temporary wetlands on the Le Vignois site, which has become a floodplain.
© SIAH Croult et Petit Rosne

The Le Vignois site in Gonesse is one of the most successful examples of a nature-based solution explicitly designed to manage flood risk and provide benefits for biodiversity. The operation carried out by the SIAH (Syndicat Intercommunal d'Aménagement Hydraulique) in 2019 involved creating a 12-hectare wetland with a storage capacity of 55,000 cubic metres to protect the area from flooding when the River Croult breaks its banks and due to rainwater runoff. Co-construction by ecologists, landscape designers and planners made it possible to design different hydrological regimes and diverse habitats such as meadows, reedbeds, willow groves and copses. Several wetlands and lakes are interconnected. The site is not lit at night to maintain a “dark corridor” for birds and bats. In terms of vegetation, some species have been planted but the existing trees have been protected and spontaneous vegetation is accepted. Although the main goal is flood management, this wetland also offers a range of habitats for biodiversity.

Since 2020, biodiversity monitoring (based on standard protocols from participatory science programmes allowing comparison over time) has been carried out on several taxons (moths, dragonflies, orthoptera, pollinators, reptiles, amphibians, plants, birds, bats and small mammals such as hedgehogs, squirrels, rats, hares). After three years, early results confirm that the restoration of wetlands has a significant impact on biodiversity as well as adaptation to climate change. While the Le Vignois site was originally fallow farmland, similar operations on sealed sites are possible with even greater benefits.

KEY TAKEAWAYS

- A wetland restoration programme takes time and requires a prior in-depth hydrological and ecological survey.
- It is important to involve local residents at an early stage of the project as acceptance of the presence of water in urban areas cannot be taken for granted. Preconceived ideas relating to cleanliness or the presence of mosquitoes need to be lifted before the project goes ahead.
- The creation of wetlands can be planned on several different scales to interconnect restored wetlands, facilitating species movement and reinforcing the blue grid.
- On larger sites it is recomended to create diverse habitats (meadows, reedbeds, copses) offering a range of ecological niches for different taxonomic groups.
- Post-project monitoring should assess the project's impact on biodiversity and improve knowledge of renaturing in urban settings.

Project 2: the Prés de Vaux floodplain
In brief: conversion of a brownfield site causing a heat island and flood risk into a 5-hectare park that will help combat both risks while offering a recreational area for the population.

The Prés de Vaux brownfield site in Besançon, located on a bend in the River Doubs. © Gwendoline Grandin

Les Prés de Vaux is a brownfield site that was abandoned 30 years ago. Nestling in a bend of the River Doubs near Besançon city centre, it is in a flood zone and is highly contaminated due to its industrial past. The ground is totally impervious due to buildings and ground sealing. The site is not only a significant heat island near the city centre; it also significantly increases flood risk should the Doubs burst its banks. Besançon City Council purchased part of the land in order to demolish the buildings and convert the site into a 5-hectare park. The aims are to deseal and restore natural environments to reduce the heat island effect and restore a floodplain upstream of the city centre; to create a cultural trail highlighting the history of the site in response to requests from the local community; to diversify environments by systematically applying ecological or passive management approaches.

Areas left to evolve naturally (left) and dry meadows (right) maintain the dynamics and environments typical of urban brownfield sites. © The city of Besançon

Demolition began after wildlife analysis was carried out. The riparian woodland and desealed areas will be planted and nature will be left to take its course. Plantings and seed sowing will merely speed up the natural recolonisation of the park. The seeds were collected by council staff in surrounding natural areas (riverbanks, hillsides, etc.). Specific combinations have been put together according to the different environments to be restored. Many environments have poor, shallow soil that encourages the growth of pioneer flora making it possible to see the different phases of the site's transformation. Special care will be taken to avoid the appearance of invasive exotic species during and after the work. Some buildings will be retained and used for leisure activities. Special gardens will be laid out to make the transition between restored areas and areas left untouched to preserve the memory of the site's history. The principle of these gardens is to encourage natural recolonisation on concrete slabs on which buildings used to stand and former circulation roads.

In total, over 2.5 ha will be desealed, including 1.8 ha given over to the creation of natural environments. The creation of new habitats (dry grassland, ordinary grassland, dense shrubs, planted swales and water collection basins, etc.) and the implementation of ecological management methods will make it possible to create refuges for biodiversity.

KEY TAKEAWAYS

- Reusing earth and rubble from the site itself avoids having to transport material (creating CO_2 emissions) and transferring impacts to other sites where exported material would be stored or from which topsoil would be removed.
- Restoration work can combine the two types of renaturing: passive and active. For reseeding, local species should be used. It is possible to mix seeds harvested from natural areas around the site, while being careful not to "plunder" these areas, which could limit their own capacity for future regeneration.
- Keeping poor soil can be an option to encourage pioneer plants or plants specific to such soils. Many remarkable or poorly conserved plant species only grow in this kind of environment.

Project 3: Agglopolys floodplain

In brief: gradual de-densification of a 60-hectare district to create not only a floodplain to help manage flood risk but also functional natural and agricultural areas.

The La Bouillie district to be de-urbanised in order to restore a floodplain. © FG. Morisseau (Chorème)

Extent of the La Bouillie project. © The city of Blois

In keeping with its flood risk prevention plan, for almost seventeen years Agglopolys, the *communauté d'agglomération* (area council) of Blois, has been recreating a floodplain for the River Loire in a district called La Bouillie. Located on the south bank of the Loire, the 60-hectare district is being gradually de-urbanised. A *zone d'aménagement différé* (gradual development zone) has been designated, giving Agglopolys the opportunity to purchase buildings and houses on sale before demolishing them so that the sites can be restored.

Since 2004, 132 buildings have been purchased and demolished out of 143 that have been identified. Various surveys carried out on the area's history, landscape, ecology, hydrology, etc. have made it possible to plan La Bouillie's future use. As well as managing river flooding, the project aims to restore functional natural areas (shrubland, meadows, hedgerows, wetlands) and agricultural areas (farms, public or non-profit orchards, allotments). The new area will also be an attractive place to walk, reconnecting local residents with the River Loire, the Cosson (river) and the forest of Russy. Far from being set in stone, this programme forms the basis for debates and discussions to which all local stakeholders can contribute. Workshops and public consultations were held in 2021 to improve participation and foster appropriation by the local community.

KEY TAKEAWAYS

- To manage the risk of flooding, it is possible to implement a gradual land purchase scheme in order to carry out de-densification projects that will eventually make it possible to restore a floodplain.
- If the site is large enough, a range of areas can be restored: some for biodiversity (meadows, woodland, wetlands) and others for farmers and local residents (orchards run by community associations, allotments).

Project 4: restoring the Petit Rosne in Sarcelles
In brief: restoring a channelled and covered river to manage flooding due to runoff while offering new habitats for biodiversity and a place for local residents to enjoy.


Before and after opening up the river in a densely built-up area of Sarcelles. © SIAH Croult et Petit Rosne

In 1992, the centre of Sarcelles found itself under 1.50 metres of water following heavy storms. The Petit Rosne, shrouded in concrete, could only overflow when its water level rose. After several years of surveys, the Syndicat Intercommunal d'Aménagement Hydraulique du Croult et du Petit Rosne (SIAH), in partnership with Sarcelles Town Council, decided to open up a stretch of this forgotten river. Work began in 2014 with the aim of controlling flood risk and restoring nature in this urban area. Along a 165-metre stretch, a new riverbed was dug, the banks were reinforced and planted using ecological engineering techniques for part of the project. Despite the lack of available space and the high degree of urbanisation in the area, the Petit Rosne has returned to its original course and a number of added amenities have made the site completely accessible.

As the river had been covered over and flowed along a concrete tunnel, no prior inventory of the watercourse could be carried out. A ground-level wildlife inventory was nevertheless carried out in 2010 before the work began. This highlighted the potential for an area of wet woodland at right angles to the new meander. The existing woodland was thus retained, both for its value as a landscape feature and for its ecological potential. A post-project wildlife inventory was carried out in 2017/2018, laying the foundations for a long-term monitoring programme including fish, bats, moths, birds and plants. Water quality was also measured upstream and downstream in 2018. A few months after the project was completed, the first aquatic species (sticklebacks and aquatic macro-invertebrates) were observed.

A poll was carried out among users of this stretch of river in March/April 2018 to assess public perceptions at each stage of the project: initiation, restoration work and day-to-day management. The poll shows that a return to nature in urban areas requires awareness on the part of local residents and that more extensive communication in the initial stages, during the work and post-project would have resulted in better acceptance of the "wildness" of the site (unmown grassy banks, diversity of plant species, etc.). Since that time, the SIAH has made consulting with local residents a strategic plank of its operations. Opening up the river is nonetheless part of a dynamic of local reappropriation that is to continue with the creation of educational gardens on the riverside.

KEY TAKEAWAYS

- In terms of engineering, the restoration of the watercourse, entirely concreted, requires a real expertise, both in civil and ecological engineering.
- The creation of a diversified hydromorphological profile (sinuosity, flow velocities, sunshine, shading) ensures varied opportunities for nesting, feeding and reproduction for various species that are dependent on aquatic environment
- The management of the renatured site must be anticipated as far upstream as possible, both in terms of its technical aspects (maintenance of the vegetation, monitoring of biodiversity) and its social aspects (safety, waste management, communication with local residents).
- The processes of co-construction with the population facilitate the acceptance of wetland renaturation projects.

Renaturing to limit runoff

On the initiative of water boards, planted areas are increasingly being used as an alternative method of managing rainwater. These techniques have the advantage of being close to the natural water cycle, relying on natural soil infiltration, the creation of multiple planted areas and the rehabilitation of wetlands and rivers. They protect the quality and quantity of water-related resources (reducing the amount of polluted water released into the environment and naturally recharging water tables) and reduce the risk of flooding and runoff.

Several towns in the Paris Region are gradually replacing grey infrastructure (concrete tanks, artificial basins) with rainwater management solutions and floodable green spaces. Several publications have shown that these solutions have the potential to provide a habitat for biodiversity (*Monberg et al, 2019*). However, certain developments are little more than landscaping. Specialists have also stressed the need to improve the design and operation of rainwater management systems (improving structural diversity and irregularities on riverbanks, lighter mowing, etc.) so that they have a positive impact on biodiversity (*Oertli et al., 2019*). These solutions must take into account the need for species that live in these environments to move by encouraging the removal of uncrossable barriers (fences, etc.) that prevent connectivity with other wetlands or green spaces (*Ahn, 2019*). More effective partnerships between landscapers and urban ecologists might help to adjust design and management practices and achieve more efficient biodiversity conservation.

As the methodology outlined in this guide shows, local authorities have a very large amount of sealed and paved areas at their disposal which could be desealed and planted to manage rainwater in sectors subject to runoff. A range of different solutions exist on all scales. Improved water management primarily requires the presence of trees, which are able to store large amounts of rainwater. This storage capacity varies from species to species and increases with age and size. An oak tree can store up to 200 litres a day, most of which is released via transpiration, but in gaseous form. An American study has shown that the trees of New York City help to reduce runoff by an estimated 69 million cubic feet a year (valued at $4.6 million per year) (*Nowak et al, 2018*). Retaining existing trees, planting new ones or even creating areas of urban woodland are clearly valuable ways of storing water and reducing runoff.

Project 5: moving from grey infrastructure to alternative rainwater management
In brief: floodable green spaces to replace underground water tanks in the *département* of Seine-Saint-Denis


Creation of a floodable garden to manage rainwater in the Clos Saint Vincent district, Noisy-le-Grand. © Département de Seine-Saint-Denis

Renaturing in urban environments can make it possible to replace grey infrastructure with ecosystems able to manage rainwater and runoff. Alternative rainwater management solutions such as planted swales, ditches, basins and floodable parks are increasingly being used by local councils (*Monberg et al, 2019).* Since the early 1990s, the *département* of Seine-Saint-Denis has focused on managing rainwater at source to relieve saturated drainage systems during heavy rain. In several towns, the council has created multi-functional landscaping that responds to the question of rainwater management while improving the living environment and fostering biodiversity in sectors where green spaces are often few and far between.

Created between 2002 and 2006, the *zone d'aménagement concerté* (ZAC: priority development area) of Clos Saint Vincent in Noisy-le-Grand was designed to manage rainwater in the open air, making the public park multi-functional. The "artists' garden", covering 2 hectares, is floodable and receives runoff from the park and neighbouring rooftops. In heavy rain, the garden is able to retain 570 cu.m. of water, and raised walkways allow visitors to move across the garden when it is submerged. The garden and surrounding amenities make it possible to avoid ground sealing and to control rainwater runoff while bringing water back into urban space as a visual feature. [15]

The increasingly widespread use of such solutions helps to create an urban blue grid. In planning schemes, increased use of these systems (planted swales, ponds, rain gardens, planted basins) helps to limit land take and increase the percentage of natural soil. In the early stage of the design of these solutions, it is important to include a system that allows water to be filtered or settle before it arrives at the "infiltration" section of the site, to limit the risk of blockage (for example by installing a grass strip ahead of the infiltration spot), and to take steps to avoid trampling or the presence of vehicles in the permeation area (for example by planting dense shrubs there).

KEY TAKEAWAYS

- Planted areas play an essential role in preserving biodiversity, even more so when the solutions used are diversified and the areas differentiated. When they are, they offer a wider range of habitats.

- For these solutions to be effective in combating runoff, it is important that they be planted with vegetation and that the soil be functional (not compacted) and managed ecologically. The height of the plants and the presence of different strata slow down the rainwater before it reaches the soil, giving it more time to be absorbed.
- Where pond design is concerned, sufficient depth is required. The generally recommended depth is 1 -1.2 metres. When designing ponds, a sufficient depth is necessary to ensure a permanent presence of water. On average, between 1m and 1.20m is generally required. Temporary ponds are just as interesting as permanent one and host a different set of species. In order to fight against various types of pollution, it may be necessary to opt for an alternative to plastic sheeting for the waterproofing of the pond.
- It is advisable to create shaded areas near wetlands to create different conditions for wildlife, especially by including varied plant strata, and to design uneven, gently sloping riverbanks and micro-environments (riprap and inaccessible areas) as well as shallow beaches.
- Over-management of green spaces often has an adverse effect on biodiversity. Researchers suggest drastically reducing management interventions (especially grass cutting) to allow flora to flourish. Close mowing along the edges of lakes is disastrous for invertebrates.
- It may also be useful to limit the impact of human footfall, which can compromise the success of the operation. It may be necessary to cordon off certain areas to protect them from trampling and damage to plants.

Renaturing to combat heat island effects

Natural spaces in urban areas help to reflect the sun's rays, unlike most concrete surfaces which directly absorb the Sun's energy and turn it into heat. Numerous scientific studies confirm the role of vegetation in reducing urban temperatures through shade and evapotranspiration, especially during the hottest months, thus reducing the urban heat island effect (*Bowler, 2010*). The presence of mature trees is one of the most effective ways of reducing the UHI effect, lowering local temperatures by as much as 3 to 5 degrees [16]. At building level, this cooling effect can result in a reduction in electricity used for air conditioning (one American study from 1990 estimates that a reduction of 5 to 6 degrees would reduce energy consumption by 50 to 70% (*Huang et al, 1990*)). The size and composition of green spaces are also important factors that influence both the cooling effect and how far it extends. A study carried out in London points out that areas of 5 to 15 hectares have a cooling effect of 0.6 to 1 degree that can be measured 180 – 330 metres beyond the study site (*Monteiro et al, 2016*), which is not the case for areas smaller than 0.5 ha where effects on the surroundings are negligible. The ADEME (French Energy and Environment Agency) summary titled "Planning with Nature in Urban Areas" [17] details this correlation and states that "*Inside a park, the difference in temperature compared to built-up areas is significant and varies in particular in proportion to surface area: 2.5°C in a 20-hectare park and 1°C in a 10-hectare park in Valencia; 2°C in a 50-hectare park and 3°C in a 200-hectare park in Berlin."*

This cooling mechanism through evapotranspiration nevertheless depends on the availability of water for the plants. In periods of hydric stress and when the need for cooling is greatest, plants generally struggle to evapotranspire because of lack of water. Urban cooling strategies using vegetation are thus inseparable from water management in urban areas, especially focusing on storing water in planted structures to be used in case of need. All forms of vegetation are welcome, from trees (isolated or not) to parks and gardens and isolated flowerbeds. Special care must, however, be taken when choosing species: it is advisable to use local species that are better adapted to the local climate.

Project 6: the Tierce Forêt in Aubervilliers

In brief: transforming a residents' car park into a recreational area designed to combat the UHI effect.

Replacing a car park with a cool island. © FIELDWORK Archi

The Tierce Forêt ("Third Forest") project involved renaturing a car park and sealed concourse in front of a building in Aubervilliers. Its aim was to improve the living environment for residents of the building and to reduce the particularly high heat island effect on the site. The project grew from the idea of turning the car park in front of the building, a hostel for young workers, into a cross between a park and a square for the use of residents and employees. Soil analysis assessed the agronomic, physical, chemical and biological quality of the existing soil, sparking a conversation on how on-site restoration techniques could avoid the need to bring in topsoil from elsewhere.

The soil was restored using decompacted soil from the site, demolition materials and compost. To restore the water cycle, the sealed areas were replaced by permeable ground covering, including the heavy vehicle access road that had to be retained to allow the fire brigade to access the building. A rainwater reservoir was built using clay soil to avoid the use of in-ground concrete structures. To avoid the use of plastics, the new drains are made of terracotta. The reservoir is a useful source of water for the trees and extends the cooling effect in periods of drought. Where the planting strategy is concerned, solar irradiance measurements guided the choice of areas to be planted. The idea was to have a large canopy where the surrounding buildings provide the least shade. The species planted are local and selected for their ability to resist urban conditions. The roots were also mycorrhized to help the plants to absorb water and minerals from the soil. Last but not least, a meteorological station was installed to monitor the efficiency of the project. Early studies show an average temperature reduction of 2°C under the canopy, with perceived temperature said to be up to 6°C lower than before.

KEY TAKEAWAYS

- Rubble from a site can be used to restore its soil.
- Preliminary surveys help to make smart choices concerning which areas to plant.
- Monitoring should assess the impact of the project on temperature and UHI effect.

2.5 Renaturing to improve health and the living environment

Ground sealing affects health and wellbeing: it is an aggravating factor, if not the cause, of phenomena such as flooding and UHIs, which have many negative impacts on health. For example, UHIs cause excess deaths during heatwaves and have indirect effects such as increasing the concentration of atmospheric pollutants.

A review of the scientific literature carried out by Plante & Cité has identified over 300 publications showing the benefits of natural spaces on physical and mental health (*Meyer-Grandbastien et al, 2021*). Renaturing urban environments is thus a way of improving the living environment and well-being of city-dwellers. To identify areas that might be desealed as a priority, vulnerability to UHI effects, air pollution and scarcity of green spaces were studied.

2.5.1 Criteria for locating priority areas

Table 8: Criteria, thresholds and bibliographical resources used to identify urban areas to be renatured to improve health and the living environment

Criteria	Thresholds	Score	Sources
Vulnerability to UHI effect	High	0	*Cordeau, 2017; Pascal et al, 2021; Basagaña et al, 2011; Urban green spaces and health, 2016*
	Moderate	1	
	Low	2	
Air pollution by $PM_{2.5}$ ($\mu g/m^3$/year)	> 15	0	*Articles R221-1 to R 221-3 of the French Environmental Code; World Health Organization, 2006*
	> 10 and < 15	1	
	> 5 and < 10	2	
	< 5	3	
Deficiency in green spaces	High	0	*Cox et al, 2017; Szulczewska et al, 2014*
	Moderate	1	
	Low	2	

Vulnerability to UHI effect

UHIs cause a significant number of excess deaths in periods of extreme heat. Night rest and recovery are affected, and the risk of death is twice as high among people exposed to heat, especially at night and when a heatwave lasts a week or longer. This risk increases when other individual factors (existing health issues, age, income, etc.) or factors relating to the environment of the dwelling (located under a roof, located in a district affected by UHIs, limited access for doctors or emergency services, etc.) are added.

Vulnerability to the effects of UHIs was analysed using the "Vulnerability"[11] indicator in the project titled "Adapting the Paris Region to Urban Heat" (*Cordeau, 2017*) carried out by the Paris Region Institute. The principle of vulnerability involves several notions: exposure of an area and a community to a hazard (here the UHI effect); the sensitivity and fragility of the exposed population; and its ability to cope with the hazard by anticipating it, reacting to it or withstanding it. Where UHIs are concerned, vulnerability thus depends not only on exposure to the hazard (high, moderate or low), but also sensitivity (e.g. because of age) and ability to cope (e.g. if a cool island exists). In the framework of the study carried out here, high vulnerability gives the cell a score of 0, moderate vulnerability scores 1 and low vulnerability scores 2.

Air pollution

Air pollution was analysed on the basis of particulate concentrations known as $PM_{2.5}$, in other words particles whose diameter is 2.5 microns (µm). These particles have many sources but the residential sector and road traffic are the two main culprits in the Paris Region [18]. $PM_{2.5}$ concentrations were chosen to assess air quality because they pose a significant health risk (they are responsible for 9% of deaths in France (*Pascal et al, 2016*)) and because research on plant-based air decontamination has mainly been carried out on this type of particle (*Prigioniero et al, 2021; Selmi, 2016)*. In France, there are 48,000 premature deaths annually due to particles whose diameter is less than 2.5 µm in the open air[19]. The data used comes from the association Airparif and corresponds to the average $PM_{2.5}$ concentration in 2014 - 2018. For the attribution of scores, the thresholds were chosen on the basis of goals set at the *Grenelle de l'Environnement* (15µg/cu.m./year) and WHO recommendations (5µg/m³/year with an intermediate threshold of 10µg/cu.m./year) [20].

On the basis of the above objectives, the cells score 0 points for areas where the concentration is 15 µg/m³/year or more, 1 point where it is less than 15 µg / cu.m./year but higher than 10 µg/ cu.m./year, 2 points where it is lower than 10µg/ cu.m./year but higher than 5µg / cu.m./year, and 3 points where it is lower than 5µg / cu.m./year.

Lack of green spaces

Several studies have shown the health benefits of nature in urban areas. The presence of natural spaces helps to reduce anxiety (*Hystad et al, 2019*) and depression (*Beute et al, 2020*); to improve mood (*Sonntag-Öström et al, 2014*); and to improve attention span and concentration (*Kaplan et Kaplan, 1989*). Although no further proof of the health benefits of nature is needed (*Meyer-Grandbastienet al, 2021; Plante & Cité, 2021; [21]*), additional research is required to improve understanding of the direct and indirect links between nature and health.

Several research projects have also succeeded in highlighting thresholds above which positive effects on health are observed. In 2017, an American study has shown that cases of stress and anxiety could be reduced by 17% or 25% if plant cover exceeded 20% or 30% respectively (*Cox et al, 2017*) within a 250-metre radius of where people live. A Polish study recommends a minimum of 45% plant cover or aquatic environments (*Szulczewska et al, 2014*) in residential neighbourhoods to ensure adequate air cooling, permeability to rainwater and evapotranspiration during heatwaves.

[11] This indicator is calculated on the basis of the "hazard" indicator (cf. chapter 2.4.1.1), a "sensitivity" indicator (presence of a nursing home, proportion of the population sensitive because of age, density of housing occupation, etc.) and a "coping" indicator (lack of public green spaces; proximity to hospital A&E, proportion of low-income households, etc.). Vulnerability at night was taken into account as this is when the UHI effect is most pronounced.

To characterise a lack of natural space, 2 components were studied: (i) lack of green spaces open to residents and (ii) a vegetation index (established on the basis of plant cover).

- (i) The study of the lack of public green spaces was based on data from the study carried out by the Paris Region Institute Région as part of the 2017 Green Plan (appendix 3), which distinguishes three types of deficient zones: zones lacking in accessibility; zones lacking both green spaces and accessibility; and zones that lack neither.
- (ii) The vegetation index was studied according to thresholds highlighted in the research quoted above.

Table 9: Attribution of scores for the 2 components studied (vegetation index and access to public green spaces).

Vegetation index	
Plant cover	**Value**
<30%	0
30% ≤ - < 45%	1
≥ 45%	2

Public green spaces	
Type of deficiency	**Value**
Both	0
Lack of spaces	1
Lack of access	1
None	2

Adding together the two components (lack of public green spaces + vegetation index) makes it possible to distinguish areas with significant deficiencies from non-deficient areas. The final score is reclassified so that it is between 0 and 2 (value in bold). A score is then attributed to the cells according to lack of natural spaces: significant deficiency scores 0, moderate deficiency 1, and low deficiency 2.

Table 10:Table combining (i) lack of public green spaces and (ii) vegetation index

Lack of public green spaces / Vegetation index	**Both** (= 0)	**Lack of spaces** (= 1)	**Lack of access** (= 2)	**None** (= 3)
Low (= 0)	0 → **0**	1 → **0**	1 → **0**	2 → **1**
Moderate (= 1)	1 → **0**	2 → **1**	2 → **1**	3 → **2**
High (= 2)	2 → **1**	3 → **2**	3 → **2**	4 → **2**

2.5.2 Where should renaturing take place to improve health and the living environment?

In keeping with the method detailed in paragraph 2.1, cells with a score from 0 to 2 were defined as priority renaturing zones. Cartographic analysis reveals that urban areas where health risks are greatest are in Paris and its immediate suburbs. It seems that the risks studied increase with densification: the denser an area is, the less green spaces it has and the higher UHI effects and levels of vehicular pollutants will be. As far as $PM_{2.5}$ pollution is concerned, it is important to note that no zone complies with the WHO recommendation of 5µg/cu.m./year, and only a few areas in the outer suburbs are below the threshold of 10µg/cu.m./year. It should also be remembered that the analysis only took account of factors on which renaturing operations might have a beneficial effect (creating a cooling island; reducing deficiency in green spaces; helping to reduce atmospheric pollution). The results cannot be extrapolated to other studies concerning public wellbeing as additional information would be required (on pollutants other than $PM_{2.5}$, standard of living criteria, etc.).

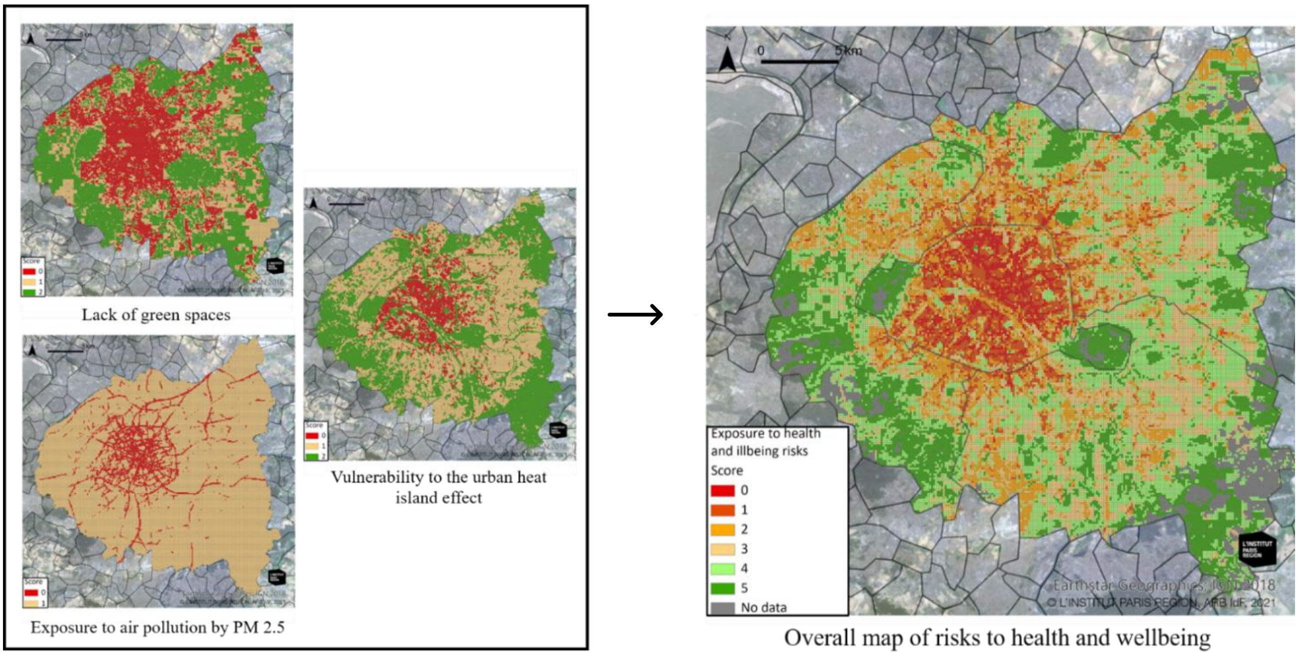


Figure 12: Once the individual criteria had been studied, the points were added up to obtain a final score, resulting in an overall map of risks to health and wellbeing exposure to health and wellbeing risks.

EXAMPLE OF HOW THE METHODOLOGY WAS APPLIED IN THE TOWN OF AULNAY-SOUS-BOIS

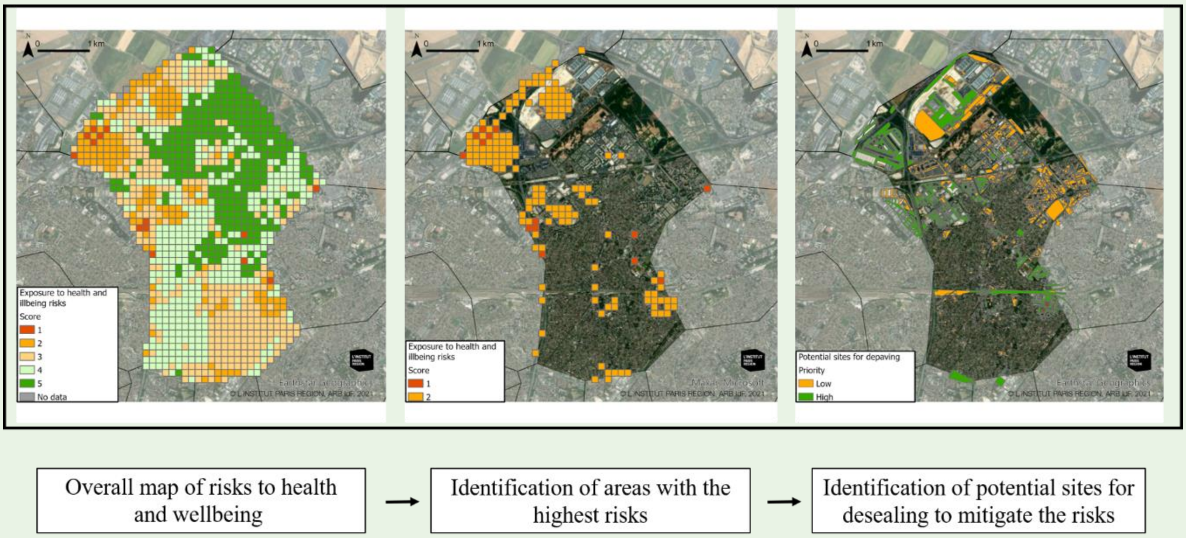


Figure 13: Identification of desealable sites in high-stakes areas to improve health and/or the living environment in Aulnay-sous-Bois (Paris Region, département *of Seine-Saint-Denis)*

The results reveal a total of 162 cells exposed to health risks or with a degraded living environment (score: 1 or 2). These are scattered across the area and risks are mainly due to a lack of green spaces and/or the vulnerability of the population to UHI effects. The 993 remaining cells do not suggest especially high risks relating to the criteria studied here (score: 3 - 5).

2.5.3 Feedback and recommendations

For a renaturing project to improve health and the living environment, it is important first to know its aims (improving air quality, combating UHIs, improving wellbeing, etc.). Although increasing the number of natural spaces will be of obvious benefit to the living environment, their ecological quality must not be neglected. More significant benefits concerning mental health have recently been attributed to lightly managed natural areas (with less mowing and no pruning) (*Clark et al. 2014*). Other studies have highlighted the importance of biological components in recreational areas. For example, the number of visual interactions with birds is thought to be linked to lower levels of stress (*Cox et al, 2017*). With a view to improving all aspects of health (physical, mental and social), several recommendations can be made, in particular:

- Offer more natural spaces and remedy deficiencies in the areas concerned.
- Reduce the number of concrete surfaces, which absorb heat, instead placing the emphasis on vegetation.
- Create a canopy capable of providing shade and promoting evapotranspiration to reduce the UHI effect.
- Use species able to fix atmospheric pollutants to improve air quality.
- Use participatory approaches making citizens into agents of change and fostering social interactions.

EXAMPLE OF INTERPRETATION OF CARTOGRAPHIC RESULTS OBTAINED FOR THE "HEALTH AND LIVING ENVIRONMENT" SCENARIO

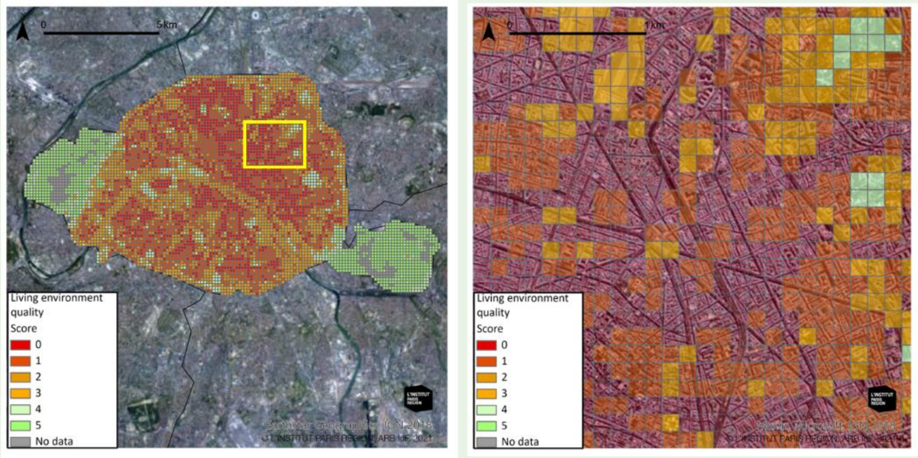


Figure 14: Map of risks to health and wellbeing in Paris and example of interpretation.

The city of Paris is an area highly deficient in green spaces. The above map highlights an extensively sealed urban area in the city centre, which is thus highly exposed to air pollution and UHI effects. The degree of densification also causes a deficiency in green spaces, except in areas adjacent to parks. Renaturing these types of areas would make it possible to tackle the lack of green spaces, to limit the heat island effect, and, to a lesser extent, to reduce atmospheric pollution (which can only be drastically reduced via measures aimed at directly curtailing pollutant emissions).

Renaturing to improve temperature comfort in urban areas

Natural areas can help to improve temperature comfort in cities, especially during heatwaves. They reflect sunlight, avoiding the accumulation and release of heat. In summer, depending on the tree species, the canopy only allows 10% - 30% of sunlight to get through, providing shade and reducing perceived temperatures. Plants are also the source of evapotranspiration, which combines evaporation (water contained in the soil and bodies of water is released in gaseous form) and transpiration (water contained in the leaves is exuded to maintain the temperature of the plant). Evapotranspiration thus cools the air thanks to the release of a large quantity of water vapour. However, for vegetation to cool a city, it must have water available to it in very hot weather. Frugal watering using collected and stored rainwater may thus be necessary. The benefits provided by natural spaces on UHIs and temperatures are, however, highly localised. More renaturing projects must be rolled out to maximise their effects. Also, the type of vegetation needs to be taken into account: multi-strata urban woodland is more efficient than hay meadows at improving temperature comfort, for example.

Project 1: rehabilitation of the Rue Garibaldi in Lyon
In brief: transformation of a major city-centre road into a planted parkway to improve urban temperature comfort.

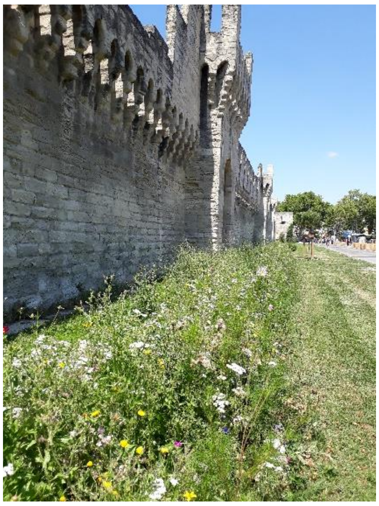
Experiencing the cooling properties of vegetation on the renatured Rue Garibaldi in Lyon. © Laurence Danière

As part of its climate plan, the Lyon Metropolitan Council is greening urban space to reduce the effects of urban heat islands. This was the aim when a 3-kilometre stretch of the Rue Garibaldi, a major traffic artery, was turned into a shaded parkway. The first stage, carried out between 2014 and 2016, retained over 80 existing trees and planted 150 new trees, shrubs and herbaceous plants of different species responding to ecological and aesthetic criteria. One of the special features of the project is the way it has turned road tunnels into rainwater storage reservoirs. In periods of extreme heat, evapotranspiration, which cools the air, no longer occurs. Giving trees stored rainwater kick-starts evapotranspiration to cool the city. According to several measurement campaigns carried out on the Rue Garibaldi, the trees brought temperatures down an average of 1.78°C to 2.33°C in August 2016 and 2017. As for perceived temperatures, the difference between planted and unplanted areas was up to 10°C.

KEY TAKEAWAYS

- Vegetation, especially trees, offers shaded areas that filter direct sunlight and provide higher levels of temperature comfort.
- A former road can become a rainwater storage reservoir to help vegetation to cool the city during heatwaves.
- Retaining existing trees should be the primary objective of any strategy aimed at developing the urban canopy.

Project 2: greening the base of the ramparts in Avignon
In brief: desealing 1,900 parking spaces along the ramparts that were causing an urban heat island, turning them into meadows to improve residents' wellbeing.




Greenery at the base of the ramparts after desealing the parking spaces. Left to right © Cécile Vo Van Cerema, and © The city of Avignon

The ramparts surrounding the old city of Avignon are on the UNESCO World Heritage list and are one of the city's major emblems. Until 2010, the outer façades were lined with parking spaces that formed a heat island in summer. Desealing 1,900 parking spaces made way for meadows at the base of the ramparts. They are planted with a variety of species adapted to full sunlight or half-shade and to the Mediterranean context. The work was also an opportunity to provide access to a shaded promenade for pedestrians and cyclists. Moreover, the project shows that it is possible to carry out such initiatives next to listed historic monuments and to comply with the demands of the historic buildings inspectorate.

KEY TAKEAWAYS

- Particular care must be taken over the choice of plant species. Giving preference to local species means that they will be better adapted to the local climate and able to withstand heatwaves even without watering.
- Planting in a continuous trench encourages growth and increases the amount of available water in the soil. Restoring soil continuity allows trees to develop crowns that can provide shade in public space and provides enough water for evapotranspiration to occur.

Creating new spaces to improve air quality

Plants help to improve air quality, reducing the concentration of atmospheric CO_2 by photosynthesis and of suspended particles which are absorbed and deposited on the surface of leaves (*Litschke & Kuttler, 2008*). Plants help to purify the air via three distinct mechanisms: pollutant deposition on leaves and branches; adsorption of lipophilic pollutants in the waxy cuticles of leaves; and penetration of pollutants through stomata. While all forms of vegetation are welcome, the absorption capacity of plants depends on several factors: chosen species, air flow, concentration of pollutants, position of the plants, and so on (*Pugh et al, 2012*). For example, larges areas of trees with rough leaves can absorb more pollutants than plants with smooth leaves (*Sæbø et al., 2012*). Renaturing car parks and roadside parking spaces can also be seen as a way of reducing the number of cars in cities and consequently helping to improve air quality. The most convincing results have been obtained in Seoul, where several highways have been removed (see project 3 below).

In 2020, Bruxelles Environnement carried out a study to summarise scientific knowledge of the impact of urban vegetation on residents' exposure to atmospheric pollutants, noise and extreme heat. The summary confirms that in general, trees are most efficient in this regard, followed by shrubs and herbaceous plants. Conifers are generally better at filtering particulate pollution (as they offer a larger surface of interaction) and the adsorption of volatile organic compounds. They are also effective all year round as they do not lose their leaves in winter, with a few exceptions. Deciduous trees deliver the best results in terms of absorbing gaseous pollutants (NO_2 et O_3 in particular). The ability of vegetation to reduce local pollution depends on numerous other factors such as the nature of the pollutants, weather conditions and the position of the plants with respect to the local source of pollution (*Baldauf et al, 2008; Lefebvre & Vranckx, 2013*). Applied to 4 critical zones in terms of air pollution, Bruxelles Environnement estimated that maximum greening scenarios would provide a reduction of 5 to 10% in local concentrations of NO_2. However, the study confirms that nature-based solutions are generally insufficient to reduce atmospheric pollution significatively and that measures taken to reduce pollutant emissions at source must remain a priority [22].

Project 3: dismantling an urban highway in Seoul
In brief: dismantling a 10-lane road (leaving only 4 lanes) to form a 5-km parkway and restore a river.

The Cheonggyecheon restoration project was centered on revitalizing the Cheonggyecheon Stream that had been covered for decades by a highway overpass ©Global Designing Cities Initiative

In 2005, the city of Seoul launched a major project to restore the River Cheonggyecheon which flowed beneath a 10-lane road with a 4-lane highway above. The project had several objectives. Its primary aim was to improve the living environment and health of residents by reducing the atmospheric pollution and noise created by 170,000 vehicles every day. The highway was dismantled and only 4 of the original 10 lanes were retained to leave space for the restored River Cheonggyecheon and footpaths along its banks. Today the river flows through a parkway stretching over 5 kilometres that attracts 60,000 pedestrians every day.

Several scientists have monitored the benefits, underlining the value of the project in terms of flood protection (*Hwang, 2005*). Between the pre-restoration work in 2003 and the end of 2008, the number of plant species rose from 62 to 308, fish from 4 to 25, birds from 6 to 36, aquatic invertebrates from 5 à 53, insects from 15 to 192, mammals from 2 to 4 and amphibians from 4 to 8 (*Revkin, 2009; Kim,* *Koh & Kwon, 2009*). The project has also helped reduce the urban heat island effect, with temperatures along the river 3.3° to 5.9 °C cooler than on a parallel road a few hundred metres away. This is due to the removal of the highway, the cooling effect of the river, the increased amount of vegetation and higher wind speed along the corridor. In terms of air quality, measurements have confirmed a 35 % reduction in fine particulates, which have fallen from 74 to 48 micrograms per cubic metre. Before the restoration work, local residents were twice as likely to suffer from respiratory illness than those living elsewhere in the city.

Despite the project's environmental performance, scientists have highlighted conflict between the City Council and a coalition of NGOs around different approaches to renaturing. The NGOs criticise the lack of ecological authenticity in the restored stream (*Cho, 2010*), while others regret the artificial way vegetation is surrounded on all sides by concrete (*Lévy, 2015*). The project nonetheless provides unique intelligence on dismantling infrastructure to restore a river and its immediate surroundings.

KEY TAKEAWAYS

- Renaturing roadways is an opportunity to limit the presence of cars in urban areas and thus to reduce pollutant emissions. It is also a way of making room for pedestrians and encouraging activities that are known to improve health. Although vital, walking has been largely overlooked in French public transport policy despite being the leading means of transport in the Paris Region. Giving pedestrians more space in urban areas is also a way of responding to challenges relating to public health, the climate and the living environment [23].
- Vegetation can absorb and directly remove certain gaseous pollutants from the air via stomata and leaves (when particles are deposited on the leaf surface). The ability of plants to absorb pollutants depends on several factors such as chosen species, air flow, concentration of pollutants, position of plants, etc. (*Pugh et al, 2012*). For example, larges areas of trees with rough leaves can absorb more pollutants than smooth-leaved plants (*Smith, 2012*).

Project 4: fighting air pollution with trees
In brief: a test site for air pollution in Metz as part of the SESAME study carried out by the CEREMA.

SESAME (Services EcoSystémiques rendus par les Arbres, Modulés selon l'Essence/Ecosystem Services provided by Trees, Modulated according to Species) is an innovative project run by the City of Metz, Metz Métropole and the CEREMA. The study originated in research carried out by Metz City Council since 2015 into how nature-based solutions, especially trees and shrubs, can respond to a number of issues relating to climate change, biodiversity and air quality**.** SESAME identifies the ecosystem services provided by 85 species of trees and shrubs in terms of air quality, support for biodiversity, local climate regulation, carbon sequestration, the living environment and adaptation to climate change. It also takes into account risk of allergies, the production of volatile organic compounds, and physical constraints (size, root system, etc.). The study resulted in the creation of an operational tool designed for the Council and planners, helping to select plant species for any green space project according to a typology of landscapes identified in the region and making it possible to adapt to constraints and leverage opportunities. The tool can be used by other local authorities, even in areas with different climate conditions and constraints (the plan is to cover 200 to 300 species).

Planting trees on the SESAME test site in Metz. 14 species were selected for their ability to absorb pollutants and host local wildlife. © City of Metz

The City of Metz climate plan includes large-scale tree planting (20,000 trees to be planted by 2030). The trees will be selected according to the results of the study, the combination and diversity of species being essential recommendations for any planting project. A SESAME test site was created at the intersection of Boulevard de Guyenne and Boulevard Solidarité, very busy roads used by 4,000 to 9,000 vehicles daily. ATMO Grand Est, an officially endorsed association that monitors air quality, has been asked to assess the site and to determine the potential impact of vegetation on air quality and thus the health of local residents. Pollutants measured as part of the study are nitrogen dioxide (NO_2) and particles whose diameter is less than 10 µm (PM10), mainly due to road traffic. Of the 18 species selected, some absorb pollutants (for example the European nettle tree) and others foster biodiversity (e.g. the common elder). Sensors will be put in place on the site and the area opposite to compare the impact of plants on air quality and biodiversity. Measurement campaigns will be carried out every two years to check the potential impact of the planted species on air quality by comparing concentrations measured near traffic, a few dozen metres away, and with no plant barrier nearby.

KEY TAKEAWAYS

- Plants can trap air pollutants, either because they absorb them (gaseous pollutants) or because pollutants are deposited on their surface (fine particles).
- The effect of plants on air quality is limited but real (*Selmi et al, 2016*). It requires developing the "urban forest" (*Cerema, 2019*).

- The example of the Strasbourg *Eurométropole* shows that trees can eliminate 0.03% of CO_2, 7% of PM_{10}, 1.5% of $PM_{2.5}$ and 0.5% of SO_2 (*Selmi et al, 2016*).
- Trees also emit pollutants, in particular volatile organic compounds (VOCs), especially terpenes (*Cerema, 2019*).
- The SESAME study provides a table showing the performance of 85 tree species in terms of regulating gaseous pollution in particular. [24]

Renaturing projects by and for the local community

Health is closely connected to the quality of the living environment and access to natural areas. Providing more room for nature in urban areas, in terms of both quantity and quality, is a way of actively improving wellbeing. This is supported by a high level of demand from the community and expressed in successful initiatives such as "planting permits", participatory budgets and the creation of allotments.

Renaturing urban areas is also a way of combating what sociologists and ecologists call "the extinction of experience" (*Miller, 2005*). Over recent years, interdisciplinary research on the subject, for example the work of Anne-Caroline Prévot at the Centre of Ecology and Conservation Sciences at the Muséum National d'Histoire Naturelle, has shown the need to maintain nature in urban areas to provide residents with opportunities to come into contact with biodiversity. It is through observation and day-to-day experience of flora and fauna that people develop a concern for, and an interest in, wildlife. You protect what you know. These experiences can be enriched by designing areas that are particularly effective at hosting biodiversity. Experiences with biodiversity also contribute to human wellbeing (*Fuller et al, 2007*). Whether it be convincing others, improving acceptance of projects or responding more effectively to demand from the community, participatory approaches with local residents have many advantages.

SCHOOL YARDS DESEALING

The Oasis schoolyard of the Emeriau School in Paris ©Théo Ménivard, CAUE Paris

An increasing number of cities are committing to desealing schoolyards and renaturing / greening them. These spaces, which are often designed with a concrete slab and a few isolated trees, have many educational and environmental benefits. Renaturating schoolyards can provide multiple benefits such as reconnection with nature, environmental education, more equitable sharing of space, fight against the urban heat island effect, etc. While in some school actions are limited to rainwater management (replacement of pavement by a permeable alternative), some schools are choosing to transform their playground into a planted space. In addition to the direct benefits on the well-being, health and awakening of children, these places become support to nature education, particularly through participatory science. The recommendations booklet produced within the framework of the OASIS program of the city of Paris offers a lot of information on how to implement the desealing of schoolyards, as well as on the co-design phase, which is essential for the success of such an operation [25].

Project 4: wild garden on the site of a former car park in Aubervilliers
In brief: destroying a disused car park to transform it into a rock garden and improve the living environment.


Concrete crushing and planting on a former parking lot in the city of Aubervilliers, France ©Wagon landscaping

La Maladrerie is a housing estate built in the 1980s in Aubervilliers, a town in the *département* of Seine-Saint-Denis. The edge of the estate overlooked a car park that had been disused for several years. To improve the living environment, Wagon Landscaping and the artist Sylvie Da Costa, who lives in the estate, commissioned by the Aubervilliers Town Council Housing Office, worked for 5 days to create the garden. First the Council broke up the surface of the car park, leaving the rubble in place to create a 1,600 sq.m. “rock garden” that is a cross between an area of waste ground and a botanical garden. Soil was brought in and 150 species of perennials, shrubs and young trees were planted to kick-start a process of recolonisation.

A total of 2,000 plants were introduced, chosen for their ability to adapt to uneven ground and requiring little maintenance. The Jardin des Joyeux is maintained as little as possible to preserve its rough, rocky appearance with asphalt peeking through the vegetation. Five years after the preparatory work, much of the broken asphalt has been overgrown. Wagon Landscaping managed the entire project, including the construction work. The garden requires minimum maintenance and no watering. Aubervilliers Council has organised several open days inviting residents to discover the project and the new on-going ecosystem.

KEY TAKEAWAYS

- Ecological management or passive management can be used in all urban areas. Communicating with the local community and showing how projects benefit nature facilitates acceptance.
- It is possible to recreate the right conditions for recolonisation, even on previously sealed ground.

Project 5: transformation of a former aerodrome in Frankfurt (Germany)
In brief: transformation of an airport into a multi-use public park featuring sports amenities, footpaths, educational workshops for schools, and spontaneous recolonisation by flora and fauna.

The new park offers guided visits and discovery trails focusing on biodiversity. ©Kai Spurling

Ten years after the former aerodrome closed, the City of Frankfurt purchased 7 hectares of land and turned it into a new natural area open to the public. There were three aims: to guarantee and reinforce spontaneous natural recolonisation; to create a recreational area for residents; and to keep the budget low. Several buildings have thus been retained to recall the history of the site and are now used as artists' studios and cafés. A third of the former runway has also been kept to cater for one of the uses identified for the site: safe from traffic, the runway is ideal for cycling, rollerblading and skateboarding.

In all, 3 hectares of runway and car parks have been dismantled. Instead of being removed, the asphalt has been crushed and left on the ground, offering cavities that can be colonised by animals and plants. The size of the chunks varies from place to place: they get smaller as you move further away from the buildings. This makes it possible to visualise natural recolonisation thanks to a desealing gradient that echoes ecological succession. Concrete is still a strong presence near the buildings, then come rocky environments, meadows, copses, and finally spontaneous woodland representing the climax of the process (the final step in ecological succession).

Today the former aerodrome has become not only a place to walk and engage in leisure activities but also an educational area. Regular events are scheduled for residents and schools focusing on plant identification, amphibian-spotting, birdwatching, and so on). The project recalls the famous Berlin Tempelhof airport, which also became an urban park in 2007 after part of its surface was desealed. Airports, like large industrial parks or railway stations, occupy significant areas of land that can be transformed into new natural spaces.

Part of the former runway has been set aside for cyclists and rollerbladers. © Stefan Cop

KEY TAKEAWAYS

- For brownfield rehabilitation projects, it is important to study the current use of the site in order to develop projects that closely respond to local community expectations.
- Renatured sites are new educational areas that can be used to raise awareness of conservation and biodiversity issues.

Project 6: renaturation of an old road in Saint-Jacques de la Lande
In brief: desealing and passive renaturation of a portion of road in the context of the creation of an ecological park.

Crushed asphalt gives way to spontaneous vegetation on an old road in Saint Jacques de la Lande. © Yann Laurent

initiated in 2004, the development of the Saint-Jacques de la Lande Ecological Park, near Rennes in Brittany, now offers 45 hectares of relaxation, leisure and walking paths for the inhabitants. In addition, the park manages the rainwater of the new city center. Streams planted with phragmites and vegetated ditches direct the water to a first basin, then to a reed bed that ensures the phyto-treatment of runoff water.

The operation has also made it possible to deseal an old road. Led by the city services and a landscape architect, the operation consisted of crushing the asphalt and keeping it in place to avoid generating waste. The principle adopted is a passive ecological restoration: the crushed blocks of asphalt constitute seed traps and habitats for the development of pioneer vegetation. A team of researchers and students from Agrocampus Ouest is monitoring the flora, lichens and insects in this freely evolving space. After a few months, opportunistic observations have confirmed the presence of reptiles (vipers, lizards), for which these rocky environments are the characteristic habitat.

By combining an ecological and artistic approach, this project succeeds in involving the local population in this restoration project. It reminds the rewilding of Berlin Tempelhof and Frankfurt Bonames airports in the late 2010s (see boxes), and brings together ecologists and landscape architects in a common approach.

Project 6: the "Transformer" in Saint Nicolas de Redon

In brief: renaturing a brownfield site via several community projects making it possible to experiment with renaturing methods while organising a range of public events.

Le Transformateur in Saint Nicolas de Redon is a low-cost brownfield renaturing project carried out by local residents. © Nature Loire Atlantique (left), © P. Pascal (right).

A 5.5-hectare brownfield site in Saint-Nicolas de Redon (Loire-Atlantique) was regularly flooded when the River Vilaine overflowed. In 2001, the *Département* of Loire-Atlantique and the town council asked students at the Ecole Supérieure du Paysage in Versailles to carry out a landscape survey reflecting upon the future use of the site. Their central proposal was to renature the site, drawing inspiration from Antoine Lavoisier's famous phrase "Nothing is lost, nothing is created, everything is transformed". Only pollutant materials were removed from the site; the rest was left in place, repurposed or used as a medium for plant recolonisation. The experimental and participatory projects led residents to form associations in order to continue with the renaturing and management of the site. In response to these successes, the Loire-Atlantique Council purchased the site in 2005 as part of its "Sensitive Natural Areas" policy and signed an agreement with the association "Les Amis du Transformateur" [26] in order to: (i) manage and renature the site, (ii) create the right conditions for opening the site to the public, (iii) collect and share information on the experiments carried out on the site.

Le Transformateur offers a range of different spaces (hangars, concrete slabs, unbuilt areas where bumps have been created using infill, herbaceous environments, wetlands, etc.), which have inspired ideas for future uses of the site and renaturing projects. A range of experiments have been carried out since 2006:

- Desealing to form gaps and micro-ditches that make it easier for plants to lift and overgrow chunks of concrete.
- Participatory projects to recreate woodland, hedges, vegetable gardens, orchards, etc.
- Using Nantaise cattle to graze the meadows.

- Artworks showcasing the identity of the site: Land Art made with demolition materials, street art festival (murals on the buildings).
- Activities and outings: nature rambles, historic visits, cookery workshops, taking part in management or planting projects, art exhibitions, etc.

Scientific monitoring has revealed the presence of several species of interest on the site, including bee orchids and Gallic pinks. Very rustic plants such as bryophytes and sedums also suggest that plants are taking over the site once more. In terms of animal life, the site hosts several species of bats (common pipistrelle and Kuhl's pipistrelle) and birds (black kite), which use it a transit point between the River Vilaine and the surrounding woodland and meadows. This illustrates how an industrial site can be spontaneously recolonised by wildlife.

Right: artwork using demolition materials and evolving as plant recolonisation progresses © La Musardise.
Left : experimental micro-ditches allowing plants to overgrow concrete slabs. ©Les Amis du Transformateur.

KEY TAKEAWAYS

- Local residents, via associations, can make decisions, organise renaturing programmes, manage the site, and organise events to share information about the project.
- Foster creativity, dare to try new things, risk making mistakes, rely on different skills, draw inspiration from existing projects and disseminate knowledge acquired from experiments.
- Reusing land and rubble reduces the financial and ecological costs of demolition, exporting materials, decontamination and the treatment and storage of waste.
- The renatured site enjoys long-term protection because the *département* acquired the land as part of its "Sensitive Natural Areas" programme, but other tools exist to protect renatured spaces (in France: "Zone N" classification, protected woodland listed in planning documents, "Real Environmental Obligation", etc. [see section 3.3.8]).

2.6 How much of the Paris Region is renaturable?

The methodology presented in this guide makes it possible to estimate the amount of potentially desealable and renaturable land. This can be calculated at the level of the *commune* (town or village), the *département* (sub-regional administrative area) and the Paris Region. The results will soon be available for consultation in “Cartoviz”, an on-line tool developed by the Paris Region Institute and ARB îdF.

As an example, calculations and data visualisation have been carried out for the *commune* of Aulnay-Sous-Bois. Statistics are also given for the *départements* of Paris and the inner suburbs. On the scale of the *commune*, it is estimated that a total of 256,66 hectares of sealed soil is potentially renaturable. About 228,24 hectares could be renatured to respond to biodiversity challenges, 158,26 hectares to aid adaptation to climate change, and 104,74 hectares to improve health and the living environment. The table below, which shows these different potentials, also indicates the surface area of the sites compared to the number of renaturing “challenges” associated with them. In some sites, renaturing does not respond to a major challenge; in others it responds to only one challenge; and in still others it responds to two or even three challenges.

Table 11: Sealed surfaces that are potentially desealable depending on what is at stake in the town of Aulnay-sous-Bois

What’s at stake? (the “challenge”)	Potential area (ha)
Biodiversity recovery	228,24
Adapting to climate change	158,26
Improving health and the living environment	104,74
No major challenge	16,92
1 challenge identified	71,87
2 challenges identified	84,26
3 challenges identified	83,61
Total	**256,66**

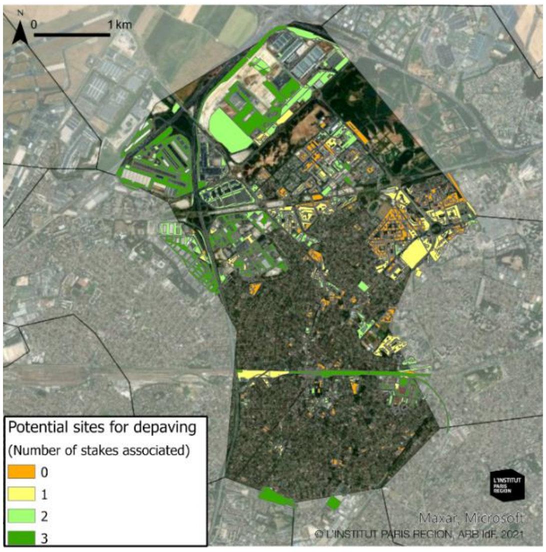


Figure 15: Map identifying sealed surfaces that are potentially desealable depending on what is at stake in the town of Aulnay-sous-Bois.

Table 12: Sealed surfaces that are potentially desealable depending on what is at stake in Paris

What's at stake? (the "challenge")	Potential area (ha)
Biodiversity recovery	1206,46
Climate change	1258,88
Living environment	1318,90
No challenge	39,20
1 challenge	62,04
2 challenges	193,23
3 challenges	1111,92
Total	**1406,38**

Table 13: Sealed surfaces that are potentially desealable depending on what is at stake in the département of Hauts-de-Seine

What's at stake? (the "challenge")	Potential area (ha)
Biodiversity recovery	1744,17
Climate change	1502,42
Living environment	1271,10
No challenge	654,46
1 challenge	524,24
2 challenges	668,97
3 challenges	885,17
Total	**2732,85**

Table 14: Sealed surfaces that are potentially desealable depending on what is at stake in the département of Seine-Saint-Denis

What's at stake? (the "challenge")	Potential area (ha)
Biodiversity recovery	2693,04
Climate change	1979,07
Living environment	2188,47
No challenge	633,75
1 challenge	775,07
2 challenges	1004,11
3 challenges	1359,09
Total	**3772,03**

Table 15: Sealed surfaces that are potentially desealable depending on what is at stake in the département of Val-de-Marne

What's at stake? (the "challenge")	Potential area (ha)
Biodiversity recovery	1993,03
Climate change	1775,60
Living environment	1618,25
No challenge	663,11
1 challenge	687,63
2 challenges	687,41
3 challenges	1108,14
Total	**3146,30**

Table 16: Sealed surfaces that are potentially desealable depending on what is at stake in the region of Île-de-France (the Paris Region).

What's at stake? (the "challenge")	Potential area (ha)
Biodiversity recovery	16109,82
Climate change	14872,52
Living environment	10373,42
No challenge	9688,61
1 challenge	7390,67
2 challenges	6402,99
3 challenges	7053,04
Total	**30535,31**

However, estimations of this potential are to be viewed with caution as they rely on sets of data from automated studies based on aerial photography and satellite views. Some sites considered to be sealed are not always sealed in reality. For example, building courtyards and the areas surrounding them are automatically considered to be sealed, whereas this is not necessarily the case. Conversely, some rows of trees where the ground is sealed, abandoned buildings, oversized pavements and roadside parking spaces have not been pinpointed in this initial approach and are thus not taken into account at this stage. Last but not least, it must be remembered that the feasibility of renaturing operations has not been assessed. These limitations confirm the importance of an on-site verification process set up by the local authority and based on the methodology.

3 SUCCESSFUL RENATURING STEP BY STEP

The third part of this guide offers a few general recommendations for each step of a successful project: planning, implementation, monitoring and assessment, as well as long-term maintenance.

Before anything else, it is necessary to put together a multi-disciplinary team to design and manage the different operations. Ideally this would involve council departments, renaturing specialists, research organisations, local associations and, if possible, members of the community affected by the project. Bringing together a panel of stakeholders at the beginning of the project makes it possible to take a broad spectrum of points of view into account and thus to ensure that the different steps run smoothly. Ecological skills are fundamental, and must be identified before the project begins.

3.1 Prioritising projects and assessing feasibility

The methodology proposed in Chapter 2 is based on the principle that the benefits of renaturing will be greater if they target adaptation to climate change, restoring biodiversity or improving the living environment. The spatial analytical tool presented in this guide also allows local authorities to prioritise their actions, but it does not make it possible to assess feasibility. The technical difficulty associated with renaturing depends on a number of parameters. In the framework of its strategy for the restoration of sealed areas, the City of Berlin relies on 4 criteria to help it prioritise its actions:

The status of the land: i.e. establishing whether the land is publicly or privately owned.

Privately owned sites will need to be purchased, and this can be time-consuming. It is important to prioritise renaturing projects on publicly owned sites**.** In parallel the local authority can come up with ways of incentivising, funding or supporting private owners willing to renature sealed areas (planting permits, water board subsidies, etc.).

Demolition

The more demolition a project involves, the harder and more costly it will be to implement. Projects concerning non-built-up or sparsely built-up areas have more chance of going ahead than those requiring the demolition of infrastructure or buildings, and should thus be prioritised. For example, on two sites of similar size, a desealing project requiring the demolition of a large structure or several buildings will be harder to put in place than the “simple” removal of an impervious surface (car park, public square, etc.). A moderate degree of difficulty may also be considered, for example for sites that have a few built structures in the area in question.

Area to be desealed

This criterion aims to estimate the total surface area that can be desealed and renatured on the site. A site whose whole surface can be desealed is of greater interest than a site where it is only possible to depave small isolated areas.

The project timeframe

It is possible to prioritise projects according to the time they will take and give priority to those that can be rapidly implemented (in 1 - 2 years) rather than those that can only be completed in the medium term (about 5 years) or long term (over 5 years).

Table 17: Criteria used by the city of Berlin for assessing the feasibility of a renaturing project on a sealed site.

	High priority	Medium priority	Low priority
Land status	Public	x	Private
Demolition	Little or no demolition	Demolition of small structures	Demolition of large structures (buildings)
Desealable area on site	Entire surface	Several separate areas	A few small, very isolated areas
Project timeframe	1 – 2 years	About 5 years	More than 5 years

To ensure the success of a project, it is also important to determine its technical feasibility. Below is a summary of some of the planning parameters that may be taken into account when putting together a project, as well as resources that help to analyse them. This is not, however, an exhaustive list, and it is important to note that although the presence or absence of certain parameters may represent risks, this does not necessarily compromise the feasibility of a renaturing project. The project can still go ahead, but special attention must be paid to these parameters so that they do not affect its viability once it is up and running.

(1) Hydrology

From a hydrological point of view, the level of the water table must be studied. Desealing can pose a risk of chronic or accidental contamination of subterranean water [27] as well as a risk of rising water table levels during heavy rain, especially if the water table is very shallow [28].

However, the presence of shallow groundwater can also be an advantage in some contexts, such as the restoration of wetlands. The highest level of a given water table is defined by a hydrogeological survey using historic data (geological databases and archives, data obtained from operators, etc.), sometimes with the addition of a local district survey or a survey using piezometric devices. [29].

(2) Permeation capacity

According to its permeation capacity, soil will lend itself more or less well to different types of projects as it determines how long water stagnates after it rains. An impervious soil may be an asset when restoring the blue grid, for example in view of creating a network of temporary ponds. In the case of permeable soil, there may be a risk of groundwater pollution if the latter is shallow (see "Hydrology" above), but it also offers the opportunity for managing rainwater at source, which limits pollution due to runoff. Assessments of this criterion and the conclusions to be drawn from it vary according to whether one studies surface soil or subsoil.

In the Paris Region, 80% of rainfall is "light", which means that no more than 10mm falls in a day. It has a return period (= frequency at which rainfall of a given intensity occurs) of less than 1 year. "Moderate" rainfall has a return period of 1 to 5 years, and the return period of "heavy" rainfall is 5 to 20 years. Above this are "extreme rainfall events", which are likely to cause severe problems. (source: [30])

There are three main types of tests to measure soil permeabilty: the Porchet method (or its variant the double ring test); test pits (especially the Matsuo test); and test drilling (for further detail, see [31]). Budget and timeframe vary according to the type of test:

(3) Risks linked to soil and bedrock type

Some soils have mechanical behaviours that can limit or even prevent permeation. Gypseous soils, for example, present a risk of dissolution that can lead to collapse [32]. Clay soils can be subject to shrinkage in dry periods and swelling in wet periods [33]. Where soils are located in karstic or fissured zones, precautions will need to be taken because fissures can act as preferential drainage points and lead to rapid and poorly controlled transfer of pollution to the water table [15]. These different phenomena must thus be studied to determine whether or not they are present on the renaturing site.

The risks mentioned here must above all be carefully considered when the renaturing project aims to create a permeation zone (floodable green space, rain garden, floodplain), but they do not necessarily make all desealing and renaturing projects unfeasible. Projects must, however, be designed with these parameters in mind (aiming at diffuse permeation by maximising evapotranspiration, etc.). Where geotechnical or geochemical risks are observed, additional surveys must be carried out. It may be necessary to change the location of the operation so that it takes place away from the area of risk. The perimeters of zones exposed to natural risks are generally available on local government websites.

(4) Pollution

Rainwater pollution usually comes partly from the rain itself and partly from the runoff process when rainwater picks up pollutants (from road cleaning, etc.). While rainwater initially contains low concentrations of pollutants, collecting and storing it tends to aggravate the problem. The best way to limit this type of pollution is thus to aim for permeation at source [34]. In the case of a renaturing project where the aim of the site is to collect a large quantity of water produced in a highly sealed area, this type of pollution must be taken into account, in particular by studying the characteristics of the site (see above for the impact of these parameters, especially concerning risk of blockage and groundwater pollution). Where the project does not have this objective, renaturing is an excellent way of limiting runoff by opting for at-source rainwater management. For example, reed-bed filters (already used elsewhere for sewage treatment) alongside major roads and car parks seem to be an interesting alternative solution for rainwater treatment and retention (*Giroud et al, 2007*).

Major pollution arising from the former use of the site, especially by substances able to migrate such as hydrocarbons and heavy metals (lead, zinc, copper, etc.), can be studied first by investigating how the site was occupied in the past. This type of study can lead to the creation of a map of areas of presumed pollution where studies and surveys may be carried out. Where analysis highlights the presence of soil pollution (see part 3.3.2), the project must be adapted accordingly. Some analyses may reveal polluted soil on which urban farming projects cannot take place, or pollution that requires the project to be adapted to prevent pollutants seeping into aquifers.

3.2 Prior analysis and ecological evaluation

Before beginning a project, a historical research phase may be useful to determine an anterior or reference state for the site, if this is known. It can take the form of archive research at local government offices or consultation with local residents (as well as studying street names and old maps).

Once the research phase is complete, it is also necessary to assess the initial ecological state of the site to find out what species are present, the state of the soil, and the landscape in which the project will be carried out. This analysis must be adapted to the location and size of the site, and must at least include inventories of fauna, flora and habitats, soil analyses, and a study of ecological continuity within the scope of the project. It may be carried out by freelance ecologists and naturalists or specialist organisations or associations. Although the sites targeted by renaturing are generally significantly degraded, some species may have established themselves and their presence may help determine the renaturing trajectory to be adopted. Moreover, wildlife surveys generally take into account a wider area than the site itself to gain a better understanding of the environment in which it lies and opt for a project which is ecologically meaningful on the scale of the broader landscape. If the project covers several sites, surveys should be carried out in each of them.

Ecological evaluation must, if possible, be based on standard, easily applicable protocols. In France, participatory science programmes offered by Vigie Nature (see table 22) are very useful for long-term monitoring.

3.3 Implementation

3.3.1 Dismantling infrastructure and desealing

As far as sealed areas are concerned, the crucial step is to remove the ground covering be it concrete, tarmac or asphalt. This step is not always sufficient to strip the ground completely as artificial layers such as gravel or clinker may remain below ground and will need to be extracted.

Desealing in progress in Saint-Nicolas du Redon carried out by the association "Les amis du transformateur". © Les amis du transformateur

This step requires specialist contractors although some collective initiatives use local volunteers. However, the latter option generally applies to smaller areas and must be carried out in an appropriate legal framework in compliance with health and safety regulations.

Carrying out waste analysis before the project starts makes it possible to identify opportunities for reuse, recycling and repurposing ground covering as part of a circular economy approach. Several specialist contractors offer these kinds of services although some types of bitumen cannot be recycled or reused. In this case, to avoid taking broken material to rubbish dumps it can be retained on site to create a rocky environment where nature can be allowed to take its course.

Breaking up concrete prior to natural regeneration at the former Bonames Airport (Frankfurt, Germany) © GTL, Michael Triebswetter

According to France Stratégie (*Fosse et al, 2019*), the average cost of desealing is between 60 and 270 euros per square metre: these are significant costs that can be offset by savings made thanks to rainwater management and the direct and indirect benefits that a new natural area provides. In the town of Douai (in the Nord département in northern France), where 25% of public space is managed using alternative techniques, it is estimated that a saving of 1 million euros per year is made (30-40%) compared to traditional methods (*Herin & Dennin, 2016*). Moreover, water agencies offer desealing subsidies via calls for projects that can fund up to 80% of the work.

3.3.2 Restoring the soil

Once its impermeable covering has been stripped away, urban soil will nevertheless have suffered significant damage. To assess the condition of soil on site, samples must be taken with a soil auger in different spots and sent to a specialist laboratory for bio-physico-chemical analysis. This preparatory analysis is a key step before planning different renaturing options. The tables below summarise the main indicators used to assess soil condition.

Table 18: Main indicators used to assess the physical or chemical quality of soil (source: Agrinnov, Observatoire Français des Sols Vivants - Lionel RANJARD, INRA Dijon, UMR Agroecology).

	Aspects studied				
Physical quality	Soil texture (silt, clay, sand) and grain size (rough elements)	Structure : penetrometer, spade test, slake test	Auger profile (0-20cm)	Soil colour	**H_2O (retention profile)**
Chemical quality	Corg, N, P	pH	MTE contaminants (Pb, Cd, Ni, Cu, Zn…)		

Table 19: Main indicators used to assess biological quality of soil (source: Agrinnov, Observatoire Français des Sols Vivants - Lionel RANJARD, INRA Dijon, UMR Agroecology [35])

Biological quality			
Organic matter in soil	**Plant cover indicators**	**Soil fauna indicators**	**Micro-organism indicators**
Litterbag (Levabag, Teabag)	Description of cover: perennials/annuals v. Spontaneous/planted	Megafauna: traces of activity (burrows, modification of soil and litter, etc.)	Microbial biomass, taxonomic density and diversity of bacteria and fungi (metagenomic)
Biochemical analysis	Indicative species (environment and contamination)	Macrofauna: Abundance and diversity of earthworms; gastropods under wooden boards	Microbial activity: enzyme activity
Organic contaminants (Pesticide, PAH, etc.)	Root system	Mesofauna (e.g springtails) and Microfauna (e.g nematodes)	

The results of physical, chemical and biological analyses will serve as the starting point for soil restoration. Involving soil specialists is essential in order to interpret the different parameters and propose solutions appropriate to the restoration of soil functions.

As far as permeability is concerned, a permeation test may be necessary to determine whether the soil is permeable to rainwater.This test can be carried out with the help of an infiltrometer, a device that measures the hydraulic conductivity of soil. An alternative consists of making shallow holes and filling them with water to measure how fast the ground absorbs water.

In terms of soil pollution, and in addition to standard analyses (heavy metals and hydrocarbons), it may be of interest to use bioindicators to check toxicity to living organisms. Chemical analysis gives no indication of the bio-availability of the contaminants, their potential transfer and their levels of toxicity to different species, either alone or in "cocktails" (synergistic or antagonistic effects). The ADEME (the French Ecological Transition Agency) has produced a guide on how to use bio-indicators to measure biodiversity and soil functions as well as to assess soil contamination in order to develop relevant renaturing strategies and monitor soil quality [36].

STUDYING POLLUTION WITH A VIEW TO FOOD PRODUCTION

When part of the renatured site is to be set aside for food production, additional tests must be carried out to ensure there are no pollutants that could be dangerous for consumers. In the light of the increasing popularity of projects that include urban farming, researchers at INRAE and AgroParisTech have developed an approach called REFUGE (Risques En Fermes Urbaines – Gestion et Evaluation/Risks in Urban Farms – Management and Assessment) to help people running this kind of project [37]. It involves first characterising the danger and then carrying out a risk assessment if the danger turns out to be present. Characterisation involves not only a historical research phase; it also involves analysis of soil destined to be used for agronomic purposes (including chemical analysis, at a cost of 90 to 150 euros per soil sample, as well as agronomic analysis costing 100 euros per sample). Details of the protocol are available in the REFUGE guide "*Caractérisation de la contamination des sols urban destinés à la culture maraîchère et évaluation des risques sanitaires*" (*Barbillon et al, 2019*).

Decontamination

More and more ground decontamination techniques have emerged in recent years. They depend on the type of pollutant (heavy metals, hydrocarbons, chemicals, etc.) and on the nature of the soil and surfaces to be dealt with. Unlike civil engineering techniques (replacement, physical/chemical processes, etc.), ecological engineering techniques aim to limit energy costs arising from soil excavation, transport and infill with imported soil, instead opting for on-site restoration. To do this, the properties of certain micro-organisms such as bacteria and fungi (bioremediation) or of plant species (phytoremediation) can be used to decontaminate soil.

Phytoremediation: decontaminating soil using plants

Phytoremediation comprises an array of techniques using the properties of plants and their microbial flora to decontaminate environments (ground, air and water). These techniques are based on the ability of various plants to extract, transform or accumulate toxic substances, often of anthropic origin, and are applied according to the pollutants encountered and the available resources. Phytoremediation has turned out to be very useful for the decontamination of large areas where pollution levels are quite low.

In 2015, the Atelier d'Ecologie Urbaine created three phytoremediation gardens each covering 400 square metres in the Parc du Peuple de l'Herbe, Carrières Sous Poissy. These experimental gardens made it possible to treat contaminated ground when the park was created. The plants were chosen according to the type of decontamination required: an agro-forest garden to fix Metallic Trace Elements (MTEs) andv hydrocarbons; a brassica garden, also for MTEs; and an acidic soil agro-forest garden for MTEs and Halogenated Volatile Organic Compounds (HVOCs). The project has been monitored on a regular basis since 2016, focusing on soil chemistry, plant biochemistry and leachate hydrochemistry. In addition to this chemical data, flora and soil have also been monitored to record planted and spontaneous plant species present on the site and to observe the evolution of restored soil. Recommendations have been made on complementary plantings that might be carried out as well as plant and soil management (e.g. mulching and the incorporation of organic matter)[38].

Example of a phytoremediation garden: the Peuple de l'Herbe Park in Carrières sous Poissy. ©Atelier d'Ecology Urbaine

Phytoremediation is still uncommon in urban areas and it struggles to gain acceptance due to legislation and doubts about how effective it is. These fears are receding as more and more examples of phytoremediation appear and as scientific results prove its effectiveness. Moreover, although this method requires monitoring and maintenance, it is less costly than the excavation and burial of contaminated soil. It can be up to ten times cheaper than traditional methods (*Chevrier, 2013*). Phytoremediation can be a financial argument, especially where the pollution to be dealt with covers a large area. This type of operation is carried out over a long period, which can be an advantage in terms of protecting a newly restored environment.

EXAMPLES OF PLANTS USED FOR PHYTOREMEDIATION

- *Buxaceae* are able to accumulate nickel.
- Sunflowers accumulate caesium, strontium and uranium.
- Plants of the genus *Arabidopsis* (mercury).
- Tobacco and mustard (zinc, cadmium and lead).
- *Thlaspi caerulescens* (zinc and cadmium).
- The willow *Salix viminalis*, which has a large root system, is able to accumulate a large quantity of metals.
- *Festuca arundinacea* (tall fescue) is a perennial grass that has an extensive root system and can support microbial flora responsible for the biodegradation of polycyclic aromatic hydrocarbons.

As well as decontamination, restoration may be necessary for the soil to return to an ecologically functional state, even if that differs from its original state in terms of structure and functions.

Decompaction

Urban soils that have been concreted over are subject to numerous impairments including compaction, which reduces the porosity necessary for the circulation of water, gases and nutrients vital for plants to function and grow. Good porosity is necessary for root penetration and also affects water circulation and retention capacities. Decompaction work may be carried out depending on the size of the site and the intensity and depth of the compaction. It is possible to use mechanical means (garden forks, broadforks, decompaction devices and machinery) or biological solutions. For example, some organisms such as earthworms or plants (i.e. their roots) can improve soil porosity. However, these techniques using living organisms take several years to work: 1 to 2 years to restore porosity in the first 20 centimetres of soil and over 10 years to get down to a depth of 30 to 50 cm. To shorten these timeframes, mechanical action may be necessary using decompactors and pseudo-ploughing tools that can work the soil to a depth of 20 or even 35 cm.

Using soil engineering species

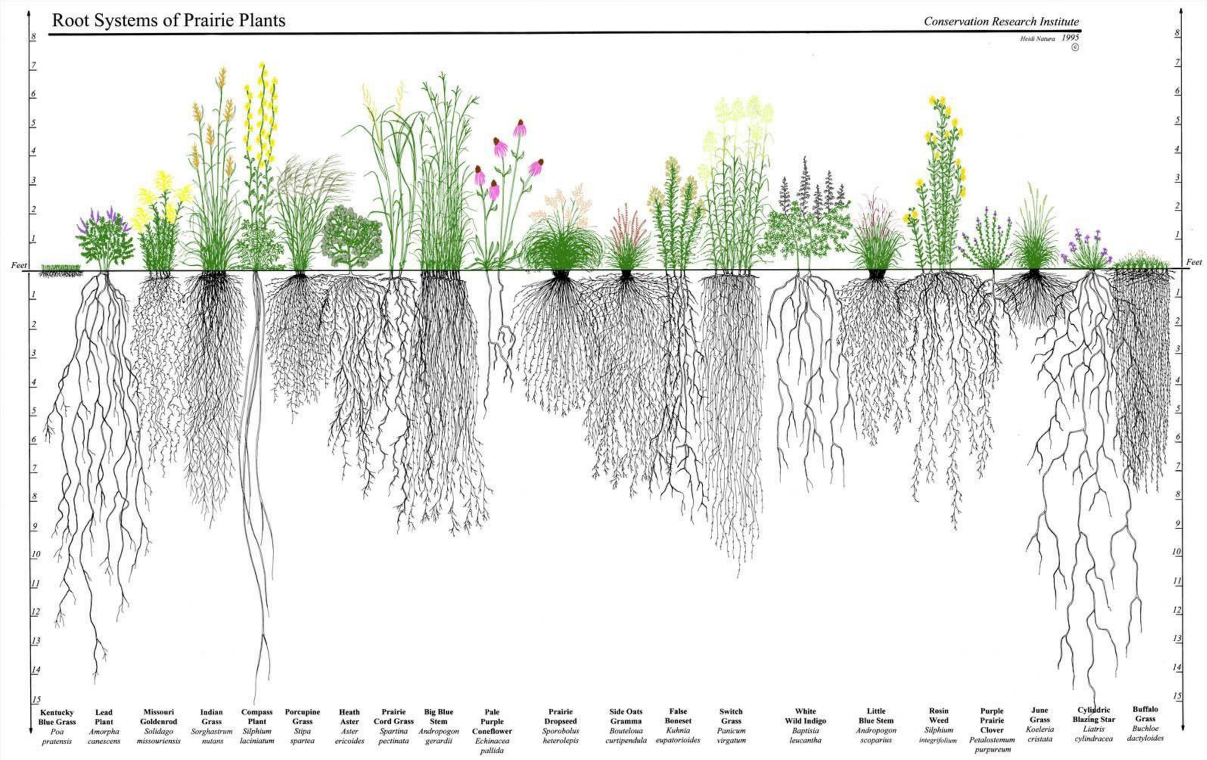
Whether it be to improve the structure of the soil or kick-start its biological activity, it is possible to use so-called “ecosystem engineers” (earthworms, ants, etc.). This principle relies on their bioturbation capacities, in other words the phenomenon by which organisms manage to restructure the soil or transfer nutrients or chemicals into it. Earthworms, according to species, are burrowers and diggers and also allow other species to take refuge naturally in freshly worked soil. The introduction of engineering species as part of a renaturing initiative entails carefully selecting species or communities of species and obtaining the advice of soil specialists. This selection must be based on prior analysis of soil condition to ensure that the introduced species can survive in the degraded environment.

Example of classification of earthworms into ecological categories

Earthworms are generally divided into 3 ecological categories* depending on their sensitivity, their role, their needs and their specific biological characteristics:

- Epigeic worms, which suffer more from weather, predators and soil surface disturbance.
- Anecic worms, which ingest decomposed matter and excrete little organic matter but play an important role in distributing organic matter in the soil.
- Endogeic worms, which are considered as major soil stabilisation agents because their diet consists of soil rich in organic matter and their casts contain large amounts of nutrients.

Plants also act upon soil structure with their roots and also affect soil fertility and colonisation by other organisms. Improving soil porosity will depend on the morphology of the root system (the shape, diameter and length) of the planted species. Plants with taproots (dandelions, burdocks, trees, etc.) affect the soil to a greater depth, while those with fasciculate roots (Poaceae) have a greater impact on the surface where they form a densely matted root network. Combining species with different root systems will help structure the soil both on the surface and deeper down. It is possible to combine varied local species so that they complement one another in the way they affect soil structure.



Root Systems of Prairie Plants, 1995 ©Heidi Natura

Vegetation also directly influences soil fertility via airborne litter, root exudates and the ability of certain species to fix airborne nitrogen in the soil. This is the case with fabaceous or leguminous plants such as lucerne, clover, vetch, Spanish lentil, etc. Also, plants (or mainly their roots) modify their abiotic environment (temperature, humidity, pH, oxygen pressure) and biotic environment by releasing exudates into the rhizosphere[12]. These compounds feed a specific range of microbiota. Plants thus control the abundance, diversity and activity of microorganisms involved in processes such as the mineralisation of organic matter and nitrification.

Restoring the soil using urban by-products: "technosoils"

One technique that has long been used for the creation of green spaces is bringing in topsoil extracted from a natural or agricultural area. This technique is, however, ecologically counterproductive as it delocalises the impacts of land take on farmland as well as generating CO_2 emissions due to transportation. In 2008, the Plante et Cité association estimated that 3 million cubic metres of topsoil had been used in France for urban purposes (*Vidal-Beaudet, 2018*).

Bringing in earth is not always necessary

Italian researchers have put forward the hypothesis that the fertility of desealed urban soil will increase without the addition of exogenous topsoil. They compared desealed plots with and without added topsoil. Both sites were planted with 2 species of shrubs and irrigated. Soil fertility was analysed using chemical indicators (total carbon and organic materials) and biological indicators (biological quality index and microbial activity). The results show that desealed soils with no added topsoil can rapidly increase both their fertility and their functional and biological stability. (*Maienza et al, 2021*)

Poor soil in renaturing projects

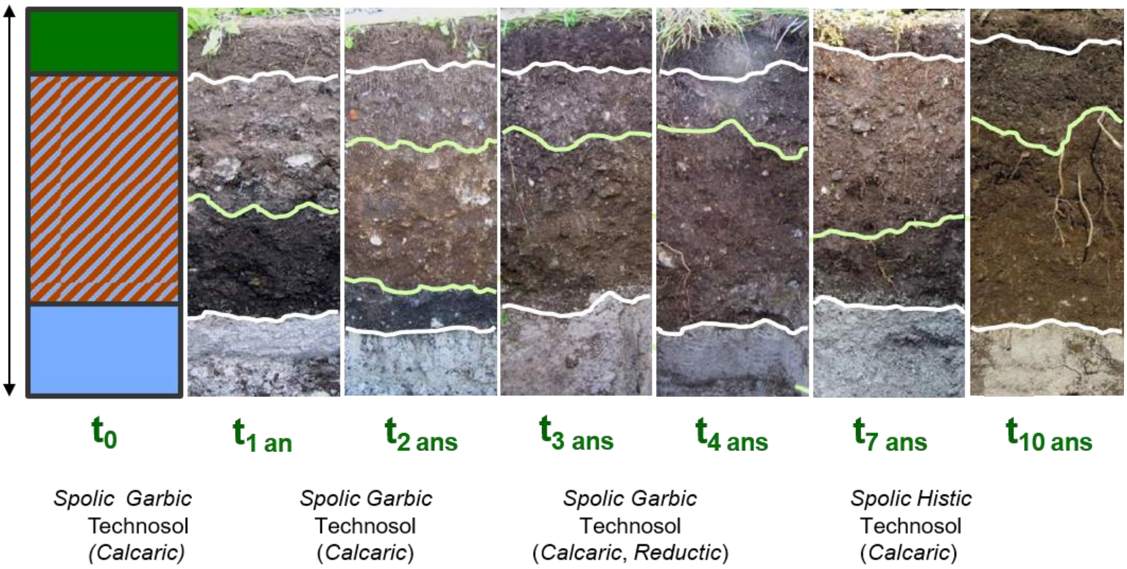
It is important to remember that soil fertility is not the ultimate aim of all renaturing projects. Many herbaceous formations (grassland, meadows, etc.) are only found on nutrient-poor soils in environments that host extremely rich biodiversity. In more urban contexts, as the GROOVES study carried out by ARB îdF on green roofs shows, these special ecosystems with poor soil are no less valuable in terms of biodiversity. Their special composition resembles nothing else in urban areas and there may be original combinations such as planted and spontaneous species and dry sandy grassland of local and more distant origin.

To avoid bringing in topsoil, innovative soil construction processes using urban waste have emerged in research programmes. The Soil and Environment Laboratory in Nancy is pioneering research into technosoils (*Séré et al., 2008*) using waste and by-products present in an area to restore functional soils degraded by the steel industry. Part of a circular economy approach, this technique relies on recycling materials available on site positioned in layers or functional horizons (*Fabbri et al, 2021*). It combines a mineral substrate (non-contaminated excavated earth, concrete, railway ballast, rubble, etc.) with an organic substrate (crushed green waste, slurry from sewage farms, compost, street sweepings, etc.). When renaturing sealed ground, it is thus possible to reuse materials that remain after the desealing process. According to the guidelines produced by the Association Française pour l'Etude des Sols (*Pédologique, R, 2008*), these "new soils" belong to the category of "constructed anthroposoils"[13].

It has been demonstrated that constructed soils evolve rapidly and that phenomena attributable to pedogenesis can be observed, such as the processes of aggregation, decarbonisation, root colonisation and microbial activity (*Hafeez et al, 2012*). A 2013 study estimates that after 4 years, technosoils are able to function in a similar way to ordinary meadow soil (in terms of production of

[12] The part of the soil that immediately surrounds roots. This section of the soil is shaped and influenced by both roots and the micro-organisms associated with them.
[13] Soils that have been constructed or significantly modified by human activity.

plant biomass and decomposition of organic matter) (*Séré et al, 2010)*. Inventories show that micro-organisms, engineer species and decomposers can be found in technosoils.



How a technosoil is created. © Schwartz, G. Séré, Université de Lorraine

COMPARISON OF SOIL REHABILITATION TECHNIQUES

As part of the Bio-TUBES project (2016-2019) funded by Valorhiz with support from BRGM and Elisol Environnement, researchers carried out experiments comparing 3 soil restoration techniques: zero intervention (control site); decompaction coupled with ecological engineering; and technosoils combined with ecological engineering. After 30 months, the results showed the positive effect of rehabilitation measures on carbon storage, fertility and water retention functions compared to the control site. As for the “medium for biodiversity” function, all the sites demonstrated an interesting dynamic of recolonisation. These early results also underline the fact that with a limited number of physical, chemical and biological parameters it is possible to observe ecological functions performed by soils following the implementation of distinct technical solutions.

One of the experimental sites 5 months after implementing different soil rehabilitation strategies. © Valorhiz

In Île-de-France, a partnership between the *département* of Seine-Saint-Denis, the ECT Group (soil recycling and upcycling).and the University of Paris-Est Créteil has tested the recovery of locally produced demolition waste and green waste to reconstitute fertile soils (*Pruvost, 2018*). On an experimental site of 4,000 m² in Villeneuve-sous-Dammartin, 26 experimental plots were set up, corresponding to the three uses to be tested: park and garden meadows, avenue trees and agricultural uses. Soils composed of sterile soil (fill, alluvium, silt) were prepared with and without compost (10% of the total volume) for the three vegetation types. Mixtures with and without crushed concrete aggregate were also tested for the tree line plots. A four-year follow-up showed that the compost used was responsible for the death of some trees, but that combined with the concrete, it greatly increased their growth rate and colonization by macrofauna. In meadow use, the addition of compost increased biomass production and altered the plant community assemblage, favoring competitive species, but not macrofauna. It is therefore possible to improve the primary productivity of new ecosystems by manipulating the composition of material mixtures while avoiding the dominance of certain species, in order to maintain diverse communities [39].

The DESSERT project (DEsimperméabilisation des Sols, Services Ecosystémiques et Résilience des Territoires - Soil sealing, Ecosystem Services and Territorial Resilience)

The DESSERT project was launched in 2021 and aims to better understand the behavior of desealed soils. This research program plans to generate new knowledge on the re-functionalization of soils following their desealing, to develop a typology of desealing modalities, to measure its effectiveness and to optimize desealing processes on pilot sites. Between 2021 and 2024, a thesis will focus on an inventory of desealing practices, on observations of the functioning of desealed soils and on the characterization of the functions and services provided by these new environments [40].

3.3.3 Renaturing degraded sites using plant communities

Renaturing an anthropised site entails restoring plant communities, either through natural regeneration or through assisted recolonisation. It is actually more a question of a plant community, interacting with its environment and other species, than of individual plants. This approach requires precise knowledge of the ecosystems to be restored or created.

Colonisation by spontaneous flora: letting nature take its course

These days, natural processes are seldom allowed to express themselves in urban settings and interventionism is the rule. However, when nature is allowed to evolve spontaneously over time, natural dynamics are established, becoming more complex and structured and leading to functional, resilient ecosystems. This type of renaturing makes it possible to observe the dynamics of plant communities via ecological succession. This succession is characterised by the height of the plant cover which increases over time. Most habitats tend to evolve naturally towards woodland in our latitudes. The process begins with pioneer species, which are the first to colonise poor, degraded or polluted soil. Their action over time modifies the soil structure physically (root action) and chemically (accumulation of litter), thus favoring their replacement by species that prefer to establish themselves on already colonised soil. After the pioneer plants,providing the shelter needed for future trees.

THE ROLE OF PIONEER PLANTS IN SOIL REHABILITATION

Pioneer plants are the first plants to establish themselves on a degraded site. They are generally considered to be “weeds” although their role in preparing the soil is essential. They are able to colonise unstable environments poor in organic matter where climate conditions are tough (absence of water, intense heat, etc.) (*Sarasin, 2011*). In urban environments, they are generally annuals belonging to Amaranthaceae, Brassicaceae or Papaveraceae families (*Muratet et al, 2017*). As these plants modify the environment, they are gradually replaced by perennial species that are less specialised or more demanding. Using these species is of special interest in the framework of spontaneous ecological restoration programmes, and they can also be used to actively restore highly degraded environments. For example, they are recommended in the context of reforestation to initiate, amplify and accelerate the early plant colonisation process.

FACILITATION

Facilitation is a mechanism by which an organism is able to modify the conditions of its environment so that the latter can host another organism that would otherwise be unable to thrive there (*Thiffault et al, 2017*). A facilitating plant, also called a nurse plant, speeds up the growth of other species by providing them with a refuge and improving the availability of resources. This refuge can offer protection from predators and from sources of environmental stress such as exposure to sunlight, drought, heat or cold. Pioneer plants can act as facilitating plants, though other species that arrive later on in the ecological succession process can also be used. For example, in tropical areas, planting tree ferns facilitates forest regeneration mechanisms (*Rivière et al, 2008*). In the Mediterranean context, a study has shown that planting previously mycorrhized species of lavender and thyme boosts the development of woodland plants and improves soil quality (*Hafidi et al, 2013*). Facilitation plays an essential role in degraded environments, in difficult conditions, for secondary species, and more broadly for the colonisation of new habitats and renaturing.

Passive renaturing does not mean “doing nothing”; it entails closely observing the first steps of spontaneous colonisation. Such observation can influence the direction the ecosystem to be restored should take (*Ravot et al, 2020*). Experimenting with spontaneous colonisation in cities can help scientists understand the value of these kinds of processes specific to urban ecosystems. Observation, and the information it can provide, is a key factor in renaturing projects as it results in more holistic scientific knowledge.

PASSIVE RENATURING OF THE BANKS OF THE SÉLUNE

As part of the project that involved dismantling two large dams on the River Sélune, a coastal river that flows into the Bay of Mont-Saint-Michel, a scientific programme to monitor the renaturing of the river was set up. This pilot project combines passive restoration (spontaneous plant colonisation) and active restoration (removing the dams; gradual draining; creating banks; excavating the riverbed). Scientists focused on the vegetation that colonised the alluvium of the former dam reservoir. In the space of two and a half years, the results show that spontaneous vegetation typical of riverbanks has established itself and helps to maintain the banks. These results confirm how relevant and effective passive renaturing operations are. Plant communities will be monitored in the long term via a valley observatory, making it possible to decide between civil engineering and passive restoration in future projects. (*Ravot et al, 2020*).

Spontaneous renaturing of the banks of the Sélune, 2 years after gradually emptying two dams and reshaping the banks. ©Charlotte Ravot

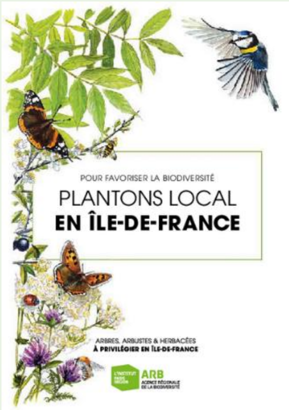
Assisted recolonisation: a leg-up for ecosystems

In some cases, the self-repair process for ecosystems can be accelerated by using plant-based engineering, whether it be sowing facilitating species or heavier work involving transferring whole patches of ground from nearby ecosystems. Though various methods can be used for sowing or planting a renaturing site, they have to be carried out on an ad hoc basis. Before the renaturing project begins, the following must be considered: the aim of the intervention (accelerating a process of spontaneous recolonisation, obtaining the most complete cohort of species for the environment to be rehabilitated, combating soil erosion, etc.), the typology of the host site (surface area, soil type, ecological connectivity, etc.), the type of technique to be used (sowing, hay, plug plants), available equipment and labour, as well as economic aspects and the management plan for the site after sowing.

Restoring with locally sourced seeds. Locally sourced plants are increasingly being used in renaturing projects. These native species have the advantage of being better adapted to current ecological conditions and have a level of genetic diversity that provides the best guarantee of adaptation to climate change. Choosing native species also ensures that the entire cohort of accompanying species (entomofauna, soil invertebrates, symbiotic bacterial and fungal flora), which are vital to their ecosystem, will also establish themselves. They will have a better chance of long-term survival and of carrying out their complete vegetative cycle, unlike commercial species. It is possible to buy locally sourced plants from certain nurseries and suppliers. The Végétal local label [41] was created with this in mind. It is a collective brand rooted in the desire of green space project leaders and managers to use wild plants collected in their region. It was created in 2015 at the initiative of the Fédération des Conservatoires Botaniques Nationaux (FCBN), Plante & Cité and Afac-Agroforesteries, and is the property of the Office Français de la Biodiversité (OFB). The “Végétal local” label makes it possible to guarantee the local provenance of wildflowers, trees or shrubs in a given ecological region (11 bioregions have thus been designated in metropolitan France), with local genetic diversity and regularly replenished seed stocks. In some cases, it is also possible to select seeds by harvesting wild seeds or hay directly in their natural environment close to the renaturing site.

CREATING A LOCAL SEED OPERATION IN BESANÇON

For several years the City of Besançon has been committed to conserving biodiversity, especially urban pollinators. To increase the presence of local species and provide a habitat for them, the City chose to develop production skills and structures (greenhouses and the municipal orangery) to create a supply stream providing locally collected wild seeds. The operation has been organised in close connection with the Conservatoire de Botanique and the Conservatoire des Espaces Naturels in Franche-Comté. The City's three gardeners and botanists are now in charge of harvesting the seeds and creating mixtures adapted to the City's ecological plan. The seeds are used in municipal flowerbeds and sown in the grassed-over part of the tramway. In 2017, 20 species were harvested in this way (creeping thyme, dianthus, sanfoin, etc.).



The "Plantons Local" guide published by ARB îdF is designed to help increase the proportion of indigenous plants in public and private areas. It provides lists of species that are best adapted to the Paris Region's environmental conditions for the creation of meadows, hedges, shrubberies, wooded areas, etc. The species presented in the guide…

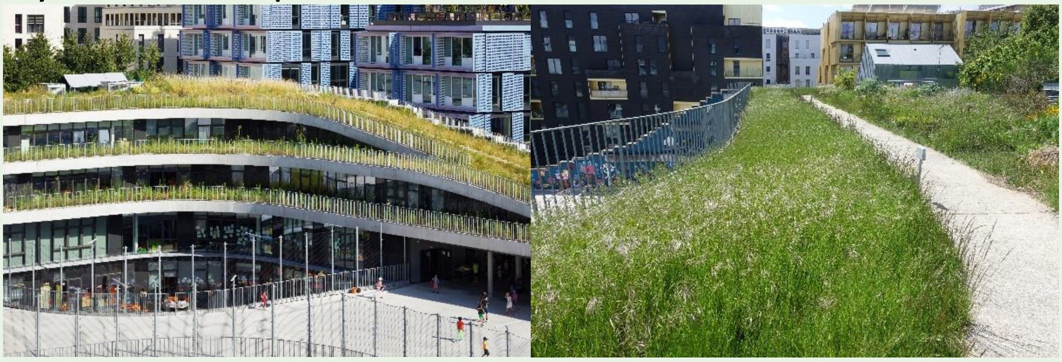
- …foster interactions with fauna: plants host larvae and caterpillars and flowers attract adult insects (butterflies, hoverflies, bumblebees, honeybees, etc.), fruit attracts birds and mammals, and so on
- …are adapted to the local climate and to the natural or impaired soils of the region, as well as to human management
- …are offered under the "Végétal local" label.

Harvesting plants and seeds. Hay transfer. One of the techniques used in ecological restoration to rehabilitate plant communities is hay transfer (*Jaunatre et al, 2014; [42]*). This technique involves mowing a species-rich meadow in an area near the project at a point where a maximum number of plants have fructified. The resulting hay can be spread either immediately on the site (green hay) or after a period of storage (dry hay). It is spread over dug and decompacted soil on the renaturing site. Ideally, the operation should be repeated several times during the fructification period. As the phenology of meadow plants varies, it may be necessary to choose a window of opportunity that makes it possible to harvest the required plants.

EXAMPLE OF MEADOW RESTORATION

The hay-spreading technique was tested in 2006 on the Crau plain to reintroduce species specific to dry grassland and increase the specific diversity of post-agricultural disused land. The initiative was unusual in that as well as mowing to a height of 20 cm, the resulting hay was then collected using a leaf vacuum. The hay was kept dry over the summer and then, after the first autumn showers, strewn on the ground. To encourage germination and limit seed loss, the soil was first harrowed. The quadrates were watered before and after spreading, and wire mesh was laid over the area to prevent the seeds from being blown away. This technique turned out to be very effective. Two years later, the diversity of plants in the quadrates had increased significantly and many steppe plants had returned (thyme, oats, pimpernel, sage, etc.).

Hay transfer: a technique not restricted to natural environments



Roof of the Ecole des Sciences et de la Biodiversité in Boulogne-Billancourt. Left ©Sophie Deramond. Right © Aurélien Huguet

Built in 2014 and designed by architects Chartier-Dalix, the Ecole des Sciences et de la Biodiversité in Boulogne-Billancourt is one of the most successful examples of green architecture in the Paris Region. Its single tiered façade and its living roof are the result of a partnership between the architects and the ecologist Aurélien Huguet. The depth of the roof substrate varies between 30 cm and 1 m, making it possible to create a range of habitats from a meadow to an urban "micro-forest". In 2020 the architects decided to renovate the meadow to increase its potential for biodiversity using ecological engineering techniques. The main aim was to increase the diversity of perennial flowering local species typical of old meadows. The project team identified areas of dry grassland in the park of Marly-le-Roi. With the agreement of the park authorities, a plot was identified as an "ideal donor" due to its exceptional floristic diversity and compatibility with conditions on the roof in Boulogne. In June and July, seeds were collected by hand from the earliest flowering species (meadow sage, erect brome, quaking grass) before the area was entirely hand mown. The harvested seeds and hay were spread out on the rooftop. Monitoring will ascertain the success of the operation and highlight any adjustments that need to be made.

Hand mowing in the Marly Royal Park to reseed the roof of the Ecole de Sciences et de la Biodiversity in Boulogne-Billancourt. © Aurélien Huguet

Sod transplant. This technique involves extracting vegetation and soil in large sods or small plugs and transferring them to the site under restoration. Plant cover is thus restored in record time. The technique makes it possible to replant seedlings, mosses and soil micro-organisms as well as flora from seed-rich micro-ecosystems. To ensure success, it is advisable to dig up about twenty centimetres of soil, though if the source site is to be entirely destroyed sods 30 - 50 cm deep may be extracted. As this technique degrades the "donor ecosystem", it should only be used when the source habitat is threatened with destruction (due to urbanisation).

Mycorrhization. A mycorrhiza is the product of co-evolution between a microscopic fungus and a root. This association brings plants many advantages: improved access to nutrients and water, protection against pathogenic organisms, better resistance to environmental stress, etc. For example, it has been shown that mycorrhizal fungi (in non-disturbed ecosystems) improve growth compared to non-mycorrhized plants (*Plenchette et al, 1983*).

Controlled mycorrhization involves "artificially" restoring the symbiotic relationship between fungi and roots. Though it is used in particular in farming, it can also be valuable in restoration projects in urban environments (*Henry et al, 2021*).

Mycorrhization is best done at the moment of planting, especially if the plant has exposed roots (e.g. trees and shrubs), which means the product containing the fungus can be applied directly to the roots. Otherwise, it is possible to mix the product with the soil. This process is used by landscapers and soil suppliers to boost soil fertility and accelerate plant growth. In addition to this productivist approach, it is possible to use mycorrhization to lastingly improve soil functions. Plante et Cité, in partnership with INRA in Nancy, carried out a study in 2009 to assess the mycorrhizal status of roots [43].

3.3.4 Creating habitats for biodiversity

Although renaturing needs to be context-specific and cannot be generalised by referring to a single type of habitat, some principles can be applied more or less everywhere when implementing renaturing projects. Depending on the project, it is advisable to:

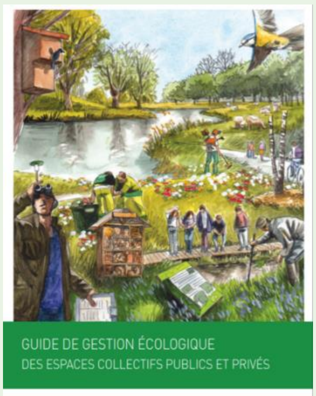
- Diversify plant strata (moss layer, herbaceous layer, shrub layer, trees), species and environments (meadows, copses, hedges, ponds, banks, stones, etc.), to offer species different conditions to which they may adapt. The aim should be to create a variety of different areas.
- Create additional micro-habitats for species, such as piles of rocks, dead wood or water (a pond for example).
- Avoid using artificial barriers (walls and fences), which significantly hinder species migration and fragment the landscape. If it is necessary to protect a site (e.g. to avoid trampling), fencing should allow small animals to pass through.
- Restore habitats specific to a cohort of species instead of setting up hives, nesting boxes, insect hotels and so on.
- Limit the ecological footprint of materials by using those already on site and by avoiding man-made materials (geotextile membranes, plastic trays, etc.).

3.3.5 Managing renatured areas

The many ways in which renatured areas are used and their value for communities often mean that they must be managed in one way or another. However, natural areas in urban environments are often maintained too intensively, to the detriment of the biological cycle of species and the free development of wildlife. Designing biodiversity-friendly areas requires tailored ecological management approaches—or even allowing the environment to develop freely. Ecological management requires finding a compromise between the relatively strict and constrained maintenance of municipal parks and gardens and the conservation of nature reserves. Combining the two can foster biodiversity while at the same time responding to users' needs and expectations. This approach can be minimalistic by reducing trees and shrubs pruning, while some areas can be left unmanaged. It can just involve making the site accessible and providing footpaths for recreational activities. In some cases, raised boardwalks can allow people to visit the site without disturbing wildlife.

A site allowed to develop freely: part of the Épinay-sur-Seine ecological reserve. ©Marc Barra

If the aim is to maintain a target species or community, management approaches can be tailored to their specific characteristics. This will depend on the group of environments targeted (removing ligneous species to focus on herbaceous vegetation, grazing to keep an area open, maintaining areas of bare earth for pollinators, bringing in dead wood, etc.). In the case of wetlands, it may be necessary to protect ponds or reedbeds to keep the environment in good condition. In any case, specialists should always be consulted in order to keep human intervention to the bare minimum.



ARB îdF and the ANVL (Association des Naturalistes de la Vallée du Loing et du Massif de Fontainebleau) have published a practical guide to ecological management. Many guides have already been published on the subject, but they tend to concentrate on one particular theme (water pollution, weeding, etc.). This book deals with cross-sectional subjects such as local biodiversity, greenhouse gas emissions and the effects different practices can have on humans. It does not replace more specialist guides, which deal with a broader range of issues and provide a more detailed description of methods relating to a particular theme. It should also be borne in mind that techniques evolve very rapidly. [44].

3.3.6 Monitoring and indicators

Monitoring is necessary to assess the success of a renaturing project or fine-tune management approaches. As well as monitoring biodiversity, a large number of parameters can be assessed over several years such as soil quality, ecological services (cooling, permeation, air quality), ecological connectivity, community acceptance, etc. Monitoring should be seen as a way of communicating around projects and a way of convincing decision-makers of their relevance. There is no “monitoring model” applicable to all restored sites: it depends on the individual project (surface area, environments restored, objectives, budget, in-house skills, etc.).

Where wildlife monitoring is concerned, it is advisable to refer to a standard protocol making it possible to compare the site with similar areas across the region and the country[14] [45;46]. Participatory science programmes[15] [47] offered by Vigie Nature are especially useful to carry out this kind of long-term monitoring. Coupled with support and/or mediation from a local association, participatory sciences are also a good way of sharing the results of a renaturing project with the local community. It is advisable to target taxonomic groups that make sense in relation to the site and the restored ecosystem. It is possible to enlist the aid of naturalist or ecological associations to put in place a follow-up plan and help carry out certain inventories when in-house skills are lacking.

[14] This means a protocol that is precisely defined in a reference document and is applicable by different operators in several regions. This type of protocol makes it possible to monitor projects on a large scale over long periods. Standard protocols used in participatory sciences make it possible, for example, to respond to key questions on ordinary biodiversity.

[15] A participatory science programme is a partnership between observers (members of the community) and a laboratory or scientific organisation. Its aim is to observe or study a phenomenon as part of a well-defined protocol. Members of the community are enlisted to collect a large amount of data that it would be difficult to obtain using other means. These programmes are especially useful for monitoring the natural environment across large geographical areas or over long periods such as monitoring biodiversity or the impact of climate change on the environment.

Table 20: Summary of different monitoring protocols on biodiversity (not exhaustive: for further information on these protocols, see [48]).

Target group	Protocol	Type of environment	Time spent Period	Level of knowledge
Rhopalocera (butterflies)	**STERF,** Suivi Temporel des Rhopalocères de France	Open environments	Minimum 4 hours per year per site	Naturalist
	Propage, Protocole Papillon Gestionnaire	Open environments	Minimum 3 x 10 mins per year on a site (June to August)	Green space manager
	Opération Papillons	Open environments	Once a year March to October	For everyone
Birds	**STOC**, Suivi Temporel des Oiseaux Communs (common birds)	All	Once a year March to June	Naturalist
	SHOC, Suivi Hivernal des Oiseaux Communs (common birds in winter)	All	Once a year December to January	Naturalist
	Oiseaux des jardins (garden birds)	Private gardens; parks	All year round	For everyone
Dragonflies	**STELI**, Suivi temporel des libellules	Aquatic environments	Once a year March to October	Naturalist/Green space manager
Flora	**Vigie-Flore** (common plants)	All	Once a year April to August	Naturalist
	Sauvage de ma rue (street wildlife)	Urban (street)	All year round	For everyone
	Florilège (urban flora)	Open environments	Once a year June to July	Green space manager
	sTREEts (foot of trees)	Urban (foot of trees)	Once a year April to June	Naturalist
Bats	**Vigie-Chiro**	All	Twice a year June to September	Naturalist
Insect pollinators	**SPIPOLL,** suivi photographique des insectes pollinisateurs (photographic monitoring)	Species in flower, all environments	All year round, time spent variable	For everyone

3.3.7 Community engagement

The ecological crisis, in the form of climate change and the erosion of biodiversity, often causes an individual feeling of powerlessness. Taking part in a desealing and renaturing project allows members of the community to get actively involved and shows them that they can have a genuine impact on their day-to-day environment. It’s also a way of getting them to re-appropriate public space and to change their way of thinking about the city in response to new aspirations. Convincing people that a project is of value, making it acceptable, creating multiple ambassadors…there are many good reasons to involve local residents in renaturing projects. Moreover, renaturing requires different levels of engagement. These include improving communication, involving people in carrying out analyses, looking for sealed areas that could be renatured, the co-construction of the project, active participation in the on-site work, and naturalist monitoring.

Whatever the renaturing project, it is vital to communicate, inform and involvepeople at every stage. Often forgotten or neglected, communication generally begins after the first steps have been taken or the first responses formulated. It must begin before this to prepare local residents, users, local government officials and agents for the changes to come and use all available means to share the information as widely as possible (newsletters, social media, workshops, etc.). This is even more essential in the framework of a passive renaturing project involving passive management. Communication focusing on the benefits in terms of biodiversity, health, improving the living environment and risk management will allow the local community to appropriate the renatured sites and understand how useful they are. There are many different means of information, consultation and participation available; here are just a few to inspire future projects:

- Debates, workshops and talks to raise awareness of what is at stake in a desealing/renaturing project and share scientific knowledge
- Communication tools can take the form of public meetings, articles in the local press and on social media, or a dedicated website
- Polls (questionnaires or one-to-one interviews) can be organised to collect opinions and ideas; project co-construction workshops can be set up; the local community can be invited to take part in on-site work; and local residents can be encouraged to take part in wildlife monitoring via participatory science programmes.

PULL UP A PARKING LOT: PARTICIPATORY DEPAVING

Several depaving initiatives have emerged in Canada and the USA. Since 2005, the “Depave” collective in Portland, Oregon has been engaging in depaving initiatives with the slogan “From Parking Lots to Paradise”. This initiative has inspired a similar approach in Canada titled “Sous les pavés” run by the Montreal Urban Ecology Center [49]. This participatory urbanism project aims to depave public and community spaces collectively and by hand and create planted areas. Local citizens are involved throughout the process: finding the site, organising co-construction workshops, green-lighting the final project, depaving and planting, and finally inaugurating the redeveloped site. Selected areas are between 100 and 300 square metres. The site is first prepared by specialist contractors who pre-cut the asphalt, which can then be carried away by hand or in wheelbarrows and thrown in a dumpster.

Community depaving and planting as part of a "Sous les paves" initiative © Martin Matteau, courtesy of Centre d'Ecologie Urbaine de Montréal. "Sous les paves" has published a guide to community depaving projects suggesting tools and activities for each phase.

4 CONCLUSION

Urbanisation is an ongoing trend in Europe leading to land take and soil sealing. Europe loses about 1.007 km^2 of soil due to land take annually, which is approximately a loss the size of the city of Berlin [50]. In France, 27,000 hectares of land were sealed between 2006 and 2016. This unsustainable process cries out for structural reform in order to slow urban sprawl and remedy past mistakes. A new pact between nature and the city seems possible, provided we find more frugal development models, improve the way we protect ecosystems and speed up the renaturing of degraded or sealed areas.

Many cities already have to cope with excess density and lack of greenery. The image of the dense, compact metropolis is being challenged by that of small and medium-sized cities (*Faburel et al, 2021*). Although 75% of the population of France lives in urban areas, the vast majority of people are in favour of restoring nature in the city to improve the living environment. The benefits of nature in cities are obvious: adapting to climate change (water management and urban cooling), improving public health (air quality, recreational areas) and hosting species whose abundance has declined sharply over recent years. All this militates in favour of renaturing urban environments.

Ecological engineering and research into ecological restoration have produced a rich corpus of knowledge and expertise that can be used to begin desealing urban areas. As many projects have already demonstrated, renaturing has already proven its worth and feedback from such initiatives can inspire future endeavours. However, ecological restoration in urban settings is a relatively recent development. The aim of this guide is to disseminate knowledge of the subject, to help local authorities fine-tune their strategies, and to encourage sharing and experimentation.

Renaturing is also an opportunity to rebuild and strengthen connections with urban stakeholders and local communities. Planners, developers, council officials and technicians must work hand in hand with ecologists and naturalists to design the city of tomorrow, taking part in renaturing projects that provide genuine responses to ecological and climate-related issues. Urban design must also open itself up to local residents, who must be given their say in urban policy-making. Convincing communities, making projects acceptable, encouraging people to reappropriate public space, creating renaturing ambassadors and finding innovative solutions are all ways of involving communities in restoring the ecological value of our cities.

5 GLOSSARY

Bio-indicator

An organism (animal, plant, bacteria, fungus) or group of organisms whose presence or condition provides information on the quality of the environment. According to the aim of the project, several types of bio-indicators can be distinguished (*Argillier et al, 2008*): diagnostic bio-indicators, which make it possible to measure modifications linked to human activities and compare them to less disturbed ecosystems; goal-related bio-indicators, which make it possible to determine whether goals have been achieved; and early warning bio-indicators, which warn of the existence of environmental intoxication processes before more severe effects appear in the ecosystem.

Desealing (also depaving)

Making the surface of the soil permeable again. Desealing belongs to an array of alternative rainwater management methods and techniques that favour permeation and at-source rainwater storage. It is a necessary but not sufficient condition for the restoration of ecological soil functions. Using porous ground covering materials (e.g. permeable paving or surfacing materials) is not the same as complete renaturing.

Ecological corridor

A stretch of the landscape that connects reservoirs of biodiversity. Such corridors provide the right conditions for species to move around and carry out all or part of their life cycle. There are 3 types of corridors: linear corridors (hedges, riparian woodland, etc.); discontinuous corridors, also called “stepping stones”, which are strings of individual stop-off points or refuges for wildlife (permanent ponds, copses on cultivated land, etc.); and landscape mosaics, which are patchworks of varied landscape features [51].

Ecological engineering

“The management of environments and the design of sustainable, adaptative, multifunctional solutions inspired by, or based on, the mechanisms that govern ecological systems (self-organisation, diversity, heterogeneous structures, resilience).” (*Abbadie et al, 2015*). Ecological engineers are involved in rehabilitating degraded ecosystems, restoring functional communities, reintroducing species and creating sustainable new ecosystems valuable to humans and the biosphere. Ecological engineering means “managing projects that are implemented and managed […] in such a way as to support the resilience of ecosystems” (*Journal Officiel*, 18/08/2015 [52]). Renaturing, when it does not happen spontaneously, makes use of the expertise and techniques of ecological engineering.

Ecological grids

In 2007, the Grenelle de l’Environnement recognised habitat fragmentation as one of the causes of biodiversity decline. This awareness resulted in the launch of a new policy supported by the Ministry of Ecology, Sustainable Development and Energy, called the “Green and Blue Grid”. The concept of “grids” is connected to the aim of maintaining or restoring networks that allow animal and plant species to move around and carry out the different stages of their life cycles. The Green and Blue Grid policy is also based on concepts belonging to landscape ecology (*Keitt et al., 1997; Henein & Merriam, 1990; Pulliam, 1988; Forman & Baudry, 1984*). Reservoirs of biodiversity are environments where wildlife can live and reproduce, whereas corridors allow species to move between these sites. Green and Blue Grid policy is applied at regional level in *Schémas Régionaux de Cohérence Écologique* (SRCEs: regional ecological coherence Plan) and at sub-regional level in planning documents, natural park charters, etc. Scientists are now suggesting new grids concerning other spaces inhabited by biodiversity—the air, the ground surface and the soil—for example the “black grid” (used by nocturnal species), the “brown grid” (soil-dwelling species), and the “aerial grid” (used by winged species) (*Sordello, 2021*).

Ecosystem services

This notion emerged in the 1980s among naturalists engaged in conservation programmes. It developed significantly in the late 1990s thanks to the work of the economists Robert Costanza (*Costanza et al, 1997*) and John Daly (*Daly, 1997*), but it really gained momentum following the publication of the Millennium Ecosystem Assessment in 2005. It refers to the benefits that human societies gain from functioning ecosystems. These services are generally divided into four main categories:

- Provisioning services: the “products” of ecosystems (timber, fish, pollen, access to water, etc.)
- Regulating services: benefits provided by properly functioning ecosystems (protection or limitation of damage during floods, pollination, CO_2 storage, limiting effects of climate change, water purification, etc.)
- Cultural services: intangible benefits arising from our relationship with an ecosystem (recreation, education, etc.)
- Supporting services: services necessary for the production of all the other services, ensuring that ecosystems function properly (soil formation, biogeochemical cycle, primary production, etc.)

This concept should be used with caution, and may arouse criticism by helping to establish a utilitarian (or even monetarist) approach while taking insufficient account of divergent visions and values relating to nature. Protecting biodiversity and managing ecosystem services are two separate processes that do not necessarily match. Biodiversity may offer multiple ecosystem services (carbon storage, landscape quality, water retention, etc.), but it cannot be reduced to categories of services alone. Such an approach might lead to bad practices focusing on one or several services while ignoring the integrity of ecosystems (monocultures for carbon sequestration, the overdevelopment of beehives to the detriment of wild pollinators, etc.). It is important to remember that biodiversity protection primarily involves ethical considerations in which utilitarian parameters have no place. Rather than asking “why protect biodiversity?”, an ethical approach makes us ask “why destroy it?” (*Sarrazin & Lecomte, 2016*)

Engineer species [53]

A species whose presence and activity significantly modifies its environment (e.g. beaver, earthworm). The concept of ecosystem engineers was suggested in 1994 by Clive Jones. It refers to organisms that modifies their environment so much that they have a significant effect on species around them. There are two types of ecosystem engineers: autogenic engineers, which are organisms that modify the environment by their mere presence (e.g. a tree that intercepts light and thus creates special conditions for the photosynthesis of nearby plants) and allogenic engineers whose activity modifies their environment. The beaver is the simplest example; the woodpecker, which allows fungus or other birds to use the holes it makes in trees, is another. In ecological engineering, engineer organisms are extremely valuable tools for renaturing environments.

Facilitating species

A species whose presence allows or improves the development of other species. A facilitating or "nurse" plant will facilitate the establishment and growth of other species by providing them with a refuge. This refuge can offer protection not only from predators but also from sources of environmental stress such as sunlight, drought, heat or cold. [54]

Ferality

The act of returning to the wild state after being domesticated. It may refer to an animal or plant, or to an entire ecosystem as Schnitzler and Génot suggest (2012). This concept is close to that of **rewilding**.

Green spaces

Green space This is a catch-all term used to refer to fundamentally different areas. In the framework of the REGREEN project, which is a scientific undertaking, we feel that it is important to avoid using the term "green space" indiscriminately to refer to a lawn, an area of urban woodland, a wetland or a meadow, as they do not have the same ecological qualities, the same value for wildlife, or the same level of efficiency in terms of adaptation to climate change. Not all urban spaces where plants grow have the same ecological value. It is useful, particularly in urban contexts, to distinguish non-wild areas with low ecological value (lawns, flower gardens, etc.) from wilder areas such as waste ground, disused areas and brownfields that are in some ways similar to natural environments and are able to provide ecological benefits.

Horticultural species

A local or exotic plant species that has been grown and selected in order to create ornamental varieties. As they are selected for their appearance, horticultural species have low genetic diversity, which makes them vulnerable to external factors (weather, pathogens, etc.). Moreover, they are likely to be less well adapted to local species (lower nectar output, less nutritious seeds, etc.).

Indigenous/local/wild species

A species whose presence in a given ecosystem or area is the result of a natural process, without human intervention. Wild plants collected in natural habitats are well adapted to projects whose aim is to restore the ecological functionality of environments. Wild and local plants (collected sustainably in the nearby bio-geographical area) have co-evolved with local wildlife for a long time: they thus contribute to the functionality of the ecosystems to which they belong.

Landscape ecology

A discipline of ecology that entails studying ecological processes on the scale of the landscape, considering its composition and configuration as key elements that influence these processes. One of the key concepts of this discipline is landscape connectivity, which highlights the importance of ecological networks in population dynamics (*Bourgeois, 2015*). The principles of landscape ecology have to be mobilised in the framework of a renaturing project to ensure that it is coherent with respect to the other spatial scales as well as its local environment.

Land take

Land take (*artificialisation* in French) is the result of the process of anthropisation whose final stage is ground sealing (paving). Before the French Climate & Resilience Act of August 2021 came into effect, *artificialisation* in the broadest sense was defined as the consumption of farmland, woodland and natural areas (collectively referred to as “ENAF”). The new law introduced a new definition that refers to “the lasting impairment of all or part of the ecological functions of a soil, in particular its biological, hydric and climatic functions, as well as its agronomic potential through its occupation or use”. This definition makes it possible to distinguish built-up and thus sealed areas from planted areas and open ground whose soil functions have not been affected. Though more precise, it requires being capable of measuring the state of soil functions using specific measurement and monitoring tools. In urban settings, the wide variety of soils and gradients of ecological quality in planted areas make the boundary between areas that have been subject to land take and areas that have not more difficult to apprehend. By the same token, some farmland may be seen as having been subject to land take due to intensive farming practices that affect the quality and functionality of their soil. **Land take reversal** (*désartificialisation* in French) means restoring some or all of the functionalities of an environment or landscape and restoring soil functions so that they return to a natural or semi-natural state.

Phytoremediation

The set of techniques mobilising the properties of plants and their microbial flora to decontaminate environments (land, air and water). These techniques are based on the ability of certain plants to extract, transform or accumulate toxic substances, often of anthropic origin, and are applied according to the pollutants encountered and the available resources.

Plant based engineering

This refers to the use of techniques involving plants and their mechanical and/or biological properties to control, stabilise and manage eroded soil; to restore, rehabilitate or renature degraded environments, including by integrating new features into the landscape; and for phyto-rehabilitation or phytoremediation, which means purifying or decontaminating soil or water using plants. The French term is ***génie végétal*** (*Rey et al, 2015*).

Pioneer species

The first species that colonise or recolonise a given environment. This may be a newly created environment (a wall, an area of waste ground, a patch of desealed ground, etc.) or a recently disturbed one (infill, an urban building site, an area of felled trees, a landslide, an area where topsoil has been removed, etc.). Pioneers are the first species to appear at the beginning of ecological succession.

Rehabilitation (also refunctionalisation)

This means creating an ecosystem that is structurally and functionally identical to the one that existed before a disturbance (*Séré, 2007*). Its composition, however (i.e. its specific diversity and abundance) differs from that of the initial ecosystem.

Renaturing

In the broadest sense, renaturing means returning ecosystems that have been degraded, damaged or destroyed by human activity to a natural or semi-natural state. It is synonymous with ecological restoration and can be either active or passive. Active renaturing involves actions that initiate or accelerate the self-repair of the ecosystem in question. Passive renaturing, used where damage is less severe, allows natural processes to restore the ecosystem. Renaturing can be used for both natural and semi-natural ecosystems. The Net Zero Land Take goal sees renaturing as a way of offsetting land take, and can be defined as the set of processes that make it possible to restore disturbed land to its initial natural state.

Resilience / natural regeneration

The word resilience comes from the Latin verb *resiliare* which means "to spring back". In ecology, the term is used to refer to how an organism, a species (taxon) or an ecosystem is able to withstand major or minor disturbances (natural or industrial disasters, etc.) and return to its normal way of functioning. Resilience generally depends on the diversity and complexity of ecosystems and on the genetic heritage of individuals. When the concept is applied to a country or area, it is used to assess social vulnerability to environmental and economic risks so that the area can better defend itself against external hazards. It denotes the stability of an ecosystem and how fast it is able to return to a stable state after a disturbance (*Triplet, 2021*). "Natural regeneration" refers to the ability of an ecosystem to restore itself spontaneously following a disturbance that might have led to its total or partial destruction; it is thus synonymous with resilience. Renaturing projects whose aim is spontaneous recolonisation leverage resilience.

Rewilding

This can refer either to the reintroduction of species that disappeared centuries or millennia ago or to the absence of human intervention in a given area (also known as natural regeneration). In cases aiming at a total lack of human intervention, all activities that impinge on nature are prohibited and the site is not managed. Humans are not entirely excluded, however, and visitors may be allowed providing they use specially laid out paths and observation points.

Sealing (also "paving")

Permanently covering the ground with a man-made non-permeable material (asphalt or concrete, for example), especially for the construction of buildings and roads.

Stratum

A stratum is a "layer" of vegetation made up of plants of similar heights. There are four major strata: the moss layer (0 – 5 cm); the herbaceous layer (5 – 80 cm); the shrub layer (1 – 8 m); and the tree layer (over 8 m).

Technosoil

In pedological engineering, a technosoil is a fertile soil created using recycled urban materials. Technosoils may be made of secondary raw materials (compost, papermill slurry, excavated earth, dredged mud, concrete granulates, other crushed inert materials, etc.) [55]

Urban ecology

A sub-discipline of ecology that studies urban ecosystems and seeks to understand the dynamics, evolution and characteristics of biodiversity in cities, towns and villages. Urban ecology is part of a multi-disciplinary approach that attempts to understand interactions between humans and wildlife in urban areas. It draws from the natural and social sciences such as sociology, demography, geography, economics and anthropology. The roots of urban ecology go back to the 1950s with the Berlin School of Urban Ecology (Sukopp) and the Chicago School of Urban Ecology (Park, Burgess & McKenzie). Urban ecology is expanding, bringing together ecologists and key urban stakeholders (planners, landscape designers, architects), and aims to develop methods and solutions to help build wildlife-friendly cities.

Urbanisation

The growing concentration of the population in urban centres. The word "metropolitanisation" refers to the same process but from a more economic, political and symbolic perspective, suggesting the highest levels of the organisation of urban systems.

Urban exploiters

A species highly dependent on humans for food and shelter or that has found ecological conditions in urban areas to be close to its original environment (e.g. ivy-leaved toadflax, common pigeon, magpie) (*Muratet et al, 2019*)

Urban adapters

A species that tends to shun the urban environment or which disappears when urbanisation leads to loss of habitat, lack of resources necessary for survival, or disturbance. Species that need a large distribution area are often affected by urbanisation, such as some birds of prey and mammals (). Some species manage to eke out an existence in the urban environment, without really benefiting from it. These are known as "tolerant species".

Waste ground => Brownfield

There is no generally agreed definition of what constitutes waste ground. Areas of waste ground vary greatly due to their history, their characteristics and the broader environments they form part of. They might be former industrial sites (in which case they are called **brownfield sites**). Waste ground inspires varied and contradictory reactions. A local resident, a planner, a local councillor, an ecologist, an anthropologist and a photographer will all have different ways of seeing waste ground. Also, waste ground is not frozen in time; it is constantly changing, which makes it even harder to define. But all areas of waste ground have one thing in common: the idea of abandonment and neglect. They are places where humans have stopped doing something, and where nature gradually returns. Although abandoned, these spaces are far from being uninhabited. Wildlife freely returns to them and they host an array of natural habitats, each corresponding to a stage in ecological succession, starting with bare earth and ending with woodland. Diversity of environments and an absence of management make patches of waste ground into hotbeds of biodiversity. Unlike parks and gardens in urban areas, waste ground hosts so-called "urban avoiders". It provides not only a refuge for biodiversity but also a stopoff point for species within the urban matrix (the "green and blue grids"). In French, the equivalent of the term "[an area of] waste ground" is une friche, and a brownfield site is une friche industrielle.

6 SCIENTIFIC REFERENCES

Abbadie, L., Bastien-Ventura, C. & Frascaria-Lacoste, N. (2015). Bilan et enjeux du programme interdisciplinaire Ingeco du CNRS (2007-2011) : un tournant pour l'ingénierie écologique en France ?. *Natures Sciences Sociétés*, 23, 389-396.

Adams, M. P., & Smith, P. L. (2014). A systematic approach to model the influence of the type and density of vegetation cover on urban heat using remote sensing. Landscape and Urban Planning, 132, 47-54.

Adobati, F., & Garda, E. (2020). Soil releasing as key to rethink water spaces in urban planning. *City, Territory and Architecture*, *7*(1), 1-16.

Ahn, C., & Schmidt, S.A. (2019). Designing Wetlands as an Essential Infrastructural Element for Urban Development in the era of Climate Change. Sustainability.

Alikhani, S., Nummi, P., & Ojala, A. (2021). Urban Wetlands: A Review on Ecological and Cultural Values. Water.

Angold, P., Sadler, J.P., Hill, M.O., Pullin, A.S., Rushton, S.P., Austin, K., Small, E., Wood, B.F., Wadsworth, R., Sanderson, R.A., & Thompson, K.A. (2006). Biodiversity in urban habitat patches. The Science of the total environment, 360 1-3, 196-204 .

Argillier, C., Levêque, C., & Oberdorff, T. (2008). Qu'entend-on par bio-indicateurs de la qualité des eaux continentales?.

Aronson, J., France, Winterhalder, K., Hobbs, R.J., Murdoch, W., Australia, J., Harris, C., Murcia, Cali, C., Rieger, J.P., & Diego, S. (2004). The SER International Primer on Ecological Restoration.

Aronson, M.F.J., La Sorte, F.A., Nilon, C.H., Katti, M., Goddard, M.A., Lepczyk, C.A. et al. (2014). A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proc. Biol. Sci., 281, 20133330.

Atger, C., & Edelin, C. (1994). Premires donnes sur l'architecture compare des systmes racinaires et caulinaires. *Botany*.

Atkinson, G.E., Doick, K.J., & Burningham, K. (2014). 'Brownfield regeneration to greenspace: Delivery of project objectives for social and environmental gain'. Urban Forestry & Urban Greening, 13, 586-594

Baldauf, R.W., Thoma, E., Khlystov, A.Y., Isakov, V., Bowker, G.C., Long, T.C., & Snow, R. (2008). Impacts of noise barriers on near-road air quality. *Atmospheric Environment, 42*, 7502-7507.

Baldock, K. C., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Osgathorpe, L. M., ... & Memmott, J. (2015). Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. Proceedings of the Royal Society B: Biological Sciences, 282(1803), 20142849.

Barbillon, A., Aubry, C., & Manouchehri, N. (2019). *Guide REFUGE Caractérisation de la contamination des sols urbains destinés à la culture maraîchère et évaluation des risques sanitaires. Cas de la région Île-de-France* (Doctoral dissertation, INRAE; AgroParisTech).

Basagaña, X., Sartini, C., Barrera-Gómez, J., Dadvand, P., Cunillera, J., Ostro, B., ... & Medina-Ramón, M. (2011). Heat waves and cause-specific mortality at all ages. Epidemiology, 765-772.

Baude, M., Muratet, A., Fontaine, C., & Pellaton, M. (2011). Plantes et pollinisateurs observés dans les terrains vagues de Seine-Saint-Denis. Livret publié par l'Observatoire départemental de la Biodiversité Urbaine, 64 pages

Bayulken, B., Huisingh, D., & Fisher, P. M. (2020). How are Nature Based Solutions Helping in the Greening of Cities in the Context of Crises such as Climate Change and Pandemics? A Comprehensive Review. Journal of Cleaner Production, 125569.

Beninde, J., Veith, M., & Hochkirch, A. (2015). Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. Ecology letters, 18(6), 581-592.

Beute, F., Andreucci, M. B., Lammel, A., Davies, Z. G., Glanville, J., Keune, H., ... & de Vries, S. (2020). Types and characteristics of urban and peri-urban green spaces having an impact on human mental health and wellbeing: a systematic review.

Bonthoux, S., Brun, M., Pietro, F.D., Greulich, S., & Bouché-Pillon, S. (2014). How can wastelands promote biodiversity in cities ? A review. Landscape and Urban Planning, 132, 79-88.

Bourgeois, M. (2015). *Impacts écologiques des formes d'urbanisation: modélisations urbaines et paysagères* (Doctoral dissertation, Besançon).

Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and urban planning*, *97*(3), 147-155.

Braaker, S., Ghazoul, J., Obrist, M. K., & Moretti, M. (2014). Habitat connectivity shapes urban arthropod communities: the key role of green roofs. Ecology, 95(4), 1010-1021.

Brelot, E., Chapgier, J., Breil, P., Valla, E., Le Nouveau, N., Arcos, M., ... & Senechal, C. (2009). Guide pour la prise en compte des eaux pluviales dans les documents de planification et d'urbanisme. *Graie, Groupe de travail régional sur la prise en compte des eaux pluviales à l'échelle des bassins versants. Villeurbanne-France*.

Brunbjerg, A. K., Hale, J. D., Bates, A. J., Fowler, R. E., Rosenfeld, E. J., & Sadler, J. P. (2018). Can patterns of urban biodiversity be predicted using simple measures of green infrastructure?. Urban Forestry & Urban Greening, 32, 143-153

Burghardt, K. T., Tallamy, D. W., & Gregory Shriver, W. (2009). Impact of native plants on bird and butterfly biodiversity in suburban landscapes. Conservation Biology, 23(1), 219-224.

Bismuth V, Merceron E. 2008. L'observatoire des papillons des jardins. Muséum national d'Histoire naturelle. Paris. France

Cerema. (2019) SESAME Services écosystémique rendus par les arbres modulés selon l'essence

Chalot, R. (2016). Trame brune. Lichen

Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A., & Calcaterra, E. (2014). User's manual on the Singapore index on cities' biodiversity (also known as the City Biodiversity Index). Singapore: National Parks Board, Singapore.

Chazdon, R.L., & Guariguata, M.R. (2016). Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges. Biotropica, 48, 716-730.

Chevrier, É. (2013). La phytoremédiation,une solution d'avenir pour le Québec.

Cho, M. (2010). The politics of urban nature restoration: The case of Cheonggyecheon restoration in Seoul, Korea. *International Development Planning Review, 32*, 145-165.

Clark, N.E., Lovell, R., Wheeler, B.W., Higgins, S.L., Depledge, M.H. & Norris, K. (2014). Biodiversity, cultural pathways, and human health: a framework. Trends in Ecology & Evolution, 29, 198–204.

Connop, S., & Nash, C. (2018). Blandscaping that erases local ecological diversity.

Coppola, E., Nogherotto, R., Ciarlo', J. M., Giorgi, F., van Meijgaard, E., Kadygrov, N., ... & Wulfmeyer, V. (2021). Assessment of the European climate projections as simulated by the large EURO-CORDEX regional and global climate model ensemble. *Journal of Geophysical Research: Atmospheres*, *126*(4), e2019JD032356.

Cordeau, E. (2017). Adapter l'Ile-de-France à la chaleur urbaine.

Cornet, N., Cocquière, A., (2021). La pleine terre : nécessité d'une définition partagée dans les PLU - Note rapide Environnement, n° 884

Cornet, N., (2021). Restaurer les continuités écologiques en Île-de-France - L'Institut Paris Region (non accessible au public)

Costanza, R., D'arge, R.C., Groot, R.D., Farber, S.B., Grasso, M., Hannon, B.M., Limburg, K.E., Naeem, S., O'Neill, R.V., Paruelo, J.M., Raskin, R.G., Sutton, P.C., & Belt, M.V. (1997). The value of the world's ecosystem services and natural capital. *Nature, 387*, 253-260.

Cox, D. T., Shanahan, D. F., Hudson, H. L., Plummer, K. E., Siriwardena, G. M., Fuller, R. A., ... & Gaston, K. J. (2017). Doses of neighborhood nature: the benefits for mental health of living with nature. BioScience, 67(2), 147-155.

Daly, H.E. (1997). Beyond Growth: The Economics of Sustainable Development.

David, A. (2016). Vers une compréhension du fonctionnement carboné et écohydrologique des tilleuls argentés (Tilia tomentosa Moench) plantés en alignement à Paris.

DeClerck, F.A., Jones, S.K., Estrada-Carmona, N., & Fremier, A.K. (2021). Spare half, share the rest: A revised planetary boundary for biodiversity intactness and integrity

Drénou, Christophe. (2006). Les racines- Face cachée des arbres.

Drinnan, I.N. (2005). The search for fragmentation thresholds in a Southern Sydney Suburb. Biological Conservation, 124, 339-349.

Dutoit, T., Buisson, E., Fadda, S., Henry, F., Coiffait-Gombault, C., Jaunatre, R., Alignan, J., Masson, S., & Bulot, A. (2013). The pseudo-steppe of La Crau (South-Eastern France): origin, management and restoration of a Mediterranean rangeland.

EEA and FOEN, 2016, Urban sprawl in Europe Joint EEA-FOEN report No 11/2016, European Environment Agency, Swiss Federal Office for the Environment.

Fabbri, D., Pizzol, R., Calza, P., Malandrino, M., Gaggero, E., Padoan, E., & Ajmone-Marsan, F. (2021). Constructed Technosols: A Strategy toward a Circular Economy. Applied Sciences, 11, 3432.

Fan, J., Rosenfeld, D., Yang, Y., Zhao, C., Leung, L. R., & Li, Z. (2015). Substantial contribution of anthropogenic air pollution to catastrophic floods in Southwest China. Geophysical Research Letters, 42(14), 6066-6075.

Ford, A.T., Sunter, E.J., Fauvelle, C., Bradshaw, J.L., Ford, B., Hutchen, J., Phillipow, N., & Teichman, K.J. (2020). Effective corridor width: linking the spatial ecology of wildlife with land use policy. *European Journal of Wildlife Research, 66*.

Fortel, L., Henry, M., Guilbaud, L., Guirao, A. L., Kuhlmann, M., Mouret, H., ... & Vaissière, B. E. (2014). Decreasing abundance, increasing diversity and changing structure of the wild bee community (Hymenoptera: Anthophila) along an urbanization gradient. PloS one, 9(8), e104679.

Foti, L., Dubs, F., Gignoux, J., Lata, J., Lerch, T.Z., Mathieu, J., Nold, F., Nunan, N., Raynaud, X., Abbadie, L., & Barot, S. (2017). Trace element concentrations along a gradient of urban pressure in forest and lawn soils of the Paris region (France). The Science of the total environment, 598, 938-948 .

France. Service technique de l'urbanisme. (1994). Guide technique des bassins de retenue d'eaux pluviales. Technique & Documentation-Lavoisier.

France, U. I. C. N. (2018). Les Solutions fondées sur la Nature pour lutter contre les changements climatiques et réduire les risques naturels en France. IUCN, Paris, France.

France, M. (2020). Les nouvelles projections climatiques de référence DRIAS 2020 pour la métropole. *Collaboration entre Météo France, CNRM, Cerfacs et IPSL*.

Foltête J.C., Clauzel C., Vuidel G., 2012. A software tool dedicated to the modelling of landscape networks Environmental Modelling & Software, 38: 316-327.

Forman, R.T., & Baudry, J. (1984). Hedgerows and hedgerow networks in landscape ecology. *Environmental Management, 8*, 495-510.

Fuller, R.A., Irvine, K.N., Devine-Wright, P., Warren, P.H., & Gaston, K.J. (2007). Psychological benefits of greenspace increase with biodiversity. Biology Letters, 3, 390 - 394.

Gardiner, M. M., Burkman, C. E., & Prajzner, S. P. (2013). The value of urban vacant land to support arthropod biodiversity and ecosystem services. *Environmental entomology*, *42*(6), 1123-1136.

Génot, J., Schnitzler, A. (2012). *La France des friches: De la ruralité à la féralité*. Versailles: Éditions Quæ.

Gillig, C.M., (2008). L'arbre en milieu urbain : conception et réalisation de plantations

Giroud, V., Esser, D., Fournet, L., & Davoli, F. (2007, June). Les filtres plantés de roseaux pour le traitement des eaux pluviales: Notion d'efficacité. In *Novatech 2007-6ème Conférence sur les techniques et stratégies durables pour la gestion des eaux urbaines par temps de pluie/Sixth International Conference on Sustainable Techniques and Strategies in Urban Water Management*. GRAIE, Lyon, France.

Grubb, P. J., & Hopkins, A. J. M. (1986). Resilience at the level of the plant community. In *Resilience in mediterranean-type ecosystems* (pp. 21-38). Springer, Dordrecht.

Graham, D. A., Vanos, J. K., Kenny, N. A., & Brown, R. D. (2016). The relationship between neighbourhood tree canopy cover and heat-related ambulance calls during extreme heat events in Toronto, Canada. Urban Forestry & Urban Greening, 20, 180-186.

Goddard, M. A., Dougill, A. J., & Benton, T. G. (2010). Scaling up from gardens: biodiversity conservation in urban environments. Trends in ecology & evolution, 25(2), 90-98.

Gouedard, Q. (2014). Les sols urbains, des milieux contraignants pour le développement de l'arbre dans la ville.

Hafeez, F., Spor, A., Breuil, M.C., Schwartz, C., Martin-Laurent, F., & Philippot, L. (2012). Distribution of bacteria and nitrogen-cycling microbial communities along constructed Technosol depth-profiles. Journal of hazardous materials, 231-232, 88-97 .

Hafidi, M., Ouahmane, L., Thioulouse, J., Sanguin, H., Boumezzough, A., Prin, Y., Baudoin, E., Galiana, A., & Duponnois, R. (2013). Managing Mediterranean nurse plants-mediated effects on soil microbial functions to improve rock phosphate solubilization processes and early growth of Cupressus atlantica G. Ecological Engineering, 57, 57-64.

Hanford, J.K., Hochuli, D.F., & Webb, C.E. (2020). Observations of an unexpected abundance of estuarine mosquitoes associated with an urban freshwater wetland. The Australian zoologist, 41, 80-85.

Henein, K., & Merriam, G. (2004). The elements of connectivity where corridor quality is variable. *Landscape Ecology, 4*, 157-170

Henry, C., Richard, F., Ramanankierana, H., Ducousso, M., & Selosse, M. A. (2021). Comprendre la dynamique des communautés mycorhiziennes lors des successions végétales. Deuxième partie: Potentialités d'applications à la restauration des écosystèmes forestiers (revue bibliographique).

Herin, J. J., & Dennin, L. (2016). Une politique pluviale volontariste et durable: bilan de 25 ans de bonnes pratiques environnementales-l'exemple chiffré du Douaisis-France. *Fonctionnement global du système d'assainissement/Global performance of the drainage system-Stratégie/Strategy*.

Hill, M. J., Biggs, J., Thornhill, I., Briers, R. A., Gledhill, D. G., White, J. C., ... & Hassall, C. (2017). Urban ponds as an aquatic biodiversity resource in modified landscapes. Global change biology, 23(3), 986-999.

Hinners, S.J., Kearns, C.A., & Wessman, C.A. (2012). Roles of scale, matrix, and native habitat in supporting a diverse suburban pollinator assemblage. Ecological applications : a publication of the Ecological Society of America, 22 7, 1923-35 .

Hostetler, M.E., & Holling, C.S. (2004). Detecting the scales at which birds respond to structure in urban landscapes. Urban Ecosystems, 4, 25-54.

Huang, Y. J., Akbari, H., & Taha, H. (1990). The wind-shielding and shading effects of trees on residential heating and cooling requirements. *ASHRAE proceedings*, *96*(pt. 1).

Hwang, K.Y., & Joon, L. (2005). Three Keys to the Success of Cheonggyecheon Restoration Project: Conflict Management Strategies.

Hystad, P., Payette, Y., Noisel, N., & Boileau, C. (2019). Green space associations with mental health and cognitive function: results from the Quebec CARTaGENE cohort. *Environmental Epidemiology*, *3*(1).

IPBES (2019): Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES secretariat, Bonn, Germany. XXX pages.

IPBES (2019): Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. Settele, E. S. Brondízio E.S., H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany. 56 pages.

Islam, M. N., Rahman, K. S., Bahar, M. M., Habib, M. A., Ando, K., & Hattori, N. (2012). Pollution attenuation by roadside greenbelt in and around urban areas. Urban Forestry & Urban Greening, 11(4), 460-464.

Jaunatre, R., Buisson, E., & Dutoit, T. (2014). Topsoil removal improves various restoration treatments of a M editerranean steppe (L a C rau, southeast F rance). *Applied Vegetation Science*, *17*(2), 236-245.

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge university press.

Keitt, T.H., Urban, D.L., & Milne, B.T. (1997). Detecting Critical Scales in Fragmented Landscapes. *Conservation Ecology, 1*, 4.

Kim, H.S., T.G. Koh, and K.W. Kwon. (2009.) The Cheonggyecheon (Stream) Restoration Project Effects of the restoration work. Cheonggyecheon Management Team, Seoul Metropolitan Facilities Management Corporation. Seoul, South Korea.

Kurylo, J. S., Threlfall, C. G., Parris, K. M., Ossola, A., Williams, N. S. G., & Evans, K. L. (2020). Butterfly richness and abundance along a gradient of imperviousness and the importance of matrix quality. Ecological Applications, 30(7), e02144.

Lefebvre W. and Vranckx S. (Eds.), 2013. Validation of the IFDM-model for use in urban applications, Study accomplished in the framework of the ATMOSYS-project, 2013/RMA/R/56

Le Roux, D.S., Ikin, K., Lindenmayer, D.B., Manning, A.D., & Gibbons, P. (2014). The Future of Large Old Trees in Urban Landscapes. PLoS ONE, 9.

Le Roux, D. S., Ikin, K., Lindenmayer, D. B., Manning, A. D., & Gibbons, P. (2015). Single large or several small? Applying biogeographic principles to tree-level conservation and biodiversity offsets. Biological Conservation, 191, 558-566.

Levrel at al., 2021. Limiter l'artificialisation des sols pour éviter une dette écologique se chiffrant en dizaines de milliards d'euros. The Conversation

Lévy, J. (2015). Habiter Cheonggyecheon : l'exception ordinaire.

Litschke, T., & Kuttler, W. (2008). On the reduction of urban particle concentration by vegetation-a review. *Meteorologische Zeitschrift*, *17*(3), 229-240.

Maienza, A., Ungaro, F., Baronti, S., Colzi, I., Giagnoni, L., Gonnelli, C., ... & Calzolari, C. (2021). Biological Restoration of Urban Soils after De-Sealing Interventions. *Agriculture*, *11*(3), 190.

Mathieu, J. (2015). *Biodiversité et syndrome de dispersion dans les communautés de macrofaune du sol* (Doctoral dissertation, Université Pierre et Marie Curie).
Meyer-Grandbastien A., Vajou B., Fromage B., Galopin G., Laille P. (2021). Effets bénéfiques des espaces de nature en ville sur la santé : Synthèse des recherches internationales et clés de compréhension. Plante & Cité, Angers, 18 p.

Maurel N., 2010, *De l'introduction à l'invasion : les plantes exotiques en milieu urbain*. Thèse de doctorat en écologie, Muséum national d'histoire naturelle.

Miller, J. R. (2005). Biodiversity conservation and the extinction of experience. *Trends in ecology & evolution*, *20*(8), 430-434.

Monberg, R. J., Howe, A. G., Kepfer-Rojas, S., Ravn, H. P., & Jensen, M. B. (2019). Vegetation development in a stormwater management system designed to enhance ecological qualities. *Urban Forestry & Urban Greening*, *46*, 126463.

Monteiro, M. V., Doick, K. J., Handley, P., & Peace, A. (2016). The impact of greenspace size on the extent of local nocturnal air temperature cooling in London. *Urban Forestry & Urban Greening*, *16*, 160-169.

Muratet, A., Machon, N., Jiguet, F., Moret, J., & Porcher, E. (2007). The role of urban structures in the distribution of wasteland flora in the greater Paris area, France. *Ecosystems*, *10*(4), 661-671.

Muratet, A., Porcher, E., Devictor, V., Arnal, G., Moret, J., Wright, S., & Machon, N. (2008). Evaluation of floristic diversity in urban areas as a basis for habitat management.

Muratet A., 2016, Etat de santé de la biodiversité en Île-de-France. Apport du programme de sciences participatives Vigie Nature. Dossier de presse Natureparif. 22 pages

Muratet, A., Muratet, A., Muratet, M., Pellaton, M., & Book., L. (2017). Flore des friches urbaines du nord de la France et des régions voisines / Audrey Muratet ; [photographies de] Myr Muratet [et dessins de] Marie Pellaton.

Muratet A, Chiron F, Muratet M (2019), Manuel d'écologie urbaine, Editions les presses du réel, 120 pages

Nowak, D. J., Bodine, A. R., Hoehn, R. E., Ellis, A., Hirabayashi, S., Coville, R., ... & Endreny, T. (2018). The urban forest of new york city. *Resource Bulletin NRS-117. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station. 82 p*, *117*, 1-82.

Oertli, B., & Parris, K.M. (2019). Review: Toward management of urban ponds for freshwater biodiversity. Ecosphere.

Ottburg, F., Lammertsma, D., Bloem, J., Dimmers, W., Jansman, H., & Wegman, R. (2017). *Tiny Forest Zaanstad: citizen science en het bepalen van biodiversiteit in Tiny Forest Zaanstad* (No. 2870). Wageningen Environmental Research.

Pascal, M., & Medina, S. (2012). Résumé des résultats du projet Aphekom 2008-2011. Des clefs pour mieux comprendre les impacts de la pollution atmosphérique urbaine sur la santé en Europe. Saint-Maurice: Institut de veille sanitaire.

Pascal, M., de Crouy Chanel, P., Wagner, V., Corso, M., Tillier, C., Bentayeb, M., ... & Medina, S. (2016). The mortality impacts of fine particles in France. Science of the Total Environment, 571, 416-425.

Pascal, M., Goria, S., Wagner, V., Sabastia, M., Guillet, A., Cordeau, E., ... & Host, S. (2021). Greening is a promising but likely insufficient adaptation strategy to limit the health impacts of extreme heat. Environment international, 151, 106441.

Pech, P. (2015). Renaturation. *Hypergeo*

Pédologique, R. (2008). Association Française pour l'Étude du Sol. *Ed Quæ*.

Pellegrini P., Maurel N., Lizet B., Machon N., à paraître, « Pieds d’arbres jardinés, espaces de diversité », in Menozzi M.-J., Manusset S., Bioret F. (éds), *Jardins, espaces de vie, de connaissance et de biodiversité*, actes du colloque de la Société d’écologie humaine, 2-4 juin 2010, Brest, PUR, Rennes.

Pileri, P. (2007). COMPENSAZIONE ECOLOGICA PREVENTIVA PER UN 'NUOVO' GOVERNO DEL TERRITORIO.

Plante & Cité, 2021. Associer santé et espaces de nature - Les clés pour comprendre et agir. Plante & Cité, Angers, 68 p

Plenchette, C., Furlan, V., & Fortin, J.A. (1983). Responses of endomycorrhizal plants grown in a calcined montmorillonite clay to different levels of soluble phosphorus. I. Effect on growth and mycorrhizal development. Botany, 61, 1377-1383.

Powers, S., Peterson, C., Grabowski, J.H., & Lenihan, H.S. (2009). Success of constructed oyster reefs in no-harvest sanctuaries: implications for restoration. Marine Ecology Progress Series, 389, 159-170.

Prach, K., & Hobbs, R.J. (2008). Spontaneous Succession versus Technical Reclamation in the Restoration of Disturbed Sites. Restoration Ecology, 16, 363-366.

Prach, K., & Moral, R.D. (2015). Passive restoration is often quite effective: response to Zahawi et al. (2014). Restoration Ecology, 23, 344-346.

Prigioniero, A., Zuzolo, D., Niinemets, Ü., & Guarino, C. (2021). Nature-Based Solutions as tools for air phytoremediation: a review of the current knowledge and gaps. Environmental Pollution, 116817.

Pruvost, C. (2018). *Potentiel de la biodiversité dans la construction de Technosols à partir de déchets urbains* (Doctoral dissertation, Paris Est).

Pugh, T.A., MacKenzie, A.R., Whyatt, J.D., & Hewitt, C.N. (2012). Effectiveness of green infrastructure for improvement of air quality in urban street canyons. Environmental science & technology, 46 14, 7692-9.

Pulliam, H.R. (1988). Sources, Sinks, and Population Regulation. *The American Naturalist, 132*, 652 - 661.

Ramsar Convention on Wetlands. (2018). Global Wetland Outlook: State of the World's Wetlands and their Services to People. Gland, Switzerland: Ramsar Convention Secretariat.

Ravot, C., Laslier, M., Hubert-Moy, L., Dufour, S., Coeur, D.L., & Bernez, I. (2020). Apports d'une observation précoce de la végétation spontanée pionnière pour la renaturation des rives de la rivière Sélune.

Requia, W. J., & Koutrakis, P. (2018). Mapping distance-decay of premature mortality attributable to PM2. 5-related traffic congestion. Environmental Pollution, 243, 9-16.

Revkin A, 2009, "Peeling Back Pavement to Expose Watery Havens", The New York Times, July 16

Rey, F., Cécillon, L., Cordonnier, T., Jaunatre, R., & Loucougaray, G. (2015). Integrating ecological engineering and ecological intensification from management practices to ecosystem services into a generic framework: a review. *Agronomy for Sustainable Development, 35*, 1335-1345.

Riboulot-Chetrit, M. (2015). Les jardins privés: de nouveaux espaces clés pour la gestion de la biodiversité dans les agglomérations?. Articulo-Journal of Urban Research, (Special issue 6).

Rivière, J. N., Hivert, J., Schmitt, L., Derroire, G., Sarrailh, J. M., & Baret, S. (2008). Rôle des fougères arborescentes dans l'installation des plantes à fleurs en forêt tropicale humide de montagne à la Réunion (Mascareignes, Océan Indien). *Revue d'écologie*.

Ropars, L., Dajoz, I., & Geslin, B. (2017). La ville un désert pour les abeilles sauvages?. *Journal de Botanique*, *79*, 29-35.

Ryu, H., Park, I. K., Chun, B. S., & Chang, S. I. (2017). Spatial statistical analysis of the effects of urban form indicators on road-traffic noise exposure of a city in South Korea. Applied acoustics, 115, 93-100.

Sæbø, A., Popek, R., Nawrot, B., Hanslin, H.M., Gawrońska, H., & Gawroński, S.W. (2012). Plant species differences in particulate matter accumulation on leaf surfaces. The Science of the total environment, 427-428, 347-54 .

Sarasin, G. (2011). Biotechnologie des symbioses racinaires en restauration écologique des écosystèmes dégradés à Madagascar.

Sarrazin, F., & Lecomte, J. (2016). Evolution in the Anthropocene. *Science, 351*, 922 - 923.

Schiechtl, H.M., & Stern, R. (1992). Handbuch für naturnahen Wasserbau : eine Anleitung für ingenieurbiologische Bauweisen.

Schirone, B., Salis, A., & Vessella, F. (2011). Effectiveness of the Miyawaki method in Mediterranean forest restoration programs. *Landscape and Ecological Engineering*, *7*(1), 81-92.

Selmi, W., Weber, C., Rivière, E.D., Blond, N., Mehdi, L., & Nowak, D.J. (2016). Air pollution removal by trees in public green spaces in Strasbourg city, France. Urban Forestry & Urban Greening, 17, 192-201.

Séré, G. (2007). Fonctionnement et évolution pédogénétiques de Technosols issus d'un procédé de construction de sol.

Séré G., Schwartz C., Renat J.C., Morel J.L., 2008, Procédé de valorisation de déchets et sous-produits en construction de sol pour la réhabilitation de sites dégradés, Déchets Science & Technique, vol. 50

Séré, G., Schwartz, C., Ouvrard, S., Renat, J., Watteau, F., Villemin, G., & Morel, J. (2010). Early pedogenic evolution of constructed Technosols. Journal of Soils and Sediments, 10, 1246-1254.

Shanahan, D.F., Miller, C.J., Possingham, H.P., & Fuller, R.A. (2011). The influence of patch area and connectivity on avian communities in urban revegetation. Biological Conservation, 144, 722-729.

Sonntag-Öström, E., Nordin, M., Lundell, Y., Dolling, A., Wiklund, U., Karlsson, M., ... & Järvholm, L. S. (2014). Restorative effects of visits to urban and forest environments in patients with exhaustion disorder. *Urban forestry & urban greening*, *13*(2), 344-354.

Shwartz, A., Muratet, A., Simon, L., & Julliard, R. (2013). Local and management variables outweigh landscape effects in enhancing the diversity of different taxa in a big metropolis. Biological Conservation, 157, 285-292.

Sordello, R., 2021. Trame verte, trame bleue et autres trames. Regard 72, Société Française d’écologie

Soubeyroux, J. M., Ouzeau, G., Schneider, M., Cabanes, O., & Kounkou-Arnaud, R. (2016). Les vagues de chaleur en France: analyse de l'été 2015 et évolutions attendues en climat futur. La Météorologie.

Spotswood, E.N., Grossinger, R.M., Hagerty, S., Bazo, M., Benjamin, M., Beller, E.E., Grenier, L., & Askevold, R.A. (2019). Making Nature's City

Stanghellini, P.S. (2010). Stakeholder involvement in water management: the role of the stakeholder analysis within participatory processes. Water Policy, 12, 675-694.

Stansfeld, S. A. (2015). Noise effects on health in the context of air pollution exposure. International journal of environmental research and public health, 12(10), 12735-12760.

Stagoll, K., Lindenmayer, D. B., Knight, E., Fischer, J., & Manning, A. D. (2012). Large trees are keystone structures in urban parks. Conservation Letters, 5(2), 115-122.

Strohbach, M. W., Lerman, S. B., & Warren, P. S. (2013). Are small greening areas enhancing bird diversity? Insights from community-driven greening projects in Boston. Landscape and Urban Planning, 114, 69-79.

Szulczewska, B., Giedych, R., Borowski, J., Kuchcik, M., Sikorski, P., Mazurkiewicz, A., & Stańczyk, T. (2014). How much green is needed for a vital neighbourhood? In search for empirical evidence. Land Use Policy, 38, 330-345.

Thiffault, N., & Hébert, F. (2017). Mechanical site preparation and nurse plant facilitation for the restoration of subarctic forest ecosystems. Canadian Journal of Forest Research, 47, 926-934.

Threlfall, C. G., Ossola, A., Hahs, A. K., Williams, N. S. G., Wilson, L., & Livesley, S. J. (2016). Variation in vegetation structure and composition across urban green space types. Frontiers in Ecology and Evolution, 4(JUN), 1-12. [66].

Threlfall, C. G., Mata, L., Mackie, J. A., Hahs, A. K., Stork, N. E., Williams, N. S., & Livesley, S. J. (2017). Increasing biodiversity in urban green spaces through simple vegetation interventions. Journal of applied ecology, 54(6), 1874-1883.

Tobias, S., Conen, F., Duss, A., Wenzel, L.M., Buser, C., & Alewell, C. (2018). Soil sealing and unsealing: state of the art and examples. *Land Degradation & Development, 29*, 2015-2024.

Triplet, P., 2021. Dictionnaire de la diversité biologique et de la conservation de la nature. 7ème édition.

Turo, K. J., & Gardiner, M. M. (2019). From potential to practical: conserving bees in urban public green spaces. *Frontiers in Ecology and the Environment*, *17*(3), 167-175.

Urban green spaces and health. Copenhagen: WHO Regional Office for Europe, 2016.

Vautard, R., Munck, C., Noblet, N ., 2021, Les grandes lignes du changement climatique en Ile-de-France, GREC Ile-de-France (non accessible au public)

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

Vidal-Beaudet, L. (2018). Du déchet au Technosol fertile: l'approche circulaire du programme français de recherche SITERRE. *VertigO-la revue électronique en sciences de l'environnement*, (Hors-série 31).

Vignoli, L., Mocaer, I., Luiselli, L., & Bologna, M.A. (2009). Can a large metropolis sustain complex herpetofauna communities? An analysis of the suitability of green space fragments in Rome. Animal Conservation, 12, 456-466.

White, M. P., Alcock, I., Wheeler, B. W., & Depledge, M. H. (2013). Would you be happier living in a greener urban area? A fixed-effects analysis of panel data. Psychological science, 24(6), 920-928.

Wilson, E. O. (2017). A biologist's manifesto for preserving life on Earth. *Sierra Club Magazine*.

World Health Organization. (2006). Lignes directrices OMS relatives à la qualité de l'air: particules, ozone, dioxyde d'azote et dioxyde de soufre : mise à jour mondiale 2005: synthèse de l'évaluation des risques (No. WHO/SDE/PHE/OEH/06.02). Genève: Organisation mondiale de la Santé.

World Health Organization. (2018). Environmental noise guidelines for the European region.

7 APPENDICES

7.1 Appendix 1: Examples of minimum surface areas required to maintain certain taxonomic groups

Species	Continuous area required for urban exploiters	Sources
Birds	5 ha	*Beninde (2015)*
Anurans	3 ha	*Drinnan (2005)*
Flora and fungi	2 ha	*Drinnan (2005)*
Pollinators	8 ha	*Hinners et al. (2012)*
Ground beetles	8 ha	*Angold et al, 2006*

Species	Continuous area required by urban avoiders	Sources
Birds	46 ha	*Beninde (2015)*
Amphibians and Anurans	50 ha to 72.5 ha	*Beninde (2015) and Drinnan (2005)*
Pollinators	20 ha	*Hinners et al. (2012)*
Reptiles	50 ha	*Vignoli et al. (2009)*

7.2 Appendix 2: details of the study of exposure to runoff risk

Type of ground sealing is deduced from the 47-point Land Use survey produced by the Paris Region Institute and divided into 3 categories: heavily sealed; moderately sealed; and lightly sealed ground. Slopes are studied on the basis of data from the Paris Region Institute and are also divided into 3 classes: steep (over 7%); moderate (3% - 7%); and gentle (less than 3%). Values are then attributed to each of these categories so that data can be cross-referenced. Highly sealed areas score 0, moderately sealed areas score 1 and lightly sealed areas score 2. As for slope classes, steep slopes score 0, moderate slopes 1 and gentle slopes 2.

Level of sealing	Associated value
Heavy	0
Moderate	1
Light	2

Slope	Associated value
Steep	0
Moderate	1
Gentle	2

These values are then cross-referenced and summarised in the table below. Cumulative values are reclassified so that they score between 0 and 2 (values in bold), providing information that reflects exposure to runoff risk depending on the slope and the level of ground sealing.

Sealing \ Slope	Steep	Moderate	Gentle
Heavy	0 ≥ **0**	1 ≥ **0**	2 ≥ **1**
Moderate	1 ≥ **0**	2 ≥ **1**	3 ≥ **2**
Light	2 ≥ **1**	3 ≥ **2**	4 ≥ **2**

Cross table showing exposure to runoff risk depending on slope and degree of ground sealing.

The cells then get the score associated with the main type of risk they are exposed to. High exposure to runoff scores 0, moderate exposure 1 and low exposure 2.

7.3 Appendix 3: details of the study of exposure to flood risk

First of all, the 11-point Land Use Survey was divided into 3 categories: unbuilt areas; open unbuilt areas (e.g. parks and cemeteries); densely built-up areas (e.g. housing and business parks). Flood risk is studied by distinguishing 3 categories of hazard: low (less than 1 m of flood water or weak current); high (1 to 2 metres of flood water); and very high. Then, in the same way as the rest of the methodology, values are attributed to the different types of areas (land use) and different types of hazard, so that their cumulative impacts can be studied. For land use: unbuilt areas score 3, open unbuilt spaces score 1, and densely built-up areas score 0. For hazards: low to medium hazards score 2, high-level hazards 1 and very high-level hazards 0.

11-point land use survey	
Type of area	**Attributed value**
Unbuilt	2
Open built	1
Dense	0

Floodable areas	
Level of hazard	**Attributed value**
Low to medium	2
High	1
Very high	0

These values were then cross-referenced and summarised in the table below. Cumulative values are reclassified to provide scores between 0 and 2 (values in bold). This provides information reflecting flood risk depending on land use and potential intensity of flooding. A score is then attributed to the 125m cells depending on the major risk in the cell.

Type of area \ Hazard	Low / Moderate (= 2)	High (= 1)	Very high (= 0)
Unbuilt (= 3)	5 → **2**	4 → **2**	3 → **2**
Open (= 1)	3 → **2**	2 → **1**	1 → **0**
Dense (= 0)	2 → **1**	1→ **0**	0 → **0**

Cross table showing exposure to flood risk depending on land use and potential intensity of flooding.

The cells are then given a score associated with the type of major risk that concerns them. High exposure to flooding scores 0, medium exposure 1 and low exposure 2.

7.4 Appendix 4: Lack of green and natural spaces open to the public

Lack of green and natural spaces open to the public in terms of ratio, the indicator used in the framework of the Regional Green Plan 2007, is equal to 1 if the sliding ratio of green and natural spaces open to the public is lower than 10 m^2 per capita and equal to 0 in all other cases. The sliding ratio of green and natural spaces open to the public is the ratio between the total surface area of green and natural spaces in 2019 and the total population in 2016 in a 9 m^2 disk centred on cell 500 (it is equal to 0 if the population is zero).

Lack of green and natural spaces open to the public in terms of accessibility, an indicator also used in the Regional Green Plan 2007, is equal to 1 if the micro-cells of the road network in the cell are on average:

- Over 150 m from a green or natural space open to the public covering less than one hectare;
- Over 300 m from a space covering 1 - 10 hectares (or a linear space 300 m - 1 km long);
- Over 600 m from a space covering 10 - 30 hectares (or a linear space 1 - 5 km long);
- Over 1,200 m from a space covering 30 hectares (or a linear space over 5 km long).

and is equal to 0 in all other cases. It should be noted that these distances are not as the crow flies; they reflect the actual distance covered on foot and take into account necessary detours due to urban obstacles and the location of entrances to parks.

7.5 Appendix 5: details of the study of the lack of natural spaces

The study of the lack of public green spaces is based on data from the survey carried out by the Paris Region Institute as part of the 2017 Green Plan. This study distinguishes zones with a lack of green spaces, zones with a lack of accessibility, zones where both are lacking and zones where neither are lacking. A score of 0 is given to non-deficient cells; cells with one type of deficiency score 1; and cells with both types of deficiency score 2.

Public green spaces	
Type of deficiency	**Value**
Both	0
Green spaces	1
Accessibility	1
None	2

To determine the vegetation index, cells with plant cover of < 30% score 0; those with plant cover of ≥ 30% - < 45% score 1; cells with plant cover of ≥ 45% score 2.

Vegetation index	
Plant cover	**Value**
< 30%	0
≤ 30% - < 45%	1
≥ 45%	2

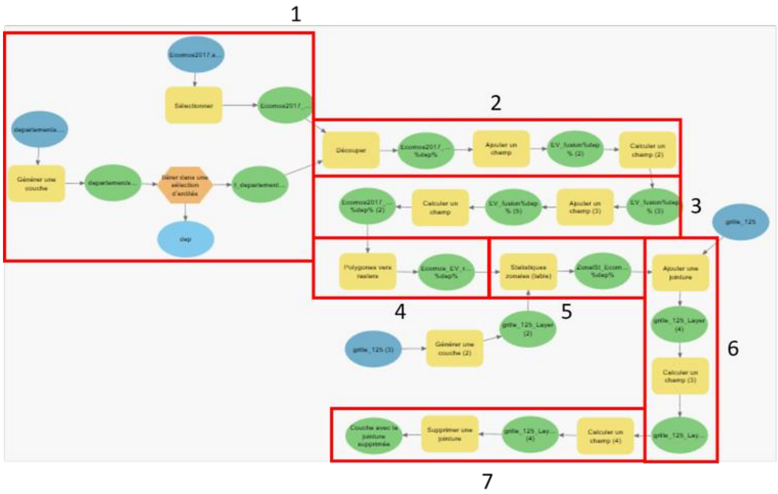
Combining the 2 components (lack of public green spaces and vegetation index) makes it possible to differentiate non-deficient zones from severely deficient zones. The final cumulative score is reclassified so that it is between 0 and 2 (value in bold). A score is then given to the cells depending on their deficiency in natural spaces: severe deficiency scores 0, moderate deficiency 1 and low deficiency 2.

Lack of public green spaces / **Vegetation index**	**Both** (= 0)	**Lack of spaces** (= 1)	**Lack of access** (= 2)	**None** (= 3)
Low (= 0)	0 → **0**	1 → **0**	1 → **0**	2 → **1**
Moderate (= 1)	1 → **0**	2 → **1**	2 → **1**	3 → **2**
High (= 2)	2 → **1**	3 → **2**	3 → **2**	4 → **2**

Cross table combining (i) deficiency in public green spaces and (ii) vegetation index

7.6 Appendix 6: Model used to study biodiversity deficiency

Study of the surface of green spaces



Detail of the steps

- 1 : Iteration
Splitting the calculation by department to reduce the weight of the operation

- 2 : Field calculation
Calculation of the area of green spaces

- 3 : Field calculation
Attribution of the score regarding the size calculated in 2

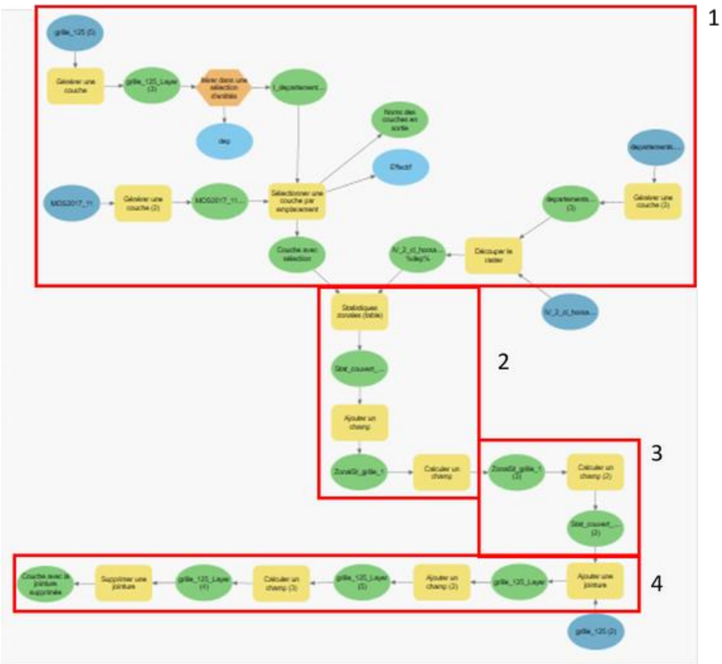
- 4 : Rasterization
Passing vector data to raster format

- 5 : Zonal statistics
Identification of the highest score occupying the cells of 125m*125m

- 6 : Field calculation
Attribution of thehighest score occupying the cell

- 7 : Field calculation
Assigning a score of 0 for cells with no data

Vegetation cover study



Detail of the steps

- 1 : Iteration
Splitting the calculation by department, and with a calculation made only on the urban areas (exluding forest and farming lands) to reduce the weight of the operation

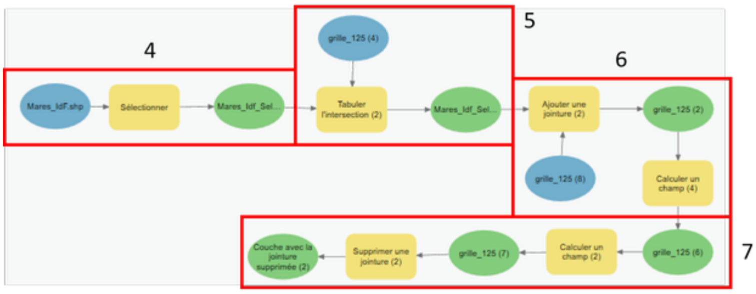
- 2 : Zonal statistics and field calculation
Calculation of the vegetation cover in the cells of 125m*125m. A pixel value of 1 indicates the presence of vegetation, a value of 0 indicates its absence. A sum of the pixel is calculated, and then divided by the total number of pixels, resulting in a percentage of vegetation cover of the cells

- 3 : Field calculation
Attribution of a score regarding the percentage of vegetation cover calculated in 2 (<25% = 0 ; ≥25% and <45% = 1 ; >45% = 2)

- 4 :Field calculation
Joining the table containing the previously calculated information to the final grid + assigning a score of 0 for cells with no data (=forests and farming lands)

Rare habitats (1/3) : study of the presence of remarkable trees

Rare habitats (2/3) : study of the presence of ponds



Detail of the steps

- 1 : Intersection
Intersection of the remarkable trees presence data with the grid of 125m * 125

- 2 : Field calculation
Assigning a score of 1 to each cell containing one (or more) remarkable tree

- 3 : Field calculation
Assigning a score of 0 to each cell not containing a remarkable tree

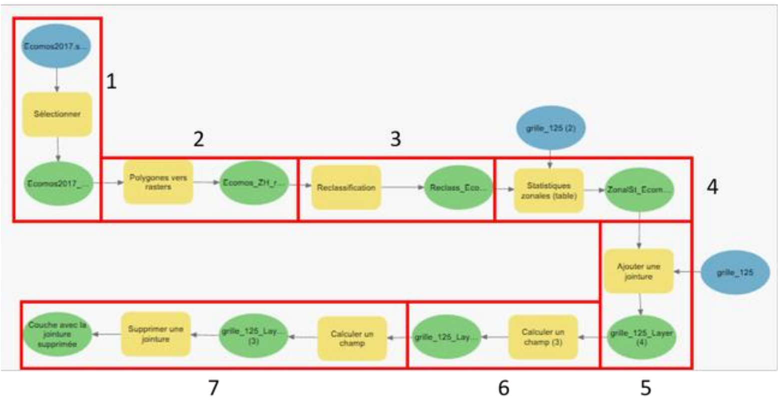
- 4 : Selection
Selection of the ponds whose existence as been verified on the field

- 5 : Intersection
Intersection of the ponds presence data with the grid of 125m * 125

- 6 : Field calculation
Assigning a score of 1 to each cell containing one (or more) pond

- 7 : Field calculation
Assigning a score of 0 to each cell not containing a pond

Rare habitats (3/3) : study of the presence of wetlands



Detail of the steps

- 1 : Selection
Selection of the natural / semi-natural areas considered as wetlands (swamps, etc.)

- 2 : Rasterization
Passing vector data to raster format

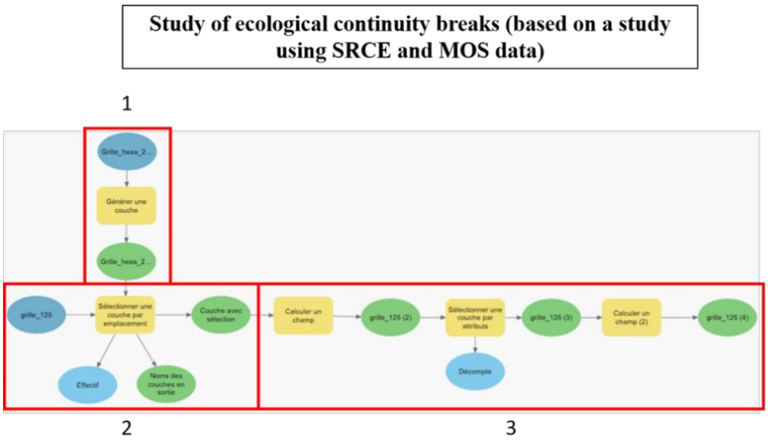
- 3 : Reclassification
Reclassification of raster data to convert them into a number

- 4 : Zonal statistics
Sum of the entities rasterized within the cells of 125m*125m

- 5 : Field calculation
Attribution of the score regarding the sum calculated in 4 : if the sum is ≥ 1 (meaning a wetland is present within the cell), a score of 2 is attributed to the cell

- 6 : Field calculation
Assigning a score of 0 for cells where the sum = 0 (meaning there are no wetlands within the cell)

- 7 : Final field calculation (not shown here)
Summary of the scores calculated for each rare habitats in a final field, providing the final score for this criteria



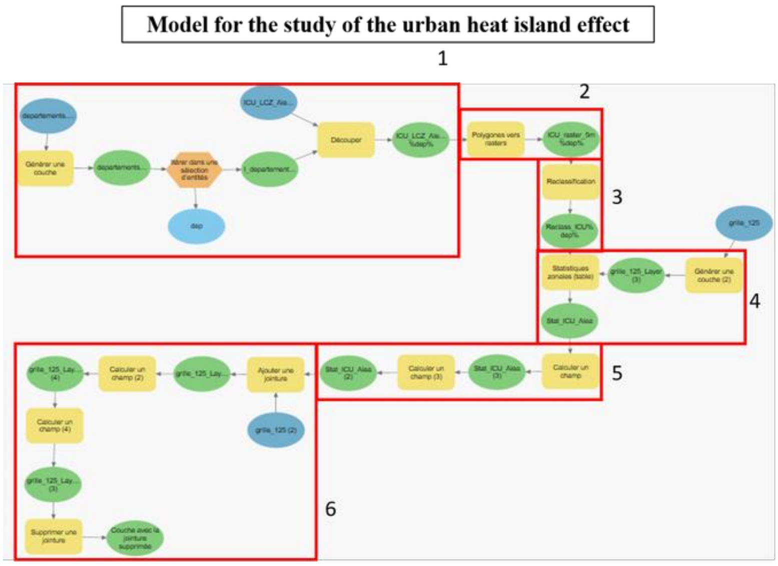
Detail of the steps

- **1 : Selection**
Selection of the cells (2km*2km) reflecting a strong ecological interest coupled with strong urbanization pressure

- **2 : Selection by location**
Selection of the cells (125m*125m) located on the cells (2km*2km) previously selected

- **3 : Field calculation**
Attribution of a score of 0 to the cells of 125m*125m located in an area of strong ecological interest coupled with urbanization pressure, attribution of a score of 2 to all the other cells

7.7 Appendix 7: Model used to study the exposure to the effects of climate change



Detail of the steps

- **1 : Iteration**
Splitting the calculation by department to reduce the weight of the operation

- **2 : Rasterization**
Passing UHI vector data to raster format

- **3 : Reclassification**
Reclassification of raster data to convert them into a score (high UHI effect = 0 ; medium UHI effect = 1 ; low UHI effect = 2 ; refreshing effect = 3)

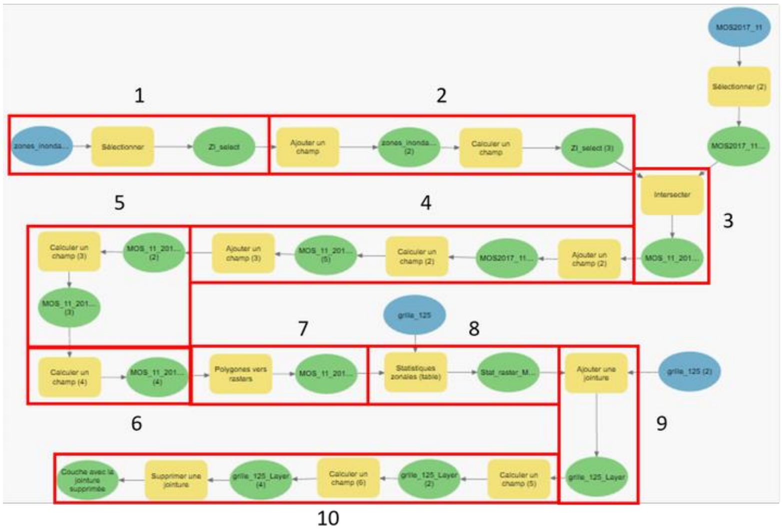
- **4 : Zonal statistics**
Identification of the score predominantly occupying the cells of 125m*125m

- **5 : Field calculation**
Attribution of the score occupying the cells in majority + assigning a score of 1 for cells with no data

- **6 :Field calculation**
Joining the table containing the previously calculated information to the final grid + assigning a score of 0 for cells with no data

- **7 : Final field calculation** (not shown here)
Summary of the scores calculated for each department in a final field, providing information at the scale of Ile de France

Model for the flooding exposure study



Detail of the steps

- 1 : **Selection**
Selection of flood zones (excluding watercourses)

- 2 : **Field calculation**
Attribution of a score to each type of hazard (strong hazard = 0 ; medium hazard = 1 ; low hazard = 2)

- 3 : **Intersection**
Extraction of MOS data located in flood zones only

- 4 : **Field calculation**
Attribution of a score to each type of land use (dense built-up area = 0 ; open built area = 1 ; unbuilt area = 2)

- 5 : **Field calculation**
Sum of the 2 scores calculated previously

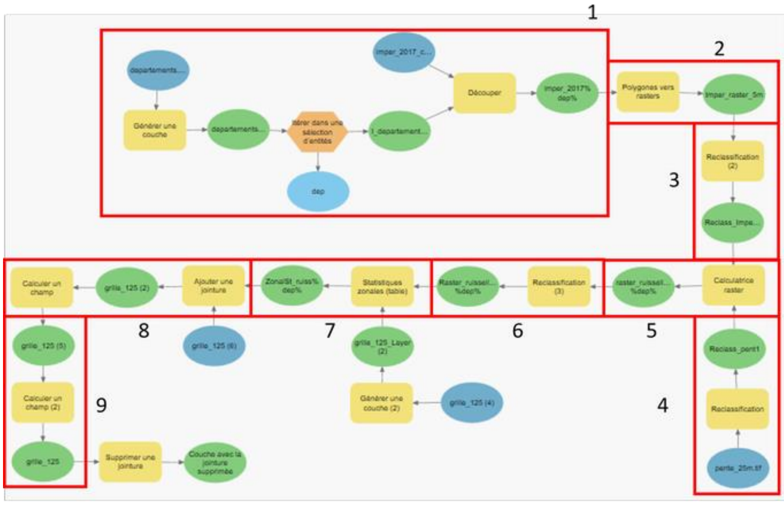
- 6 : **Reclassification**
Reclassification of the score obtained in 5 to contain it between 0 and 2

- 7 : **Rasterization**
Passing the previously calculated vector data to raster format

- 8 : **Zonal statistics**
Identification of the score predominantly occupying the cells of 125m*125m

- 9 and 10 : **Final field calculation**
Joining the table containing the previously calculated information to the final grid + assigning a score of 0 for cells with no data

Model for the runoff exposure study



Detail of the steps

- 1 : **Iteration**
Splitting the calculation by department to reduce the weight of the operation

- 2 : **Rasterization**
Passing soil waterproofing vector data (calculated from the MOS) to raster format

- 3 : **Reclassification**
Reclassification of raster data to convert them into a score (high waterproofing = 0 ; medium waterproofing = 1 ; low waterproofing = 2)

- 4 : **Reclassification**
Reclassification of a topographic raster data to convert the data into a score (steep slope = 0 ; average slope = 1 ; low slope = 2)

- 5 : **Raster calculation**
Sum of the 2 scores calculated previously

- 6 : **Reclassification**
Reclassification of the score obtained in 5 to contain it between 0 and 2

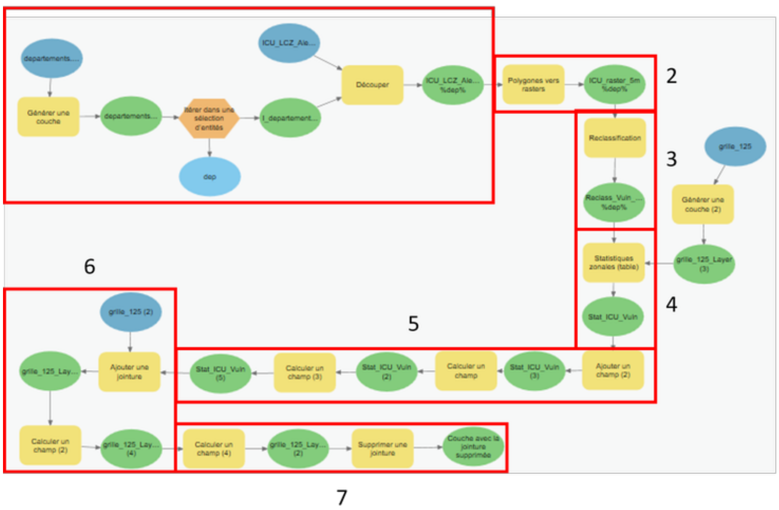
- 7 : **Zonal statistics**
Identification of the score predominantly occupying the cells of 125m*125m

- 8 : **Field calculation**
Joining the table containing the previously calculated information to the final grid + assigning a score of 0 for cells with no data

- 9 :**Final field calculation** (not shown here)
Summary of the scores calculated for each department in a final field, providing information at the scale of Ile de France

7.8 Appendix 8: Model used to study health and wellbeing risks

Study of the population vulnerability to the urban heat island effect



Detail of the steps

- **1 : Iteration**
splitting the calculation by department to reduce the weight of the operation

- **2 : Rasterization**
passing UHI vector data to raster format

- **3 : Reclassification**
reclassification of raster data to convert them into a score (high vulnerability = 0 ; medium vulnerability = 1 ; low vulnerability = 2)

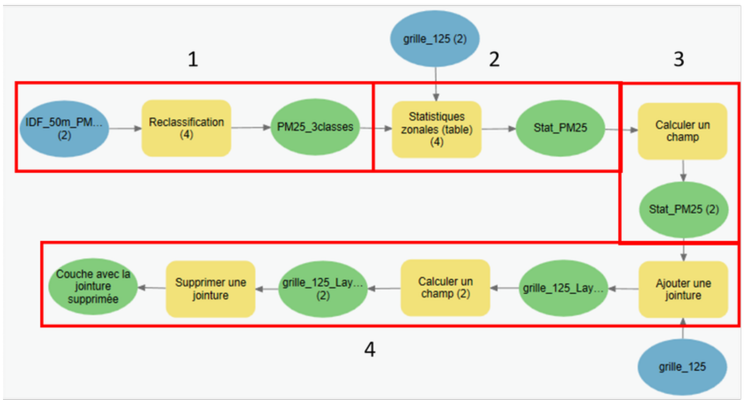
- **4 : Zonal statistics**
identification of the score predominantly occupying the cells of 125m*125m

- **5 : Field calculation**
attribution of the score occupying the cells in majority + assigning a score of 2 for cells with no data

- **6 :Field calculation**
Joining the table containing the previously calculated information to the final grid + assigning a score of 0 for cells with no data

- **7 : Final field calculation**
Summary of the scores calculated for each department in a final field, providing information at the scale of Ile de France

Model for the air pollution (PM2.5) study



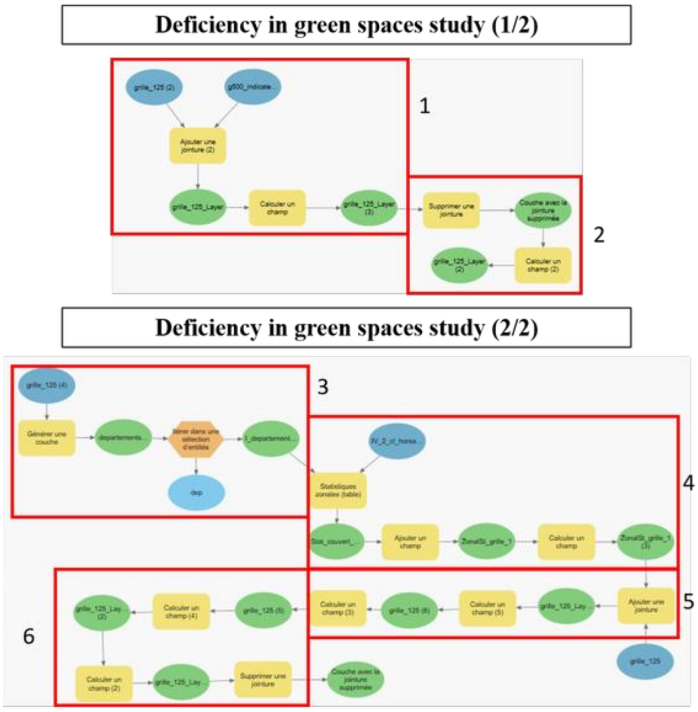
Detail of the steps

- **1 : Reclassification**
Reclassification of the air pollution raster data to convert the data into a score (≤ 5 = 3 ; >5 and ≤ 10 = 2 ; >10 and ≤ 15= 1 ; >15 = 0)

- **2 : Zonal statistics**
Identification of the score predominantly occupying the cells of 125m*125m

- **3 : Field calculation**
Attribution of the score occupying the cells in majority + assigning a score of 1 for cells with no data

- **4 : Calculation of field**
Joining the table containing the previously calculated information to the final grid



Detail of the steps

- 1 : Joining information
Joining of information on deficiency in green spaces from the Paris region institute to the study grid

- 2 : Field calculation
Assignment of a score of 0 for cells with both types of deficiency (equipment and accessibility), a score of 1 for cells with only one, a score of two for non-deficient cells

- 3 : Iteration
Splitting the calculation of the vegetation cover by department to reduce the weight of the operation

- 4 : Zonal statistics and field calculation
Calculation of the vegetation cover in the cells of 125m*125m. A pixel value of 1 indicates the presence of vegetation, a value of 0 indicates its absence. A sum of the pixel is calculated, and then divided by the total number of pixels, resulting in a percentage of vegetation cover of the cells

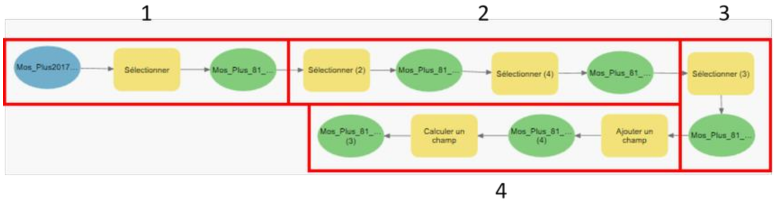
- 5 : Field calculation
Attribution of a score regarding the percentage of vegetation cover (<30% = 0 ; ≥30% and <45% = 1 ; >45% = 2)

- 6 : Field calculation
Sum of the 2 scores (calculated in 2 and 5), and reclassification to contain it between 0 and 2

- 7 : Final field calculation (not shown here)
Summary of the scores calculated for each department in a final field, providing information at the scale of Ile de France

7.9 Appendix 9: Model used to locate sites for depaving

Model used to extract the sites corresponding to the typology of waterproof spaces



Detail of the steps

- **1 : Selection**
Selection of the unbuilt part of the sites (excluding the buildings to only keep their surroudings)

- **2 : Selection**
Selection of the impermeable and potentially impermeable sites only

- **3 : Selection**
Selection of the MOS+ entities corresponding to the typology only

- **4 : Field calculation**
Calculation of the area of the selected sites

7.10 Appendix 10: Model used to study the potential value of depaving with regard to current biodiversity deficiency, exposure to the effects of climate change and risks to health and wellbeing.

Model used to calculate the final score for each scenario and then priorising the actions on the impermeable sites selected in the previous model

Detail of the steps

- **1 : Field calculation**
Sum of the scores of the different criteria studied in the scenario

- **2 : Field calculation**
Assigning a "no data" information to cells located on non-urban areas (farming lands, natural areas, etc)

- **3 : Selection**
Selection of the cells with a low score

- **4 : Intersection**
Selection of the impermeable sites located on the cells with a low score

- **5 : Field calculation**
Attributing a score of 1 to the sites located on a cell with a low score (meaning the site should be priorized for depaving operations)

- **6 : Repetition for each scenario** (not shown here)
These four steps are repeated for each scenario

- **7 : Final field calculation** (not shown here)
Sum of the scores calculated in 4 for each sites. The sites end up with a score going from 0 to 3. The higher the score, the more the depaving operations are to be prioritized

8 LINKS TO WEBSITES CONSULTED

[1] European Environment Agency : Land take in Europe : https://www.eea.europa.eu/data-and-maps/indicators/land-take-3/assessment

[2] No net land take by 2050 ? : https://ec.europa.eu/environment/integration/research/newsalert/pdf/no_net_land_take_by_2050_FB14_en.pdf

[3] Terrestrial Protected Areas Strategy Methodology – SCAP 2009/2019 : https://www.ecologie.gouv.fr/sites/default/files/STRAT%C3%89GIE%20NATIONALE%20POUR%20LES%20AIRES%20PROT%C3%89G%C3%89ES%202030.pdf

[4] Urban forests: https://urban-forests.com/fr/

[5] Urban Tree: An Implementation Guide: https://www.citeverte.com/fileadmin/Citeverte_Ressources/PDF/Publication_Arbre-en-milieu-urbain.pdf

[6] Green grid, blue grid, and all these other grids that we should be concerned about: https://www.sfecologie.org/regard/r72-mai-2017-r-sordello-corridors-ecologiques/

[7] Potential for the removal of impervious soil coverage 2020 https://www.berlin.de/umweltatlas/en/soil/removal-of-impervious-soil-coverage/continually-updated/summary/

[8] No Net Land Take in Île-de-France: https://www.institutparisregion.fr/environnement/zero-artificialisation-nette-en-ile-de-france.html

[9]Nature 2050 program : https://www.nature2050.com/

[10] Ideas for vacant land re-use in Cleveland : https://planning.clevelandohio.gov/ftp/8IdeasForVacantLandReuseCleveland.pdf

[11] Météo France, 2018, The urban heat island : https://www.apc-paris.com/system/files/file_fields/2018/11/07/icu-brochureapc-mf.pdf

[12] Agence d'eau Seine Normandie, janvier 2017, Rainwater press workshop: http://www.eau-seine-normandie.fr/mediatheque/presse/dossier_de_presse/dossier_de_presse_pluvial_V6.pdf

[13] Flood prevention: a partnership policy at all levels: https://www.ecologie.gouv.fr/sites/default/files/19150_plaquette-inondation_light_interactif.pdf

[14] Flood risk management and river restoration: https://professionnels.ofb.fr/fr/node/171

[15] Stormwater management in urban areas: https://www.france-libertes.org/wp-content/uploads/save/pdf/gestion_des_eaux_pluviales.pdf

[16] Trees in urban areas: climate actors in Hauts-de-France: file:///D:/Profiles/deboeuf/Downloads/Guide%2520l%2527arbre%2520acteur%2520du%2520climat%2520en%2520milieu%2520urbain%25202018.pdf

[17] Planning with nature in urban areas: from preconceptions to characterization of environmental, health and economic effects: https://www.ademe.fr/sites/default/files/assets/documents/amenager-with-la-nature-en-ville-8873.pdf
[18] Fine particles: https://www.airparif.asso.fr/les-particules-fines
[19] Health impact of air pollution in France: new data and perspectives : https://www.santepubliquefrance.fr/presse/2016/impacts-sanitaires-de-la-pollution-de-l-air-en-france-nouvelles-donnees-et-perspectives
[20] Ambient (outdoor) air pollution : https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health
[21] Plante & Cité, 2020, Nature in the urban environment and health - state of knowledge " : https://www.youtube.com/watch?v=k6CKJh2KPK8
[22] Greening to reduce local exposure to air pollution: nature-based solutions: https://environnement.brussels/lenvironnement-etat-des-lieux/en-detail/environnement-pour-une-ville-durable/vegetaliser-pour-reduire-localement-lexposition-la-pollution-de-lair-des-solutions-basees-sur-la-nature
[23] Cécile Diguet et Frédérique Prédali, 2021, Chronique de la marche et de l'espace public n° 1, https://www.institutparisregion.fr/mobilite-et-transports/modes-actifs/chroniques-de-la-marche-et-de-lespace-public/gardons-les-pieds-sur-terre/
[24] Services écosystémique rendus par les arbres, modulés selon l'essence - Ecosystem services provided by trees, modulated by species : https://metz.fr/fichiers/2019/12/02/SESAME_Etude_complete.pdf
[25] OASIS book of recommendations : https://www.ac-paris.fr/portail/upload/docs/application/pdf/2020-11/cahier_de_recommandations_oasis_v5_compressed_2.pdf
[26] Website of the association: http://le-transformateur.fr/
[27] Infiltration in question: recommendations for the feasibility and management of stormwater infiltration structures in urban areas: http://www.graie.org/ecopluies/delivrables/55729e_guidemodifie_20090203fin6-2.pdf
[28] Flooding by rising water tables: https://www.georisques.gouv.fr/articles-risques/les-inondations-par-remontee-de-nappe
[29] The level of the groundwater: https://www.eaufrance.fr/le-niveau-des-nappes-souterraines#:~:text=Cette%20mesure%20s'effectue%20gr%C3%A2ce,aide%20d'un%20flotteur
[30] Managing rainwater : principles and practices in the Paris Region : http://www.driee.ile-de-france.developpement-durable.gouv.fr/IMG/pdf/plaquette_-_bien_gerer_les_eaux_de_pluies_-_driee_-_2019_vf_.pdf
[31] What infiltration capacity should be used for the sizing of alternative techniques: https://www.graie.org/graie/graiedoc/reseaux/pluvial/TA_FreinsAvantages/capacite_infiltration_sept20VF.pdf

[32] DREIAT : Subsidence and collapse related to underground cavities: http://www.driee.ile-de-france.developpement-durable.gouv.fr/les-affaissements-et-effondrements-lies-aux-a3773.html#sommaire_2
[33] Land movement (ministère de la transition écologique) : https://www.ecologie.gouv.fr/mouvements-terrain
[34] Should stormwater be infiltrated in urban areas ? : https://www.graie.org/eaumelimelo/IMG/pdf/infiltration_eaux_pluviales_cle0cea51-1.pdf
[35] AgrInnov : Testing indicators of the biological state of soils in relation to agricultural practices: https://www.ofsv.org/images/documentations/rapport_agrinnov_final_8_juin_2016.pdf
[36] Bio-indicators of soil condition: principles and examples of use: https://www.ademe.fr/sites/default/files/assets/documents/bio-indicators_010216.pdf
[37] Procedure available on : https://www.inrae.fr/actualites/agriculture-urbaine-contamination-demarche-evaluer-gerer-risques-sanitaires
[38] Quarry Phytoremediation Gardens under Poissy – parc PPDH : http://www.hekladonia.com/portfolio_item/jardins-de-phytoremediation-hekladonia-csp/
[39] Project to reconstitute fertile soil from recycled materials: https://www.audreymuratet.com/pdf/SolsReconstitues.pdf
[40] Desimperméabilisation des Sols, Services Ecosystémiques et Résilience des Territoires - Soil sealing, Ecosystem Services and Territorial Resilience : https://www.plante-et-cite.fr/projet/fiche/101/desimpermeabilisation_des_sols_services_ecosystemiques_et_resilience_des_territoires_dessert/n:25
[41] The list of species benefiting from the mark as well as the list of producers are available on the site: www.vegetal-local.fr
[42] Clémentine Coiffait Gombault,, Élise Buisson,, Thierry Dutoit, Restoring steppe vegetation by vacuuming and transferring hay, Espaces naturels, janvier 2010, n°29. Available on : http://www.espaces-natural.info/restaurer-vegetation-steppique-aspiration-et-transfert-foin
[43]Plante et Cité study program on mycorrhizae: https://www.jardinsdefrance.org/programme-detudes-plante-et-cite-sur-les-mycorhizes/
[44] Guide to ecological management of public and private collective spaces: https://www.arb-idf.fr/fileadmin/DataStorage/user_upload/guide_gestion_ecologique_natureparif_2016.pdf
[45] Definition of a standardized protocol: https://campanule.mnhn.fr/concepts-et-definitions/
[46] Interest of standardized protocols : https://www.vigienature.fr/fr/programme-vigie-nature-2877
[47] Participatory science: https://www.tela-botanica.org/thematiques/sciences-participatives/
[48] The different participatory science protocols: https://www.vigienature.fr/fr
[49] Sous les pavés : https://souslespaves.ca/

[50] RECARE : soil sealing and land take :
https://www.ecologic.eu/sites/default/files/publication/2018/2730_recare_soil-sealing_web.pdf
[51] What is an ecological corridor ? : http://www.gridverteetbleue.fr/presentation-tvb/foire-aux-questions/qu-est-ce-qu-corridor-ecologique
[52] JORF du 18 aout 2015 : https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000031047578
[53] The « engineer species » - Les organismes « ingénieurs de l'écosystème» : https://www.canal-u.tv/chaines/canal-uved/les-bases-ecologiques-de-l-ingenierie-ecologique/les-organismes-ingenieurs-de-l
[54] The phenomenon of facilitation: when plants help each other to survive: https://www.tela-botanica.org/2017/07/article8209/
[55] How to make new soils: https://www.brgm.fr/fr/reference-project-acheve/comment-fabriquer-nouveaux-sols