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PHAM THI HAI YEN

"Ville intelligente pour la préservation de la biodiversité urbaine "

Soutenue le 28 Septembre 2020 devant le jury composé de

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ABSTRACT

This work aims to develop and implement some monitoring systems in the Scientific Campus of Lille University, North of France in order to observe and evaluate its biodiversity state. The site is representative to a small town with an area of 110 hectares and about 25000 users including students, faculty members and technical and administrative staffs.

This thesis includes four parts.

The first part includes a literature review concerning the role of biodiversity and the impact of urbanization on it as well as the development of Smart City concept and its application in the field of ecology.

The second part creates a framework for urban biodiversity monitoring includes selecting indicators to surveillance, data collection, data analyst, and evaluating the urban biodiversity status.

The third part presents the application of the methodology presented in part 2 to the scientific campus of Lille University. This part presents successively the scientific campus, the indicators used in this work, data collection and analysis and finally the main outcome of this work and recommendations for the preservation of the biodiversity at the scientific campus.

The last part deals with open data, the application of open data for biodiversity research. It also presents how to access and how we can use it in the biodiversity domain.

Keywords: smart monitoring, smart city, urban biodiversity, biodiversity preservation, biodiversity indicator, digital technology in ecology, sensors networking, open data.

RÉSUMÉ

Le travail vise à développer la prise en compte et les méthodes de suivi de la biodiversité en ville dans des projets de smart city en prenant ici comme démonstrateur e Campus Scientifique de l'Université de Lille, Nord de la France. Le site est représentatif d'une petite ville d'une superficie de 110 hectares et d'environ 25 000 utilisateurs dont des étudiants, des professeurs et du personnel technique et administratif.

Cette thèse comprend quatre parties.

La première partie comprend un état de l'art concernant le rôle de la biodiversité et l'impact de l'urbanisation sur celle-ci ainsi que le développement du concept Smart City et son application dans le domaine de l'écologie.

La deuxième partie crée un cadre pour le suivi de la biodiversité urbaine qui comprend la sélection d'indicateurs de surveillance, la collecte de données, l'analyse de données et l'évaluation de l'état de la biodiversité urbaine.

La troisième partie présente l'application de la méthodologie présentée dans la deuxième partie au campus scientifique de l'Université de Lille. Cette partie présente successivement le campus scientifique, les indicateurs utilisés dans ce travail, la collecte et l'analyse des données et enfin le principal résultat de ce travail ainsi que les recommandations pour la préservation de la biodiversité sur le campus scientifique.

La dernière partie traite des données ouvertes: l'application des données ouvertes, leur accessibilité et leur utilisation dans le domaine de la biodiversité.

Mots-clés: surveillance intelligente, ville intelligente, biodiversité urbaine, préservation de la biodiversité, indicateur de biodiversité, technologie numérique en écologie, mise en réseau de capteurs, données ouvertes

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Introduction

Problem statement

While urban areas only constitute around 3% of the global terrestrial area (Gordon McGranahan, Deborah Balk, 2007) they contain the majority of the human population, they are also center of human action. According to the United Nation and the World Bank global statistics, more than half of the urban population lives in cities with less than 500.000 inhabitants, and just one-eighth lives in cities bigger than ten million inhabitants (London, Tokyo, Mumbai, Shanghai etc.). The global urban population is expected to grow by 63 %t between 2014 and 2050 ï compared to an overall global population growth of 32 % during the same period. Megacities with over 20 million inhabitants will see the fastest increase in population ï and at least 13 new megacities are expected by 2030, in addition to the 28 existing today. The fastest growing urban centers contain around a million inhabitants, and are located in the lower-middle-income countries in Asia and Africa - according to global statistics of the UN and the World Bank. These trends lead to emissions and consumption of natural resources that generate global impacts, for instance already a decade ago urban activities were estimated to account for 78% of carbon emissions, 60% of residential water use, and 76% of wood used for industrial purposes (Brown et al, 2001).

Thus, cities provide the daily living environment for a growing part of the worldôs population. However, cities are currently facing numerous challenges related to climate change, aging infrastructure and growing urbanization. The importance and role of cities are increasing recognized - the future of cities will greatly impact all of our futures. Increasing the livability in urban environments and self- sufficiency of cities is thus a crucial step towards increasing sustainability of local and global developments. Nature provide services to humans with everything from food, to feelings of joy and protection against storms. Much of the well-being of future generations will depend on the choices we make today. It is thus crucial to base urban development trajectories on supporting and enhancing ecosystem functions, which can also provide cost-effective solutions. While these rapid and extensive changes lead to considerable challenges for biodiversity, they also create new opportunities to protect nature in cities and beyond, and enhance the values that nature in cities generates for people.

Urban areas represent important potential host sites for a large number of animal and plant species However, they are currently facing numerous challenges, as stated above, which could have dramatic consequences such as reduction of green areas, space fragmentation and species loss or threatened. The rapid urbanization threatens urban biodiversity such as combat climate change and urban heat islands, recharge groundwater supplies, and restore habitat for native fish and wildlife.

Nature in cities hosts to a large number of species and provides great benefit to humans. Indeed, nature is crucial for human wellbeing and sustainable development by regulating the micro-climate, cooling by canopy, creating urban landscape, maintenance ecosystem services function and improving the environmental quality for city dwellers as well. Considering the importance of biodiversity for the quality of life as well as for the biological and environmental equilibrium, cities should take great care for the protection and enhancement of the biodiversity.

Despite the numerous benefits that urban biodiversity offer to cities, statistics show that these areas are on the decline in several cities across the world. For example in Europe, a study on changes in land-use in 25 European cities found between 7.3 and 41 % of green areas lost to different land-uses (European Environment Agency, 2002). Similarly, in USA, a study on land-use change in 274 metropolitan areas revealed about 1.4 million hectares of green areas converted to different land developments (McDonald et al, 2011). The situation in developing countries is even more critical as studies show that most urban green areas in these areas have excessively been destroyed to make way for different human activities. Other studies focusing of developing countries produced similar results with urban green spaces found to be depleting at an alarming rate (Moretto & Gomes, 2011; Yusof et al, 2012). These rapid decrease in the amount of the urban green areas is worrying. This is because the problem is bound to get worse in the years ahead since intensive human activities and infrastructural developments which often destroy these spaces are much concentrated in urban areas.

It can be seen the importance of biodiversity and the loss of the surface of the areas hosting this biodiversity as well. So it needs accurate, quantified information about this biodiversity and the loss of biodiversity. Thus, developing effective methods to conservation urban biodiversity is crucial. The preservation of biodiversity for city is a major goal in nature conservation, but measuring the total biodiversity of a site or a region is so complex, costly and taking time because of the huge variety of parameters of the biodiversity as well as the long-term timescale. The biodiversity conservation requires first of all monitoring in order to scan the current situation, to track the biodiversity evolution and to take the appropriate measures to stop the biodiversity degradation and even more to ensure its development. It also requires strategies based on collection of complex data at different timescales as well as the implementation of sustainability and resiliency approaches. To assess the urban biodiversity status, it needs to determine the indicators after that selecting the method to monitoring then implementing monitoring and final assessing the outcome.

The new Information and Communication Technologies (ICT) applied in urban networks has generated the concept of a Smart City, where the infrastructure components become more intelligent, interconnected and efficient. Thanks to the digital technologies, the Smart City solution could help to solve urban complex problems in particular those related to transportation, energy, water and pollution. Based on the latest development in the biodiversity monitoring sensor technology and online data acquisition systems, the traditional biodiversity turned to be smart. This technology could enable cities to create a smart monitoring to track trends of in urban biodiversity change. It provides also valuable data for the management, the exploitation and the conservation the biodiversity in cities. Smart monitoring will help to take the right measurements to stop biodiversity degradation and even more to ensure its development.

Analysis of previous works?

Smart city development has emerged as a pertinent response to the challenges and created by rapid urbanization. It deploys intelligent urban systems to serve socio-economic and ecological development, to improve quality of life and to address social instability challenges. The Smart City initiatives can help to overcome the limitations of traditional urban development, in particular the management of urban infrastructure systems in silos. The siloed system leads to poor information sharing between systems, functions and stakeholders, such as citizens, businesses, government and civil society organizations. Smart City initiatives leverage data and services offered by digital technologies, such as cloud computing, open data sets, or the Internet of Things to help connect city stakeholders, improve citizen involvement, offer new or enhance existing services and provide context-aware views on city operations. A city-wide digital infrastructure can help to integrate different urban infrastructure systems including energy, water, sewage or transport, and enable efficient management, control and optimization of such systems. These initiatives also address environmental and human-capacity issues (Estevez et al., 2016)

The rapid development of the Smart City model could help in monitoring the biodiversity in the city. Increasingly complex research questions and global challenges (e.g., climate change and biodiversity loss) are driving rapid development, refinement and uses of technology in ecology. This trend is spawning a distinct sub discipline, here termed ñtechno-ecology.ò It highlights recent ground-breaking and transformative technological advances for studying species and environments: bio-batteries, low- power and long-range telemetry, the Internet of things, swarm theory, 3D printing, mapping molecular movement, and low-power computers. These technologies have the potential to operate great change in ecology by providing ñnext-generationò ecological data, particularly when integrated with each other. It could comply diverse range of biodiversity requirements (e.g., pest and wildlife management, informing environmental policy and decision making) (Allan et al., 2018).

Research and developments needs

The rapid urbanization leads to the urban biodiversity related problems such as reduction of green areas, space fragmentation and species loss or threatened. These changes have an impact on the quality of life of city dwellers as well as on the biological and environmental equilibrium. The question is how the smart city solution could help to improve and manage urban biodiversity? The implementation of the Smart City solution requires smart monitoring system to track the biodiversity as well as the causal factors, tools to collect useful, analysis tools to analyze the collected data in order to understand and take decisions, and finally a platform for the coordination of tasks related to the smart management.

My contribution

My contribution on the consideration of urban biodiversity in a smart city approach includes the following:

- Identification of indicators related to urban biodiversity as well as to causal factors that affect the biodiversity.
- Design of a smart-technology monitor system for the urban biodiversity indicators as well as its causal factors

- Development of analysis tools (Artificial intelligence, Engineering,..) to assess the biodiversity and its relation with causal factors
- Implementation of the methodology on the Scientific City Campus of Lille University.
- Proposal of recommendation about the use of the Smart City solution for the urban biodiversity protection.
- Proposal of recommendation applying of open data for biodiversity research

Organization of the thesis

This present work aims to develop and implement some monitoring systems in the Scientific Campus of Lille University in order to observe and assess its biodiversity state. The site is representative to a small town with an area of 110 hectares and about 25000 users including students, faculty members and technical and administrative staffs. It was constructed between 1964 and 1966. Later on, some buildings were renovated, while others were constructed. The campus includes 145 buildings with a total construction area of 325,000 m². Buildings are used for research, teaching, administration, studentsô residences and entertainment activities. The campus is deserved by 100 km of urban networks: drinking water, stormwater, sanitation, electrical grid, public lighting, district heating and roads.

This thesis is divided into four chapters in addition to a main introduction and a general conclusion.

The first chapter includes a literature review. The review describes the role of biodiversity and impact of urbanization on it as well as the development of Smart City concept and its application in the field of ecology.

The second chapter creates a framework for urban biodiversity monitoring includes selecting indicators to surveillance, data collection, data analyses and assessment of the urban biodiversity status.

The third chapter presents the application of the methodology presented in chapter 2 to the scientific campus of Lille University. Since the area of the campus is very small to be considered as an ecosystem for the biodiversity evaluation, this application aims at exploring the application of the methodology presented in the second chapter. This chapter presents successively the scientific campus, the indicators used in this work, data collection and analysis and finally the main outcome of this work and recommendations for the preservation of the biodiversity at the scientific campus.

The chapter 4 deals with open data and their application for biodiversity research. It also presents how to access and how we can use it in biodiversity domain.

Chapter 1:

Urban biodiversity preservation - State of the art

1 Introduction

Urban biodiversity provides a series of benefits (commonly termed ecosystem services) to cities ranging from the more directly perceived, such as water supplies and recreation facilities (parks) to less tangible effects of large biodiversity areas, such as hosting species which may help cure diseases or contribute to long-term climate stability (Puppim de Oliveira et al., 2011). For example, urban green areas such as parks and vegetation help microclimate regulation, tree canopy may contribute to reduce the urban heat island effect and save large amounts of energy used in air conditioning. It reduces pollution, improves air quality and enhances human well-being. Many researches showed that improvement of urban biodiversity impact directly both physical and mental health of citizens.

The increasing rate of urbanization, industrialization and population growth in developing countries over the last decades has forced society to consider whether human beings are changing the conditions that are essential to life (UN Habitat, 2011). This disturbing trend has led to more calls on cities to advance sustainable land use to make cities and the world a better place to live in. Unfortunately, there is a deficiency of planning tools for monitoring and supporting decisions regarding urban biodiversity protection. The biodiversity conservation requires first relevant monitoring in order to scan the current situation, to track the biodiversity evolution as well its causal factors.

1.1 Role of urban biodiversity

Biodiversity is crucial to the planet equilibrium, human wellbeing and sustainable development (Quijas & Balvanera, 2013). It regulates and preserves the quality of soil and water. It contributes to the reduction of our vulnerability to natural hazards such as flood and fires. Its loss has negative impact on human health and security of food and energy and could disturb ecosystem function. Cities are huge hubs for ecosystem services with large environmental impact (Elmqvist et al., 2015).

Urban biodiversity is the variety or richness of living organisms, including genetic variation and habitats found in and on the edge of human settlements. Species range from rural fringe to urban core. At the landscape and habitat level, it includes:

- Remnant vegetation (remnant habitats of native plant communities, rock faces).
- Agricultural landscapes (meadows, arable land).
- Urban-industrial landscapes (wastelands and vacant lots, residential areas, industrial parks, railway areas, brownfields).
- Ornamental gardens and landscapes (formal parks and gardens, small gardens and green spaces) (Güneralp & Seto, 2013)

The diversity of plants and animals in urban landscape shows interesting patterns:

- The age of the city affects species richness; old cities have more species than young cities.
- Diversity may correlate with economic wealth. For example, in Phoenix, USA, plant and bird diversity in urban neighbourhoods and parks shows a significant positive correlation with median family income.
- 20% of the worldôs bird species and 5% of the vascular plant species are located in cities.
- Around 70 % of the plant species and 94% of bird species found in urban areas are native of surrounding region (CBD, 2012)

Biodiversity provides indirect benefits to human beings. These include social and cultural values, ethical values, aesthetic values, option values and environment service values. These environment service values such as the most important benefit of biodiversity is maintenance of environment services which includes(i) Carbon dioxide fixation through photosynthesis; (ii) Maintaining of essential nutrients by carbon (C), oxygen (O), Nitrogen (N), Sulphur (S), Phosphorus (P) cycles; (iii) Maintaining water cycle and recharging of ground water; (iv) Soil formation and protection from erosion; (v) Regulating climate by recycling moisture into the atmosphere and (vi) Detoxification and decomposition of waste.

An ecosystem is an array of living things (plants, animals, and microbes) and the physical and chemical environment with which they interact. Examples of ecosystems include forests, wetlands, grasslands, streams, and estuaries. Healthy ecosystems provide the conditions and processes that sustain human life. In addition to provide goods such as foods and medicines, ecosystems also provide us services, such as purification of air and water, the binding of toxins, decomposition of wastes, mitigation of floods, moderation of storm surges, stabilization of landscapes, and regulation of climate. We tend to take these services for granted and do not generally recognize that we can- not live without them, nor can other life on this planet. Healthy ecosystems deliver life-sustaining services for free and in many cases on a scale so large and complex that humanity would find it practically impossible to substitute for them. With respect to complexity, we often do not know which species are necessary for the services to work, what numbers they must be present in, and whether there are ñkeystoneò species for ecosystem services. Disruption of these natural services can have catastrophic effects. For example, if natural pest control services ceased or populations of bees and other pollinators crashed, there could be major crop failures. If the carbon cycle were badly disrupted, rapid climate change could threaten whole societies. From an economic standpoint, numerous examples illustrate that ecosystem services that have been diminished by human activities can be restored for a fraction of the cost of building artificial substitutes (Chivian, 2002).

1.2 Impact of urbanization on urban biodiversity

The rapid urbanization causes increased pressure on biodiversity, with dramatic consequences such as reduction of green areas, space fragmentation and species loss or threatened transformation.

1.2.1 Change in land-use

Change in land-use can alter ecosystem services. Globally, the conversion of native grasslands, forests and wetlands into croplands, tree plantations and developed areas has led to vast increase in production of food, timber, housing and other commodities, but with negative impact on ecosystem services and biodiversity (Arico et al., 2005). Humans may destroy natural landscapes with consequences on habitat destruction and reconversion of natural habitat to human use, which are not necessarily compatible with native organisms.

The most direct impact of urbanization on biodiversity is the change in land use? Urban growth is clearly a significant global driver of land-use conversion and deforestation. Urban areas occupy approximately 3% of the Earthôs land surface (Gordon McGranahan, Deborah Balk, 2007), although the actual number varies significantly depending on the definition of urban and the spatial grain of analysis (A Schneider, 2009; Karen C. Seto, Roberto Sánchez-Rodríguez, 2010)

The spatial correlation between urban growth and endemism means urban growth has already impacted biodiversity significantly (Mcdonald et al., 2008) analyzed the implications of urban areas *circa* 1995 for ecoregions (David M. Olson, Eric Dinerstein, Eric D. Wikramanayake, Neil D. Burgess, George V. N. Powell, Emma C. Underwood, Jennifer A. D'amico, Illanga Itoua, Holly E. Strand, 2001), protected areas across the world (www.wdpa.org), and rare species (Ricketts et al., 2005). They found the effect of urban areas to be concentrated in certain localities. The majority of terrestrial ecoregions (comprising 62 % of the Earth's land surface) are currently less than 1 % urbanized and will experience little change through 2030. However, around 10 % of terrestrial vertebrates are in ecoregions that are heavily impacted by urbanization, even though these ecoregions only represent 0.3 % of the Earth's land surface. These ecoregions are concentrated along coasts and on islands, which are generally areas of high endemism (Ricketts et al., 2005). In addition, urban areas seem to have increased the threat to survival of certain vertebrate species, especially those having smaller ranges (Güneralp & Seto, 2013).

1.2.2 Urban pollution

Urban pollution concerns the air, soil and water. Air pollution causes decline of majority of species. Plants are more affected than animals by the pollution. Tickle et al, (1995) showed that more than 1,300 species were threatened in Europe due to acid deposition in the 1990s, including 11 mammals, 29 birds, 10 amphibians, 398 higher plants, 305 fungi, 238 lichens and 65 invertebrates, providing the most detailed survey to date. Water pollution results from various sources, such as sewage leak, industrial spills or direct discharge in water bodies, biological contamination and farm runoff. Water contamination has serious negative effects on all species. The degradation of local habitats through human activities causes downstream effects like leaching of harmful chemicals from mines into the water table. Water pollution can have effects on the reproductive viability of organisms. Soil pollution is mostly due to human activities such as heavy industries or use of pesticides in agriculture. Absorption of pollution by the plants may lead to alter metabolism and introduce pollution in the food chain. These processes occur with microorganisms and arthropods in a given soil environment. This may destroy some layers of the primary food chain and thus has a negative effect on predator animal species. Small life forms may consume harmful chemicals which may then be passed in the food chain to larger animals so this may lead to increased mortality rate and even animal extinction.

Noise pollution is harmful and annoying to humans and animals. It can result from transportation, construction and human activities such as sport events or concerts. Halfwerk et al. (2011) showed that high traffic noise has an impact on avian reproduction by smaller clutches and fewer fledged chicks.

Light pollution affects many groups of animals, especially birds and nocturnal insects (Green et al., 2005). Patterns of reproduction can also be disturbed by light extension to new places.

1.2.3 Alien species

Alien species are plants, animals, pathogens and other organisms that are non-native to ecosystems, and which are expected to cause a net economic, environmental or social harm or adversely affect human health (Kareiva et al., 2018). They are introduced by humans intentionally or unintentionally into urban environment. This can negatively affect the ecosystem because the new species may out-compete native organisms and displace them. The impact could concern entire habitat. For example, when the Asian chestnut blight fungus virtually eliminated American chestnut from over 180 million acres of eastern United States forests in the first half of the 20th century, it was a disaster for many animals that were highly adapted to live in forests dominated by this tree species. Similarly, the Australian paperbark tree has replaced native plants, such as sawgrass, over 400,000 acres of South Florida, because it has a combination of traits that increases fire hazards. Many birds and mammals adapted to native plant community declined in abundance as paperbark spread (CBD, 2012).

1.2.4 Construction activity

Construction activities have replaced the nature surfaces with artificalization and waterproofing of soil. It causes fragmentation and reduction of natural habitats, which could lead to the disappearance of some species in the urban environment (Puppim de Oliveira et al., 2011). Many species are unable to thrive in their former habitats due to the fundamental environmental changes caused by this reason. Consequently, any construction project in urban area should be based on analysis of its impact in urban biodiversity.

1.2.5 Urban heat island

An urban heat island occurs when a city experiences much warmer temperatures than nearby rural areas. The difference in temperature between urban and less-developed rural areas has to do with how well the surfaces in each environment absorb and hold heat.

In rural areas, vegetation and open land typically dominate the landscape. Trees and vegetation provide shade, which helps lower surface temperatures. They also reduce air temperature through evapotranspiration, in which plants release water to the surrounding air, dissipating ambient heat. In contrast, urban areas are characterized by dry, impervious surfaces, such as conventional roofs, sidewalks, roads, and parking lots. The change in ambient temperature and humidity could affect the health of species in cities and could cause their disappearance or departure to other familiar areas.

Urban heat island results from construction and urban activities such as material that stores heat, road traffic, domestic heating, greenhouse gases, etc....Today, the majority of cities are around 2°C warmer than surrounding rural areas. Commercial and high density residential areas are hotter by 5 to 7°C than rural areas (Bonan et al, 2002). Urban heat island is caused by different factors: (1) meteorological factors, such as cloud cover, wind speed and humidity; (2) urban parameters, such as city and population size, anthropogenic heat and urban canyon.

1.2.6 Flood

Flood risk increases with urbanization activity. The construction activity results in large-scale ground impermeabilization, which induces important increase in the water runoff and could lead to flood. In addition, interception of rainfall by trees, other vegetation, and permeable soils is crucial in reducing the pressure on the drainage system and in lowering the risk of surface water flooding (Science Communication Unit, 2013). Urban landscapes with 50ï 90% impervious ground cover can lose 40ï 83% of incoming rainfall to surface runoff whereas forested landscapes only lose 13% of rainfall input from similar precipitation events (Marie, 2014). Flood has highly negative impact on biodiversity. It causes large scale habitat destruction, species destruction or migration, water and soil pollution and sediment transportation. This impact is generally catastrophic for the biodiversity.

1.3 Smart city

1.3.1 Concept and definition

The Smart City uses smart technology to build eco- and socio- friendly cities. Many cities have started the process of smart transformation by using technologies in transport, energy, water and social services. This concept has emerged as a response to challenges created by the rapid urbanization (Estevez et al., 2016; Sofeska, 2017)

According the data of Web of Science (figure 1) the Smart City concept meets an important scientific development since 2010. The number of published papers increased rapidly nearly 40 times from 75 in 2010 to around 2,800 in 2018. For urban biodiversity and biodiversity monitoring, it also got a raise 3 to 4 times. However, the number of articles on smart city and biodiversity is quite rare, with only 16 in the same period.

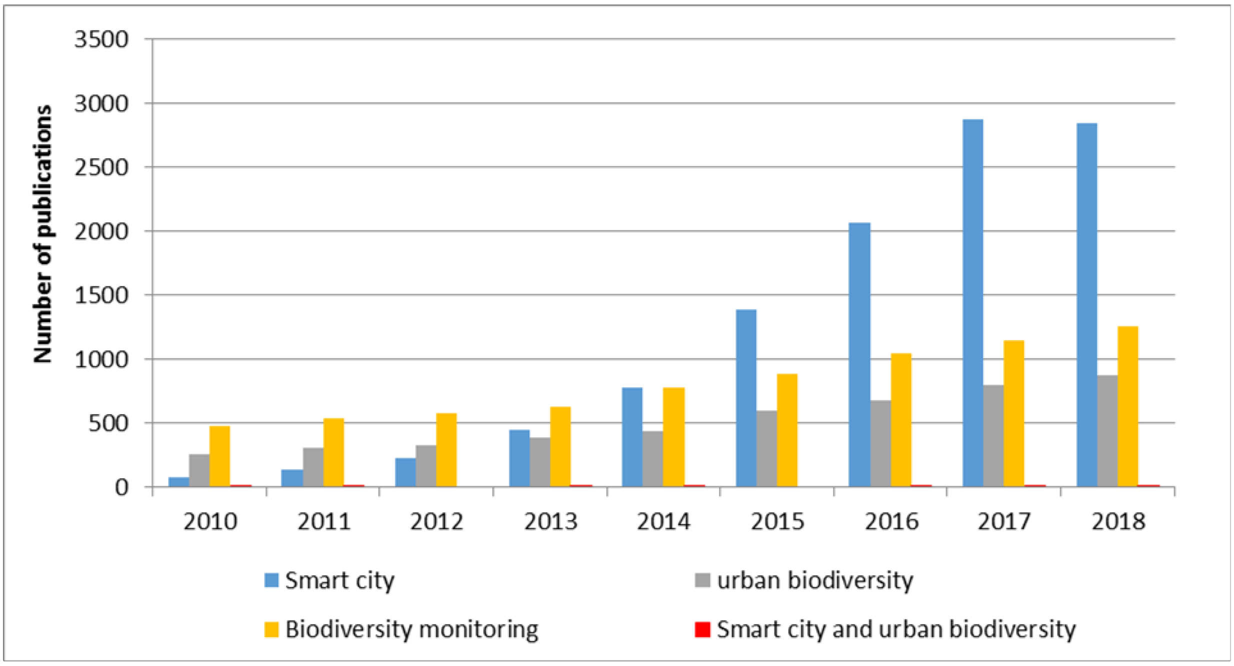


Figure 1.1: Statistic of Number of publications about Smart City, urban biodiversity monitoring from 2010-2018 Source (Web of Science)

It shows that the concept of the smart city combines the use of ICT (Information and communication technology) in cities, the optimisation of urban processes, the optimal management of urban infrastructures, the improvement of the quality of life as well as the integration of urban activity, services with citizens. The relationship with the environment is well established, but generally with focus on pollution and energy performances. The relationship with the biodiversity is missing.

1.3.2 Dimensions of a Smart City

Albino et al., (2015) pointed the following dimensions of the Smart City: mobility, public security, utilities, and cityô infrastructure. They indicate that these systems must work and be managed together. The Centre of Regional Science at the Vienna University of Technology has determined six key dimensions for the Smart City; smart people, smart living, smart environment, smart economy, smart mobility, and smart governance (Albino et al., 2015).

According to Cassandras (2016) ñThe Smart City is connected to urban environment with a new generation of innovative services for transportation, energy distribution, healthcare, environmental monitoring, business, commerce, emergency response, and social activitiesò. Smart City also refers to ña city well performing in a forward-looking way in these six characteristics, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizensò (Purnomo et al, 2016) (figure 1.2):

- Smart Economy refers to the overall competitiveness of a city through innovative spirit, productivity and flexibility of labour market.
- Smart People setting up the human capital and social interaction between people via affinity for life - long learning, participation in public life, creativity and flexibility.
- Smart Government encourages participation of citizens in governance through participation in decision making and transparent governance.
- Smart Mobility, prepares transportation and infrastructure to support local ICT accessibility, ICT infrastructure, sustainable, innovative and safe transportation systems.
- Smart Environment maintains natural resources through the attractiveness of natural condition, environmental protection and sustainable resource management.
- Smart Living improves the Quality of Life by providing cultural facilities, good health conditions, good housing quality and social cohesion.

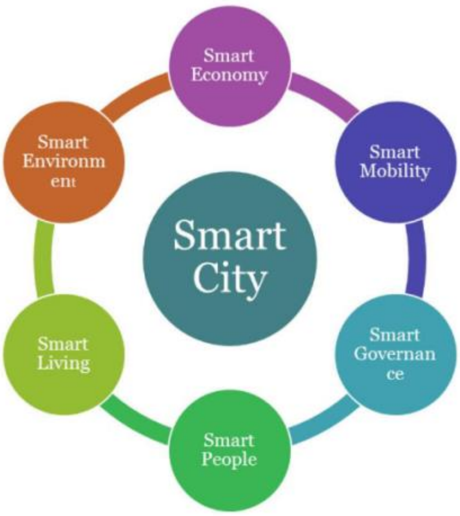


Figure 1.2: Six Characteristics of the Smart City Model Source: (Purnomo et al., 2016)

According to (Manville et al., 2014) ñThe most successful Smart City strategies might be expected to adopt a multi-dimensional approach to maximise such synergy and minimise negative spill-over effects, as might happen, for example, if a Smart Economy strategy were prioritised which was detrimental to the environment. For this reason, we might expect to see more than one characteristic present in the most successful Smart Citiesò (Manville et al., 2014). They describe six characteristics of the smart city (table 1.2).

While Smart City solution may be used to monitor various environmental parameters, such as air pollution, temperature, vibrations, noise (Zanella et al, 2014) and make humans consume less energy and water, and even reduce greenhouse gas emissions (Naphade et al., 2011), it yet has to be sensitized to social- ecological relations in the complex webs of life of which we are all part (Colding & Barthel, 2017).

Table 1.1: The Smart City characteristics Source: (Manville et al., 2014).

Characteristic	Description
Smart Governance	By Smart Governance we mean joined up within-city and across-city governance, including services and interactions which link and, where relevant, integrate public, private, and civil and European Community organisations so the city can function efficiently and effectively as one organism. The main enabling tool to achieve this is ICT (infrastructures, hardware and software), enabled by smart processes and interoperability and fuelled by data. International, national and hinterland links are also important (beyond the city), given that a Smart City could be described as quintessentially a globally networked hub. This entails public, private and civil partnerships and collaboration with different stakeholders working together in pursuing smart objectives at city level (http://www.tema_lab.unina.it/smart-city-2/the-characteristics-smart/). Smart objectives include transparency and open data by using ICT and e-government in participatory decision-making and co-created e-services, for example apps. Smart Governance, as a transversal factor, can also orchestrate and integrate some or all of the other smart characteristics.
Smart Economy	By Smart Economy we mean e-business and e-commerce, increased productivity, ICT-enabled and advanced manufacturing and delivery of services, ICT-enabled innovation, as well as new products, new services and business models. It also establishes smart clusters and eco-systems (e.g. digital business and entrepreneurship). Smart Economy also entails local and global inter-connectedness and international embeddedness with physical and virtual flows of goods, services and knowledge (http://www.tema_lab.unina.it/smart-city-2/the-characteristics-smart/).
Smart Mobility	By Smart Mobility we mean ICT supported and integrated transport and logistics systems. For example, sustainable, safe and interconnected transportation systems can encompass trams, buses, trains, metros, cars, cycles and pedestrians in situations using one or more modes of transport. Smart Mobility prioritises clean and often non-motorised options. Relevant and real-time information can be accessed by the public in order to save time and improve commuting efficiency, save costs and reduce CO2 emissions, as well as to network transport managers to improve services and provide feedback to citizens. Mobility system users might also provide their own real-time data or contribute to long-term planning.

Smart Environment	By smart environment we include smart energy including renewables, ICTenabled energy grids, metering, pollution control and monitoring, renovation of buildings and amenities, green buildings, green urban planning, as well as resource use efficiency, re-use and resource substitution which serves the above goals. Urban services such as street lighting, waste management, drainage systems, and water resource systems that are monitored to evaluate the system, reduce pollution and improve water quality are also good examples (http://www.tema_lab.unina.it/smart-city-2/the-characteristics-smart/).
Smart People	By Smart People we mean e-skills, working in ICT-enabled working, having access to education and training, human resources and capacity management, within an inclusive society that improves creativity and fosters innovation. As a characteristic, it can also enable people and communities to themselves input, use, manipulate and personalise data, for example through appropriate data analytic tools and dashboards, to make decisions and create products and services (http://www.tema_lab.unina.it/smart-city-2/the-characteristics-smart/).
Smart Living	By Smart Living we mean ICT-enabled life styles, behaviour and consumption. Smart Living is also healthy and safe living in a culturally vibrant city with diverse cultural facilities, and incorporates good quality housing and accommodation. Smart Living is also linked to high levels of social cohesion and social capital (http://www.tema_lab.unina.it/smart-city-2/the-characteristics-smart/).

1.4 Biodiversity monitoring

1.4.1 Overview

Monitoring concerns collection and analysis of repeated observations or measurements to assess changes in conditions and progress towards meeting a management objective (Edwards, 2001). Monitoring of biodiversity and related parameters allows the detection, quantification and forecasting of trends in the state of biodiversity and to measure compliance with standards and effectiveness of management. It also allows understanding of causal relationships between human actions and biodiversity. By allowing informed decision-making, monitoring provides a fundamental basis for effective management and governance of biodiversity (Marchetti, 2005).

Monitoring the state of, and changes in, biodiversity can help to assess and improve conservation outcomes (Lindenmayer et al., 2012). But monitoring is expensive and resources for conservation are limited and time-consuming. (Balmford et al, 2003; McCarthy et al., 2012; Waldron et al., 2013). Targeted monitoring strategies for specific management decisions naturally lead to wonder what to monitor. Some researchers propose direct monitoring of species to detect declines in responses to threats (e.g. Maxwell & Jennings, 2005; Woinarski et al., 2010; Williams et al, 2016;), while others recommend using proxies to measure elements of biodiversity or monitor threats that are too difficult to monitor directly (Fleishman & Murphy, 2009; McGeoch et al., 2010; Stoms, 2000). These proxies are known as biological or ecological indicators (Heink & Kowarik 2010). Whatever the approach chosen, to select the best monitoring strategy, we need systematic approaches that evaluate the benefit of competing strategies. Failing to do this may lead to the selection of inefficient monitoring strategies that do not change or improve management decisions, or worse, lead to unexpected or potentially harmful consequences for biodiversity (see Lindenmayer et al. 2013 for example). As such, monitoring may fail to show progress towards management targets, or effectively inform management decisions (Lyons et al, 2008).

1.4.2 Purpose of monitoring

The purpose of indicators and monitoring is succinctly summed up by the United States National Academy of Sciences (2000, p. 1) (Council, 2000):

Developing indicators and monitoring them over time can help to determine whether problems are developing, whether any action is desirable or necessary, what action might yield the best results, and how successful past actions have been. To develop and implement sound environmental policies, data are needed that capture the essence of the dynamics of environmental systems and changes in their functioning. There are therefore three separate monitoring purposes:

1. Monitoring for changes in ecological status and integrity. Here the question is: Are things changing and to what extent? It provides the bulk of the figures and indices for state of the environment reporting, the policy development and some of the material for organizational audit. The main risks are spending too much effort in collecting data that have little intrinsic value, are not used for policy, but look credible in reports.

2. Monitoring for management action. This sort of monitoring answers questions such as: When should we intervene? What might we need to do? Have we been successful? How can we do better? Better? When aggregated and assessed, the data provide basic information for audit purposes. The main shortcoming of this sort of monitoring is failing to adequately analyze and report the results, and therefore not actually using them in decision making.

3. Monitoring for fundamental understanding. This type of monitoring attempts to answer the questions: Do we understand what is going on? How can we predict the future? Can we apply his knowledge to biodiversity management? It is thus focused on multiple or generalized objectives and often the collection of long time-series (relative to the time- constant of the organism or phenomenon) data. Sustaining this type of monitoring is the main problem. Funding is often under pressure, it often depends solely on the enthusiasm of a few individuals and, especially when continued on without any visible output, can be viewed as competing with apparently more relevant projects.

Effective monitoring for conservation decision-making when resources are limited needs to focus specifically on gaining information that informs and improves management outcomes (McDonald-Madden et al., 2010). Long-term monitoring programs like the UK Breeding Bird Survey (Robinson et al, 2016) monitor species to assess changes and establish baseline data against which efforts to reduce biodiversity loss may be evaluated. This type of monitoring can indicate directionality or magnitude of observed trends, providing invaluable ecological insights (Wintle et al, 2010). Monitoring species, as well as threats, to establish statistical associations between trends in numbers and threats can reveal the relative importance of threats and the associated management actions (e.g. Siriwardena et al, 2008). Alternatively, species can be monitored in combination with experimental manipulations of the threats, such as controlling predator abundance or the degree of disturbance, to learn about the consequences of management (U.S. Fish & Wildlife Service, 2015; Walters & Holling, 1990). In this study, we the aim is to assess/use? the monitoring as a means of quantifying the effectiveness of management in multi-species, multi-threat systems.

There are many examples of monitoring or modelling the response of species to multiple threats and their management (e.g. Stephens et al, 2003; Siriwardena et al., 2008). However, these studies assess the effectiveness of alternative management rather than monitoring actions. There is also extensive literature on techniques to assess priorities the most effective actions for management, such as cost-effectiveness analysis, project prioritization protocols, and management strategy evaluation (e.g Joseph et al., 2009). Similar studies for evaluating the effectiveness of alternative monitoring actions for management decision-making are limited (but see Runge et al., 2011; Tulloch et al., 2011). In particular, few studies assess the effectiveness of alternative monitoring strategies (such as monitoring species only versus combining experimental manipulations with monitoring) to resolve uncertainty to inform threat management. We also know little about the determinants of the best species to monitor to inform threat management.

1.4.3 Types of monitoring

We recognize clusters of monitoring activities sometimes centered on a particular purpose but often spanning more than one and propose the following types as a framework.

In addition to the various purposes monitoring can be used for, there is an array of types of monitoring. Short definitions of different types are given here from Wilson et al., 2005.

ÅInventory monitoring ï the goal is a comprehensive documentation of the elements and complete coverage of the area. No particular re-measurement time frame is given. Includes rapid assessments and casual surveys.

ÅStatus and trend monitoring ï regular re-measuring of elements is intended from the outset. Plots are often used, but not essential. The target may be an organism, or a range of ecological elements.

ÅSurveillance monitoring ï is focused on a few organisms or processes where the problem is well understood and the threat is immediate. It is based on specialised survey techniques to detect presence. Routine biosecurity surveillance is an example.

ÅManagement monitoring ï can be divided into two categories:

Pre-intervention ï is made up of ótriggerô and óassessmentô monitoring, to detect and assess a pressure or problem. Trigger monitoring determines if intervention is necessary and assessment monitoring quantifies the success of the intervention.

Post-intervention ï is óactionô and óoutcomeô monitoring. Action monitoring assesses the success of the management action in reducing the pressure or altering the immediate situation. This is also called óresultô monitoring. Outcome monitoring assesses the improvements to biodiversity as a result of the action taken.

ÅResearch monitoring ï is often an intensive, multi-dimensional, long term research programme. All long-term ecological research involves careful investigations, usually at sites chosen to provide unambiguous results. Internationally, such sites are valued as Long-Term Ecological Research (LTER) areas and allocated sustaining funding. Twenty-five countries now have formal LTER networks. Mainland Islands in New Zealand are forming a new core around which LTER-like activities may develop. However, Mainland Islands are not representative of the New Zealand landscapes as a whole and at the very least would have to be supplemented by more typical sites. Historically, in New Zealand, commitment to LTERs tends to fluctuate, and usually it is only the dedication of a few inspired individuals that keeps them going. That situation will have to change if long-term ecological research is to play an important role in the future.

Long-term value of monitoring data

It is often assumed that monitoring and inventory data increase in value with time, and loss of any data is to be regretted. However, this is not true for many types of monitoring and the costs of archiving have to be considered against the changing value of information with time. From a management point of view, information value falls exponentially with time since last measurement (relative to the time constant of the organism or process). On the other hand, certain types of inventory data have a stable, high value for many different purposes. From a research point of view, information value of a time series rises steeply with remeasurement frequency and availability of ancillary data, but is insensitive to time since last remeasurement. Furthermore, long records of single organisms are of limited research use unless measurements of other variables are available.

The essential principle to be considered here is the time constant and stability of the organism, element or process. If the time constant is short, or the population fluctuates rapidly, it has to be measured frequently or the value of the data is slight. A fundamental split, therefore, has to be made not only between abiotic and biotic elements but also between different classes of biotic elements, which we will call labile and stable components.

Labile elements have short time-constants, are more variable in abundance and are often more cryptic or fugitive and thus have to be measured indirectly or by indices. Examples are many insects, rodents and rapidly reproducing birds. Stable elements have long time- constants, are easily observed, can be tracked as individuals or quantitatively measured populations. Examples are trees, colonial marine animals, long-lived birds and large indigenous invertebrates. The more labile an organism, the more difficult and costly it is to get a useful long-term record. Furthermore, there is less value in the long-term record unless there are excellent records of all the major biological and non-biological influences in a compatible format.

A comparison of two organisms, trees and mice, demonstrates the difference. With regard to trees, long-term monitoring records can be secured relatively easily and have lasting value: the individuals are immobile, and can be revisited; non-cryptic, so possible to have a complete census; time constants range between 150 and 1000 years, so measurement can be infrequent; other important environmental factors include soil and climatic variables that are routinely monitored or can be interpolated. For organisms such as mice, the situation for long-term monitoring is much more fraught. The individuals are mobile, cryptic, and become observer-shy, meaning census and re-location is near impossible; time constants are in the order of a few months, so remeasurement has to be frequent; other important factors (food availability, predator abundance, and local site weather) are almost as difficult to monitor as the mice themselves. Therefore, knowing mice were abundant in 1956 in a certain catchment is, by itself, not a very useful piece of information, whereas the same information for a tree species retains high value.

1.5 IoT technologies for Smart Cities

The Internet of Things (IoT) is a recent communication paradigm that envisions a near future, in which the objects of everyday life will be equipped with microcontrollers, transceivers for digital communication, and suitable protocol stacks that will make them able to communicate with one another and with the users, becoming an integral part of the Internet (Atzori et al., 2010). The IoT concept, hence, aims at making the Internet even more immersive and pervasive. Furthermore, by enabling easy access and interaction with a wide variety of devices such as, for instance, home appliances, surveillance cameras, monitoring sensors, actuators, displays, vehicles and so on, the IoT will foster the development of a number of applications that make use of the potentially enormous amount and variety of data generated by such objects to provide new services to citizens, companies and public administrations. This paradigm indeed finds application in many different domains, such as home automation, industrial automation, medical aids, mobile healthcare, elderly assistance, intelligent energy management and smart grids, automotive, traffic management and many others (Scenarios et al., 2013; Zanella et al., 2014)(Scenarios et al., 2013; Zanella et al., 2014).

The IoT consists of three layers, including the perception layer, the network layer and the application layer, as shown in Figure 1.3. The perception layer includes a group of Internet-enabled devices that are able to perceive, detect objects, gather information and exchange information with other devices through the Internet communication networks. Radio Frequency Identification Devices (RFID), cameras, sensors, Global Positioning Systems (GPS) are some examples of perception layer devices. Forwarding data from the perception layer to the application layer under the constraints of devicesô capabilities, network limitation and the applicationsô constraints is the task of the network layer. IoT systems use a combination of short-range networks communication technologies such as Bluetooth and ZigBee which are used to carry the information from perception devices to a nearby gateway based on the capabilities of the communicating parties (Jaradat et al, 2015). Internet technologies such as WiFi, 2G, 3G, 4G, and Power Line Communication (PLC) carry the information over long distances based on the application. Since applications aim to create smart homes, smart cities, power system monitoring, demand-side energy management, coordination of distributed power storage, and integration of renewable energy generators, the last layer which is the application layer, is where the information is received and processed. Accordingly, we are able to design better power distribution and management strategies (Hancke et al, 2013; Talari et al., 2017)

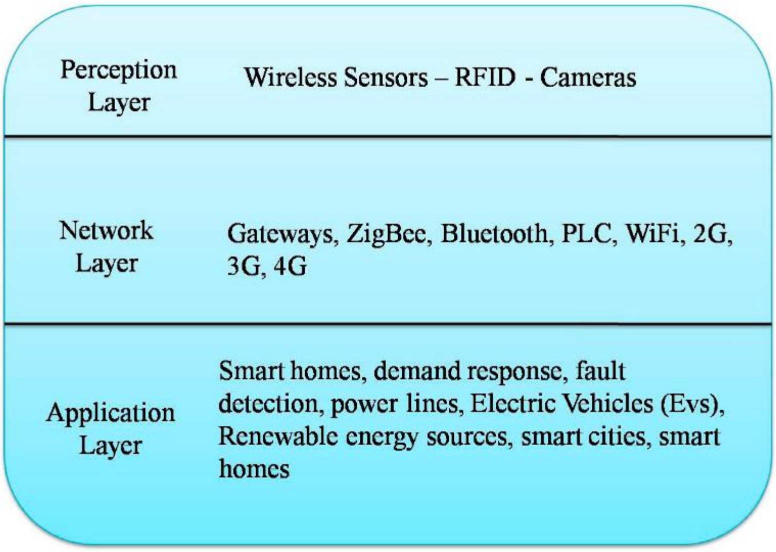


Figure 1.3: IoT layers (Talari et al., 2017)

The IoT uses the Internet to merge various heterogeneous things. Accordingly and for providing the ease of access, all existing things have to be linked to the Internet. The reason behind this is that smart cities include sensor networks and connection of intelligent appliances to the internet is essential to remotely monitor their treatment such as power usage monitoring to improve the electricity usage, light management, air conditioner management. To get this aim, sensors are able to be extended at various locations to gather and analyse data for utilization improvement (Botta et al, 2016). The figure 1.4 illustrates the major utilizations of the IoT for a smart city. The key aims in this field of knowledge are expressed in the following subsections (Talari et al., 2017).

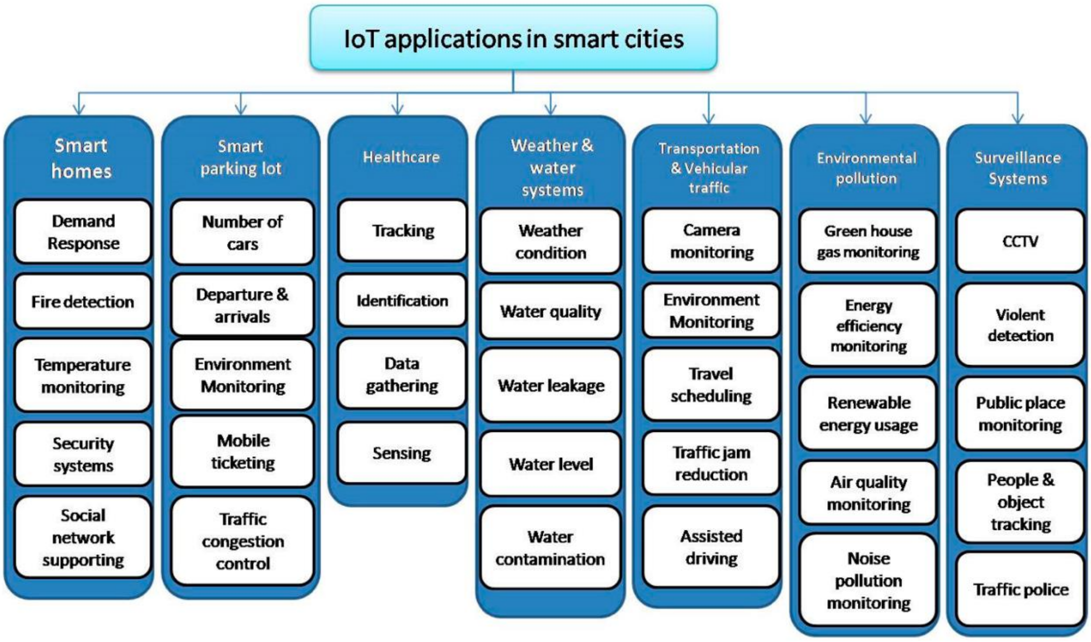


Figure 1.4: The main applications of the IoT (Talari et al., 2017)

1.6 EIoT system for ecological and environmental management

Environmental Internet of Things (EIoT) integrates stationary and mobile sensors, geographic information system (GIS), global positioning system (GPS) and remote-sensing technology into urban environments (Dong et al., 2016; Li et al., 2015; Zhao et al., 2013). It aims at describing the key technologies, including wireless sensor networks (WSN), network techniques, GIS, WebGIS and distributed database techniques. It is often used to monitor aquatic and atmospheric environments, soil, sound, and wind (Wang et al., 2013). Data of various environmental parameters can be collected, transmitted, processed and applied to environmental models, forecasts and early warning systems, thereby enabling in-situ, real-time, remote environmental monitoring. The concept of landsenses ecology is adopted to design the EIoT system for optimal ecological planning. This concept studies land-use planning, construction and management towards sustainable development, based on ecological principles and the analysis framework of natural elements, physical senses, psychological perceptions, socio-economic perspectives, process-risk, and associated aspects (Zhao, Liu, Dong, & Shao, 2016). EIoT can improve the performance and effectiveness of ecological and environmental management. It subdivides the application layer into two parts: the storage layer and user-oriented application layer. The procedure for processing environmental data contains three steps: (i) sensors are used to monitor and collect environmental data; (ii) the data are transmitted to a backend storage system; (iii) the data are computed and analysed for management and application purposes (Zheng et al., 2016).

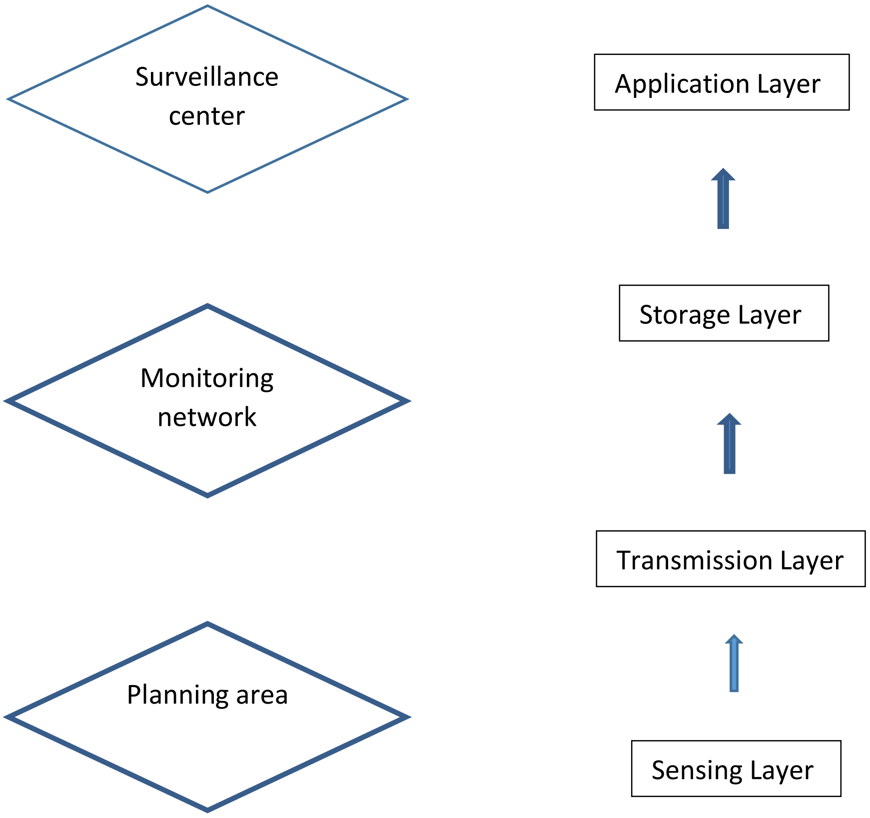


Figure 1.5: The pattern of environment monitoring based on EIoT (Zheng et al., 2016)

1.7 Conclusion

The role of biodiversity and ecosystem services provided is very important for cities. It helps to improve the living environment, the quality of life and the human health. Improving urban biodiversity enhances the sustainability, the quality of life and interaction between nature and human.

The intense urbanization as well as the climate change constitutes a great menace for urban biodiversity. This degradation will cause a disruption in the natural equilibrium with dramatic consequences on the urban environment and citizensô quality of life. Consequently, the city stakeholders should work together for the preservation and improvement of this biodiversity.

The digital revolution and the emergence of the Smart City concept should offer new capacities to monitor at large scale the urban environment, including the biodiversity as well as to analyse the collected data using powerful tools such as the Artificial Intelligence. The use of these new capacities will help to understand the complex urban biodiversity and to take relevant decisions for its preservation. The present PhD work aims at contributing to this goal. The chapter 2 will describe and discuss the smart-based methodology proposed for the biodiversity, then, the chapter 3 will present the application of this methodology on the campus of Lille University.

2 Chapter 2

Methodology

Chapter 1 presented the role of biodiversity in urban area as well as the impact of urbanization on biodiversity. It presented also the smart city concept and how this concept could help in monitoring urban biodiversity as a first step in biodiversity conservation.

This chapter presents the methodology followed in this research for the design and implementation of a smart urban biodiversity monitoring including indicators selection, data collection, data analysis, and urban biodiversity evaluation.

2.1 Introduction

The conservation of biodiversity is a significant goal in nature conservation. But it is very difficult to monitor the biodiversity, because of its high diversity. Indicators are required for the biodiversity surveillance, as well as for establishing strategies and methods for biodiversity protection and for the assessment of these latters. However, the purposes for which indicators are applied and thus sometimes the criteria themselves differ between ecological science and environmental policy (Heink & Kowarik, 2010). Biodiversity indicators are necessary to merge complex ideas and information into a concise assessment. Various indices, which synthesize several individual indicators into sets, are currently used worldwide to assess biodiversity health. Currently, we do not have standardized and global set of indicators for urban biodiversity monitoring that could be used in the world's major cities. Since there is not a single set of biodiversity indicators for global use, various indices help provide a glimpse into the health of multiple aspects of biodiversity, but not a complete or even comparable picture (Alvarez et al., 2015).

A key objective for biodiversity monitoring is to reduce uncertainty regarding management actions and their outcomes for biodiversity (Possingham et al., 2012). By ignoring uncertainties, selected indicators could overestimate the benefits of monitoring to improve decisions-making or may not be cost-effective (Lyons et al., 2008).

2.2 **Objectives**

Urban biodiversity monitoring has the following objectives:

- Identify the biological profile of the research area

- Identify species; locate, and track individual plants and animals
- Track changes in land used
- Track changes in species abundance and occurrence
- Determine soil parameters
- Assess the effect of pollutions (air, noise, light, soil, wateré) on habitat and species
- Monitor sustainability and environmental impact of businesses
- Raise awareness of conservation issues

2.3 Method of biodiversity monitoring

Indicator species are frequently used for biodiversity management. But it is yet unclear whether indicator species selection could improve decision-making. Literature review shows that the majority of research focused on improving monitoring efficiency rather than on effective management, potentially leading to ineffective indicators for decision making. Only 21% of the studies explicitly accounted for management objectives and actions. Crucially, 94% of the reviewed studies and one-half of indicators selection methods overlooked constraints (e.g. budgets), as well as uncertainties in indicator responses to management. To improve the selection of indicators species, a systematic approach is suggested, that uses key concepts from structured decision making. This approach facilitates explicitly evaluating management outcomes as part of the indicator species selection process and allows for the review of indicator choices over time to improve future monitoring and management decisions (Bal et al., 2018).

Siddig et al. (2016) suggested a process for ecological monitoring including the role of indicators species (IS) within the monitoring cycle (Fig. 2.1). It includes:

- Set clear monitoring goals that can be reflected by the selected IS.
- Identify the ecological setting (forest, watershed, wetland, desert, etc.) and the spatial extent of the study site (i.e. scope of inference).
- Select the candidate IS and demographic parameters based on criteria given by Cairns and Pratt (1993); Carignan and Villard (2002); Dale and Beyeler (2001).

- Select ecological covariates/predictors (e.g. habitat types, climatic factors, soil properties, water chemistry) to which the IS is particularly responsive.

- Simultaneously sample species abundance and ecosystem covariates then conduct the indicator species analysis to get the indicator value (IndVal) for each species following the method of Dufrene and Legendre (1997).

However, the use of IS as ecological indicators for monitoring environmental changes is reliable and cost-effective, but a selection of specific indicator(s) and identification of the relationship between these indicators and their specific applications remains challenging. The future utility of IS will depend on selected groups of indicators that reflect the environment in realistic ways and also reflect cause-effect relationships between the IS and under-lying processes of interest (Siddig et al., 2016).

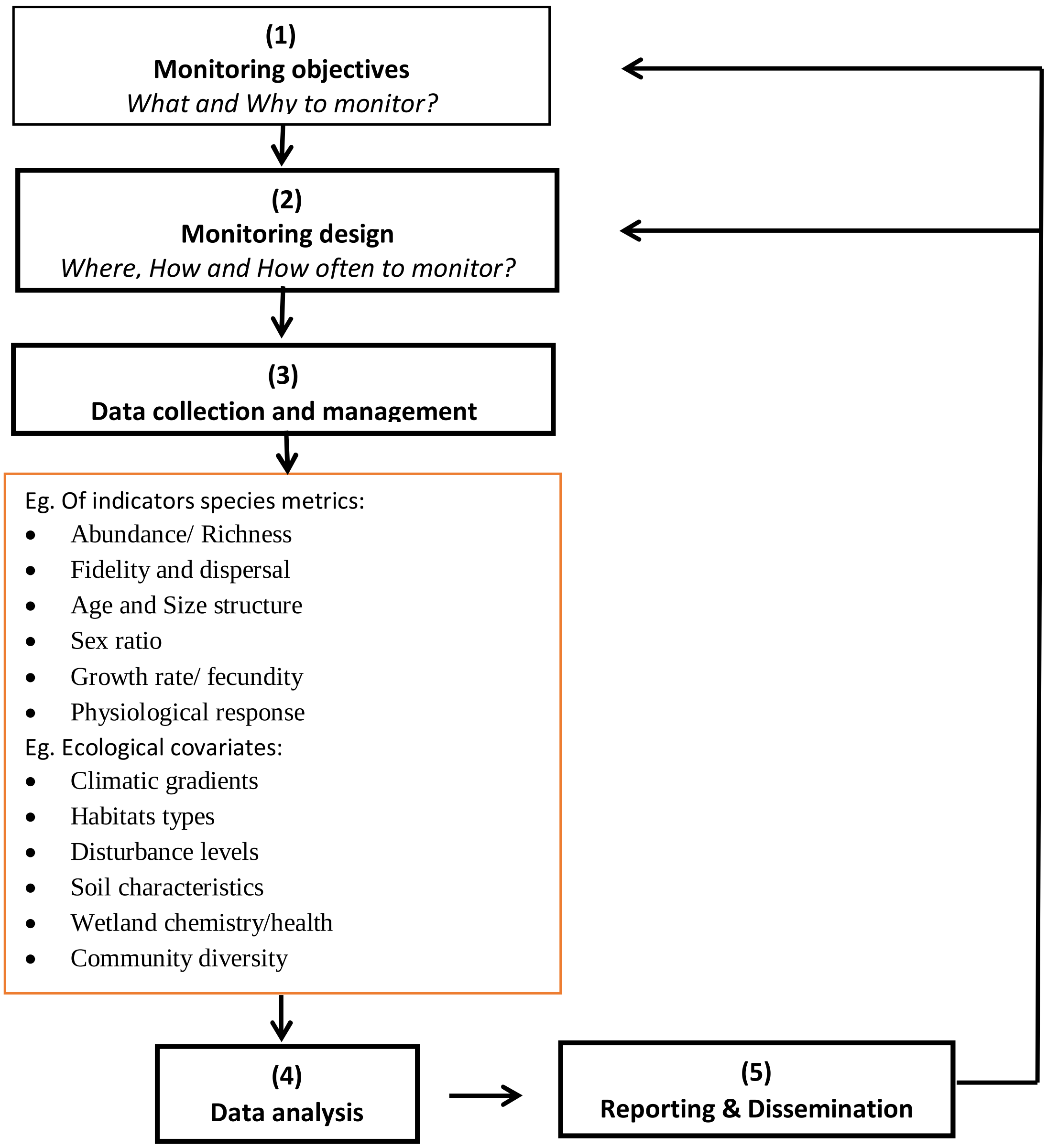


Figure 2.1: Process of ecological monitoring and the position of indicators species and commonly related state covariates within the monitoring cycle (Siddig et al., 2016)

2.4 Biodiversity indicators

A high number of indicators given were proposed to evaluating biodiversity at different scales such as City Biodiversity Index of Singapore (CBI)[1], Convention on Biological Diversity (CDB)[2], Living Planet Index[3], Global Wild Bird Index[4] and Management Effectiveness of Protected Areas[5]...

The table 2.1 summarizes some proposition for biodiversity indicators including their classification, the goal and the number of indicators. Since this research concerns urban biodiversity, it will focus on specific indicators.

Tab.2.1: List of biodiversity and services indicators (Yu, Lu, & Fu, 2017)

Institutions	**Indicator classification system**	**Goals**	**Number of indicators**			
			Biodiversity	**Provisioning services**	**Regulation/ maintenance services**	**Cultural services**
CBD (UNEP, 2004)	Seven focal	Global biodiversity areas assessment	22	-	-	-
2010 Biodiversity Indicators Partnership (Http:// www.twentyten.net)	PSR/DPSIR Regional	Regional and national biodiversity assessment	55	-	-	-
Millennium Ecosystem Assessment (Arico et al., 2005)	MA	Global and sub-global ecosystem assessment	Some indicators provided by the CBD	200	52	35
World Resources Institute (Layke, 2009)	MA	Measuring natureĝs benefit		41	27	9

[1] https://www.cbd.int/subnational/partners-and-initiatives/city-biodiversity-index

[2] https://www.cbd.int/convention/

[3] https://livingplanetindex.org/home/index

[4] https://www.bipindicators.net/indicators/wild-bird-index

[5] https://www.iucn.org/commissions/world-commission-protected-areas/our-work/management-effectiveness

Swiss Federal Office for the Environment (Staub et al., 2011)	FEGS-CS	Inventory of final ecosystem goods and services		15	27	14
European Environment Agency (Haines-Young & Potschin, 2013)	CICES (Forests ecosystems)	Ecosystem capital accounting	6	38	63	16
	CICES (Agro-ecosystems)		5	20	28	19
	CICES (Freshwater ecosystems)		2	26	45	39
	CICES(Marine ecosystems)		1	5	21	7
Singapore Index of Citiesô Biodiversityò (Singapore Index or SI) (Rodricks, 2010)	CBI	self-assessment tool for evaluating biodiversity status of city	10	4		9

From table 2.1, it can be seen that these existed indicators in different scale which is almost the global, regional and national biodiversity assessment with a huge number of indicators. To assess the biodiversity status of the city there is only Singapore index - SI (also known as City Biodiversity Index - CBI). However, the experiences from municipalities in several countries where the newly developed City Biodiversity Index (CBI) has been applied and tested, were shown some challenges.

Based on experiences in implementing the CBI in 14 cities in Japan, in Lisbon (Portugal), Helsinki (Finland), Mira Bhainder (India) and Edmonton (Canada) it is evident that the CBI has limitations (Kohsaka et al., 2013). It could be summarized as relating to (1) the lack of data; (2) the scale, boundaries, and definitions; (3) the scoring that needs to capture the vast bio-geographical differences among cities and (4) the number and scope of ecosystem services are limited (Kohsaka et al., 2013). Moreover, CBI does not mention the effects of human activities such as air, soil, lighté pollution, changes in land usedé on urban biodiversity. While these factors are the main cause of green areas reduction and threat to habitat of all species.

2.5 Use of digital technology in ecological conservation

Digital technology is increasingly used for ecological conservation. It includes five key dimensions: data on nature, data on people, data integration and analysis, communication and experience and participatory governance (Wal et al, 2015).

2.5.1 Use of mart technology in ecology and environment

Due to a lack of digital networks, traditional data logger used manual data collection (Martinez, 2016). This manual method presents the following inconvenient:

- Poor temporal resolution. Due to the periodical collection, it is impossible to obtain real-time environment data. There is a time delay between identifying a problem and making a corresponding response.
- Heavy workload. Because of the large monitoring region and sparse monitoring points, artificial data collection requires a large amount of manpower and resources.
- Weak continuity. Environmental data can be lost because data collection is not continuous. Hence, it cannot provide the complete, long- term status of environmental parameters (Zheng et al., 2016).

Figure 2.2 and table 2.2 present progress in the use of new technology in ecology and environmental science (Allan et al., 2018). Thanks to the development of technology which overcomes the inconvenient of traditional manual data. Internet of things and low-power computers technology which allow obtaining real-time data with the long-term goal so increasing the reliability of data collected, saving time and reducing labour costs.

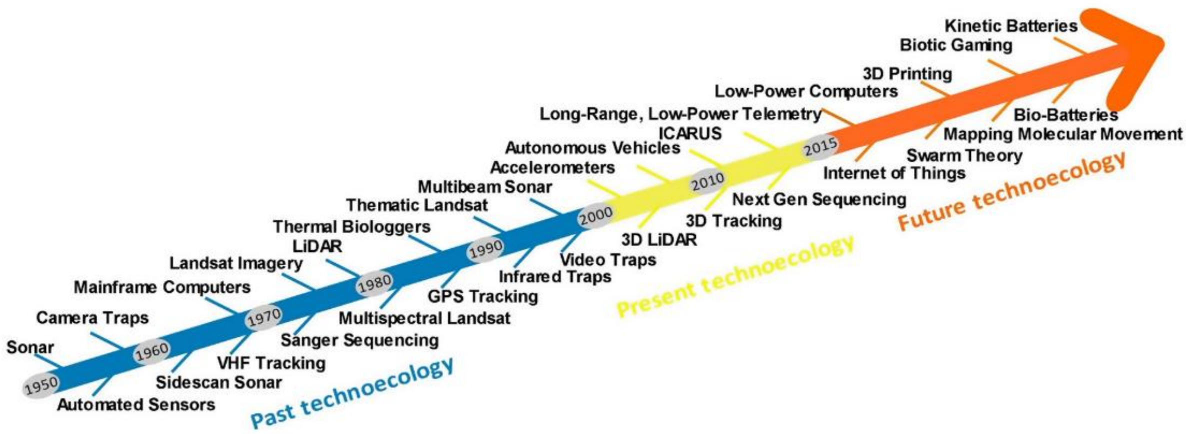


Figure 2.2: Timeline of the use of new technologies in ecology and environmental (Allan et al., 2018)

Table 2.2: Technology used in ecology and environmental science (Allan et al., 2018)

Technology	Description
Past	
Sonar	Sonar first used to locate and record schools of fish
Automated sensors	Automated sensors specifically used to measure and log environmental variables
Camera traps	Camera traps first implemented to record wildlife presence and behaviour
Sidescan sonar	Sidescan sonar is used to efficiently create an image of large areas of the sea floor
Mainframe computers	Computers able to undertake ecological statistical analysis of large datasets
VHF tracking	Radio-tracking, allowing ecologists to remotely monitor wild animals
Landsat imagery	The first space-based, land-remote sensing data
Sanger sequencing	The first method to sequence DNA based on the selective incorporation of chain-terminating dideoxynucleotides by DNA polymerase during in vitro DNA replication
LiDAR	Remote sensors that measure distance by illuminating a target with a laser and analyzing the refracted light
Multispectral Landsat	Satellite imagery with different wavelength bands along the spectrum, allowing for measurements through water and vegetation
Thermal bio-loggers	Surgically implanted devices to measure animal body temperature
GPS tracking	Satellite tracking of wildlife with higher recording frequency, greater accuracy and precision, and less researcher interference than VHF
Thematic Landsat	A whisk broom scanner operating across seven wavelengths and able to measure global warming and climate change
Infrared camera	Able to sense traps animal movement in the dark and take images without a visible flash
Multibeam sonar	Transmitting broad acoustic fan-shaped pulses to establish a full water column profile
Video traps	Video instead of still imagery, able to determine animal behaviour as well as identification
Present	Measures animal movement (acceleration) that is irrespective

Accelerometers 3D LiDAR Autonomous vehicles. 3D tracking ICARUS Next-gen sequencing Long-range, low-power telemetry	of satellite reception (geographic position) Accurate measurement of 3D ecosystem structure Unmanned sensor platforms to collect ecological data automatically and remotely, including in terrain that is difficult and/or dangerous to access for humans The use of inertial measurements units devices in conjunction with GPS data to create real-time animal movement tracks The International Cooperation for Animal Research Using Space (ICARUS) Initiative is to observe global migratory movements of small animals through a satellite system Millions of fragments of DNA from a single sample can be sequenced in unison Low-voltage, low-amperage transfer of data over several kilometres
Future Internet of things Low-power computers Swarm theory 3D printing Mapping molecular movement Biotic gaming Bio-batteries	 A network of devices that can communicate with one another, transferring information and processing data Small computers with the ability to connect an array of sensors and, in some cases, run algorithms and statistical analyses The autonomous but coordinated use of multiple unmanned sensor platforms to complete ecological surveys or tasks without human intervention The construction of custom equipment and constructing animal analogues for behavioural studies Cameras that can display images at a sub-cellular level without the need of electron microscopes Human players control a paramecium similar to a video game, which could aid in the understanding of microorganism behaviour Electro-biochemical devices can run on compounds such as starch, allowing sensors and devices to be powered for extended periods in remote locations where more traditional energy sources such as solar power may be unreliable (e.g., rainforests)

2.5.2 Use of Geographic information system (GIS)

GIS uses digital technology to capture, store, manipulate, analyse, manage, and present geographical data. Each type of data such as climate, air quality, and human health, is presented as a layer and could be visualized in two- or three-dimensional digital map. By observing how layers overlap, and by noting the measurements of multiple parameters at a specific point on the map, potential trends and relationships may be drawn between land use, socioeconomic factors, environmental factors, etc.

Tabular data must be merged with spatial data or information that identifies geographic locations through latitude, longitude, and topographical coordinates. This conversion may occur in several ways:

- GIS users may manually select a point on the map that corresponds to the location where data was collected.
- Sensors, cameras, and other devices that collect GIS-compatible data may contain built-in tracking devices that can relay their location to GIS software via radio waves and Wi-Fi signals.
- Computerized data from satellite images may already be associated with a specific geographic location, and this information may be transferred to the GIS software through functions built into the program (Loukaitou-Sideris et al., 2018).

GIS is useful for planning and assessment of biodiversity. It can help managers to identify locations for new green space or display an existing green spaceȸs physical features. Biodiversity data that include location of infrastructure, such as light fixtures and irrigation pipes, and natural landmarks, such as plants and water sources. GIS can also display community population density; vegetation and soil distribution; wildlife habitat; sites that produce pollution and those that are sensitive to various types of pollution; buildings and archaeological landmarks; wireless signals from cellular towers, mobile devices and Wi-Fi equipment; land and property values within and surrounding the vegetation areas; air, water, and soil quality; water distribution, watersheds, and stream flows, among others (Loukaitou-Sideris et al., 2018).

Biodiversity managers could use GIS to determine suitable habitat to accommodate wildlife. Indeed, map layers tracking vulnerable species of flora and fauna could be overlaid with those illustrating spatial distributions of predator species and climate. After determining the habitat conditions for various endangered species, a map of all areas matching the requirements could be created, allowing managers to see where these species could thrive. GIS could also inform decisions-makers about the optimization of artificial watering patterns, light fixture placement, soil fertilization, and other components based on park characteristics as measured by manual field observations or digital sensors (Loukaitou-Sideris et al., 2018).

2.6 Urban biodiversity monitoring

2.6.1 Framework of urban biodiversity monitoring

From the literature reviews, a framework is proposed to monitor urban biodiversity. It includes the following steps (Figure 2.3):

- Select indicators, determine monitoring objectives and management.
- Select and implement monitoring technology; use of smart technology to biodiversity monitoring and management.
- Collect and manage data
- Analyze data using IT (information technology) tools, such as AI (artificial intelligent).

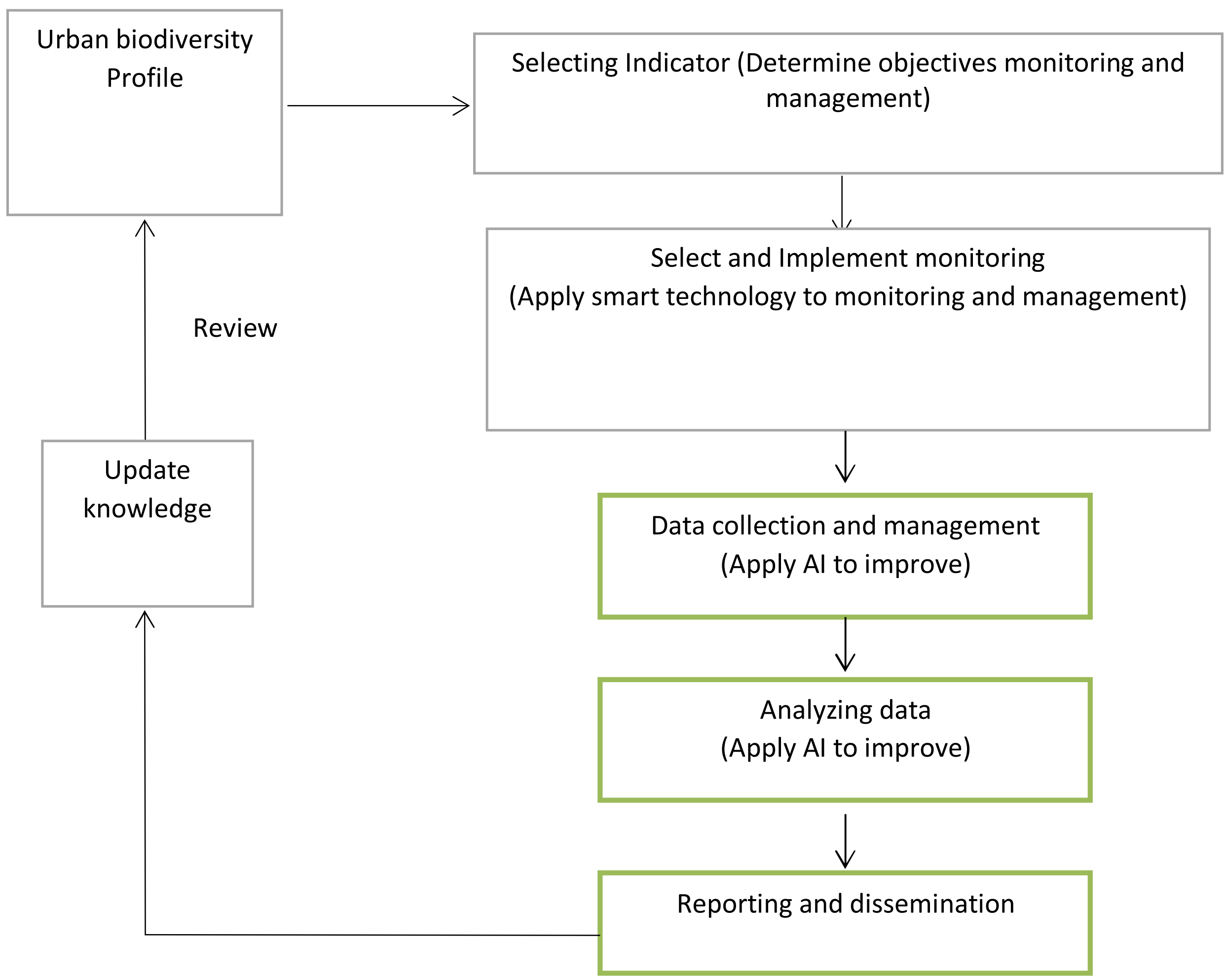


Figure 2.3: Framework for urban biodiversity monitoring

2.6.2 Indicators selection

The selection of relevant indicators is crucial for effectively managing biodiversity, because indicators provide information, which could impact decisions. The risk of failing in the selection of relevant biodiversity indicators is high, and could lead to irreversible consequences for biodiversity such as extinctions or loss of critical habitat (Lindenmayer et al., 2012). Literature review shows that indicator selection continues to focus on improving monitoring efficiency rather than improving management effectiveness. Indicator species chosen to achieve a particular monitoring objective may be recommended for complex management decisions that often involve multiple objectives, without adequate testing of their performance to improve decision-making. To overcome this deficiency, decision-makers should explicitly consider the decision context rather than relying purely on the ecological validity of indicators. A decision framework for indicator selection that draws on the core tenets of SDM (Structured decision-making) provides a distinct advantage over ad-hoc selection methods, because it can help to ensure that indicators are relevant to the decision process, lead to improvements in management decisions and cost-effective spending of scarce resources (Bal, 2016).

An indicator is commonly defined as a measure based on verifiable data that conveys information about more than itself. In very general terms, the appeal of biodiversity indicators is thus to provide information of broader relevance to biodiversity in a technically and financially feasible fashion. Indicators are routinely linked to specific criteria, especially in forest management (ócriteria & indicatorsô). Criteria define the range of management targets and the essential elements or principles of management. Each criterion relates to a key element of management success and tying indicators to specific criteria helps set up a comprehensive and efficient (targeted) set of indicators. Any discussion on biodiversity monitoring must begin with the question ówhat are the ultimate goals of our monitoring?ô The choice of suitable indicators is made only after agreeing on clear and specific monitoring objectives among key stakeholders (Werner & Gallo-Orsi, 2016).

The indicator selection needs to focus on problems within a clear decision and developing better. Indicator selection methods focused on improving management outcomes, incorporating iterative learning regarding key uncertainties in the indicator selection process to improve indicator choices over time.

The need to make decisions about indicator selection, therefore, comes from identifying (and articulating) a conservation or management problem that calls for monitoring to improve management outcomes (McDonald-Madden et al., 2010). This means that it needs to move beyond the much-cited trade-off between measurement accuracy and practical constraints of monitoring indicators (Lindenmayer et al., 2012), to a full clarification of the management decision factors that govern indicator choice. Alternative indicators can then be evaluated to choose the ones that best help achieve the management objective given the constraints. While monitoring objectives may also be specified, e.g. improving monitoring accuracy, they suggest that these are secondary to the management objective when indicators are being selected for management decision-making.

However, due to the specific ecological profile of each city, it is difficult to select general representative indicators. Indicators shows in table 2.3 provide a set of indicators for urban biodiversity monitoring.

Table 2.3: Urban Biodiversity indicators

Biodiversity	Coverage	1. Proportion of green areas 2. Connectivity/Fragmentation of green areas
	Biology	1. Abundance and distribution of selected species 2. Change in number of native species 3. Proportion of invasive alien species
Cause factors	Physical factors	1. Temperature, Humidity of air 2. Temperature, Humidity of soil 3. Weather conditions
	Human activities	1. Change in land used 2. Soil pollution 3. Water pollution 4. Air pollution 5. Noise pollution 6. Light pollution
Management	Finance	1. Budget for urban biodiversity projects
	Participation of stakeholder	2. Number of Agencies/Private Companies/NGOs/Academic Institutions/International Organizations with which the City is Partnering in Biodiversity Activities, Projects and Programs

2.6.2.1 *Proportion of green areas*

❖ Why select it?

Green area is defined as any vegetated land in urban area (Alvarez et al., 2015) including bushland, nature reserves, national parks, outdoor sports fields, school playgrounds and rural or semi-rural areas (Chong et al., 2013).

Urban green area such as domestic gardens, parks and woodlands provide a multitude of benefits to urban populations and a vital habitat for biodiversity. By improving physical fitness and reducing depression, the presence of green areas can enhance the health and wellbeing of people living and working in cities. Green areas indirectly impact our health by improving air quality and limiting the impact of heatwaves. In addition, urban vegetation stores carbon, helps to mitigate climate change and reduces the likelihood of flooding by storing excess rainwater (Scott, 2015).

❖ How to determine

(Total area of green areas) / (Total area of city) × 100%

❖ Monitoring

This indicator can be determined using GIS, Google maps and satellite images.

❖ Score

Based on the assumption that, by definition, a city comprises mainly man-made landscapes, the maximum score will be accorded to cities with natural areas occupying more than 20% of the total city area (Chan et al., 2014).

0 points: < 1.0%

1 point: 1.0% ï 6.9%

2 points: 7.0% ï 13.9%

3 points: 14.0% ï 20.0%

4 points: > 20.0%

2.6.2.2 *Connectivity/Fragmentation of green areas*

❖ Why select it?

Fragmentation of natural areas is one of the main threats to the sustainability of biodiversity in urban area. It is recognized that the fragmentation of natural areas affects species. For example, a road may not be a barrier for birds, but it can seriously fragment a population of arboreal primates. A strip of urbanization may not affect the dispersal of wind-pollinated plants, but a plant that depends on small mammals for dispersal will be adversely affected. Dupont et al (2017) tested the hypothesis that the genetic structure of belowground organisms also responds to landscape structure in an agricultural landscape in the North of France, where landscape features were characterized with high accuracy. They found that habitat fragmentation impacted genetic variation of earthworm populations at the local scale. This indicates that the fragmentation of natural habitats has shaped their dispersal patterns and local effective population sizes. Landscape connectivity analysis confirmed that a priori favorable habitats such as grasslands may constitute dispersal corridors for these species. To consider these differences, a pragmatic approach is used for the calculation of this indicator. Furthermore, to encourage positive actions to increase connectivity or reduce barriers to connectivity, it would be more meaningful to measure connectivity rather than fragmented plots (Chan et al., 2014).

Barriers such as roads, industrial zoneé make a mosaic of the landscape creating patches and which connects these patches is urban green corridors. Corridors connect patches together and can be a wide variety of sizes, widths, compositions and structures. Some can be small such as a hedgerow and some may be many miles wide and hundreds of miles long. Some cities historically planned linkages although, like the case of Seattle, the original Olmsted plan was never fully realized. However, in Boston, the Emerald Necklace, another Olmsted plan, was realized and is still in place today and is an important park[6].

❖ How to determine

$$\boldsymbol{Indicator2} = \frac{\mathbf{1}}{\boldsymbol{A_{TOTAL}}}\left(\boldsymbol{A_1^2} + \boldsymbol{A_2^2} + \boldsymbol{A_3^2} + \cdots + \boldsymbol{A_n^2}\right)$$

A_{total} is the total area of green areas in city such as domestic gardens, parks and woodlands, outdoor sports fields, school playgrounds and rural or semi-rural areas.

A_1 to A_n are areas that are distinct from each other (i.e. more than or equal to 100m apart); n is the total number of connected green areas.

This measures effective mesh size of the natural areas in the city. A_1 to A_n may consist of areas that are the sum of two or more smaller patches which are connected. In general, patches are considered connected if they are less than 100m apart.

However, exceptions to the above rule include anthropogenic barriers such as roads (15m or more in width; or are smaller but have a high traffic volume of more than 5000 cars per day). Rivers that are highly modified and other artificial barriers such as heavily concretized canals and heavily built-up areas. Any other artificial structures that the city would consider as a barrier (Chan et al., 2014).

[6] https://www.smartcitiesdive.com/ex/sustainablecitiescollective/corridor-ecology-and-planning

❖ Monitoring

This indicator determined using GIS, Fragstats, Google map and satellite images.

❖ Score

The effective mesh size is an expression of the probability that two points randomly chosen within the green areas of a city are in the same patch or are considered connected (< 100m between the patches with no major barrier between). It can also be interpreted as the ability of two animals of the same species placed randomly in the natural areas to find each other. The more barriers in the landscape, the lower the probability that the two locations will be connected, and the lower the effective mesh size. Therefore, larger values of the effective mesh sizes indicate higher connectivity (Chan et al., 2014).

0 points: < 200 ha

1 point: 201 - 500 ha

2 points: 501 - 1000 ha

3 points: 1001 - 1500 ha

4 points: > 1500 ha

2.6.2.3 *Abundance and distribution of selected species*

❖ Why select it?

This indicator shows trends in the abundance and distribution of selected species. It contributes to the assessment of biodiversity conservation policy and land use policy, as well as to overarching factors such as climate change. Selected species can be excellent barometers of the health of the environment. They occur in many habitats, can reflect changes in other animals and plants, and are sensitive to environmental change (European Environment Agency, 2016).

❖ How to determine?

The number of native species in research areas where urban areas include impermeable surfaces like buildings, roads, drainage channels, etc., and anthropogenic green spaces like roof gardens, roadside planting, golf courses, private gardens, cemeteries, lawns, urban parks, etc..

Depend on the biological profile of the city, it can select some taxonomic groups such as birds, butterflies, insects, bryophytes, fungi, amphibians, reptiles, freshwater fish, molluscs, dragonflies, beetles, spiders, hard corals, marine fish, seagrasses, sponges, etc.

❖ Monitoring

Each species reacts differently to the various anthropogenic pressures. By monitoring a large number of populations of different species, different bio-geographical regions and areas subjected to different types and levels of pressure, this indicator has the potential to alert decision-makers to the decline in populations due to environmental and geographic factors, as well as their potential drivers (European Environment Agency, 2016).

Citizen science: the data could be collected from citizens through open data systems and some smartphone apps.

❖ Score

The number of native species in urban areas and anthropogenic greenery and green spaces is inevitably lower than that found in sites with natural ecosystems (Chan et al., 2014).

0 points: < 19 species

1 point: 19 - 27 species

2 points: 28 - 46 species

3 points: 47 - 68 species

4 points: > 68 species

2.6.2.4 *Change in number of native species*

❖ Why select it?

It is essential to consider native flora and fauna diversity as an indicator of urban biodiversity. Two key taxonomic groups that are most surveyed worldwide, i.e., plants and birds have been selected as ñcore indicatorsò. To ensure fairness and objectivity in the index, cities can select two other taxonomic groups that would reflect their biodiversity

❖ How to determine.

Net change in species from the previous survey to the most recent survey is calculated as the total increase in number of species (as a result of re-introduction, rediscovery, new species found, etc.) minus number of extinct species.

❖ Monitoring

The footprint identification technique (FIT) translates millennia-old tracking practices. Pelage or skin patterns have been used to identify individuals, usually from camera-trap images. Infrared sensors provide the potential to identify individual animals either at traditional camera-trap stations; from sensors directly connected to smartphones; or aerially from drones (Pimm et al., 2015).

Quadrats and plots: Quadrats and plots are commonly used methods for surveying plants, and can also be used to survey amphibians and reptiles and larger invertebrates that can be easily observed. Quadrats can be systematically placed (e.g. in a grid or along a transect to monitor changes in vegetation along an environmental or disturbance gradient) or randomly within the target habitat to record species within. Quadrats should be searched systematically from the outside edge to the middle. Species (or higher taxonomic groups) present, and percentage vegetation cover (e.g. using the Braun-Blanquet scale), within each quadrat are recorded (Latham et al., 2014).

Data are collected by field visit, by cameras installed at significant locations and from citizens involved in the project. The observation time should be established for each species.

Monitoring period - for example: birds, it is monitored breeding season, migration operation, non-breeding season.

❖ Score

Profile of the city will be used to measure change in species diversity. Citiesô first application will be considered as the baseline information for all subsequent monitoring. In their subsequent applications of the Index, cities will calculate the net change in species for the respective taxonomic groups (Chan et al., 2014).

The scoring range below is based on the acceptance that it is not easy to recover or re-introduce species successfully over a short period of time. However, species recovery, re-introduction and restoration efforts must be given due recognition (Chan et al., 2014).

0 points: maintaining or a decrease in the number of species

1 point: 1 species increase

2 points: 2 species increase

3 points: 3 species increase

4 points: 4 species or more increase

2.6.2.5 *Proportion of invasive alien species*

❖ Why select it?

Invasive alien species out-compete native species and, thus, threaten the survival of native species and the integrity of ecosystems. As cities are very open to an influx of alien species, this indicator measures the status of this threat.

The definition of alien invasive species is proposed by SCBD (Secretariat of the Convention on Biological Diversity): an alien species whose introduction and/or spread threatens biological diversity (For the purposes of the present guiding principles, the term "invasive alien species" shall be deemed the same as "alien invasive species" in Decision V/8 of the Conference of the Parties to the Convention on Biological Diversity)

❖ How to determine?

To ensure that the comparison of invasive alien species with that of native species is meaningful, comparison should be conducted on identical taxonomic groups.

(Number of invasive alien species) / (Number of native species) × 100%

❖ Monitoring

The footprint identification technique (FIT) translates millennia-old tracking practices. Pelage or skin patterns have been used to identify individuals, usually from camera-trap images. Infrared sensors provide the potential to identify individual animals either at traditional camera-trap stations; from sensors directly connected to smartphones; or aerially from drones (Pimm et al., 2015).

Quadrats and plots: Quadrats and plots are commonly used methods for surveying plants, and can also be used to survey amphibians and reptiles and larger invertebrates that can be easily observed. Quadrats can be systematically placed (e.g. in a grid or along a transect to monitor changes in vegetation along an environmental or disturbance gradient) or randomly within the target habitat to record species within. Quadrats should be searched systematically from the outside edge to the middle. Species (or higher taxonomic groups) present, and percentage vegetation cover (e.g. using the Braun-Blanquet scale), within each quadrat are recorded (Latham et al., 2014).

Citizen science: the data could be collected from citizens through open data systems and some smartphone apps.

❖ Score

The scoring range is based on the premise that the more invasive alien species that are in the city; the more destructive impact will be to the native species (Chan et al., 2014).

0 points: > 30.0%

1 point: 20.1% - 30.0%

2 points: 11.1% - 20.0%

3 points: 1.0% - 11.0%

4 points: < 1.0%

2.6.2.6 *Physical factors*

❖ Why select it

It includes all the physical factors like temperature, humidity of air and soil and weather conditions. In the last 100 years, the average global temperature has increased by 0.74°C, rainfall patterns have changed and the frequency of extreme events increased. Change has not been uniform on either a spatial or temporal scale and the range of change, in terms of climate and weather, has also been variable[7].

Change in climate has consequences on the biophysical environment such as changes in the start and length of the seasons, glacial retreat, and decrease in Arctic sea ice extent and a rise in sea level. These changes have already had an observable impact on biodiversity at the species level, in term of phenology, distribution & populations, and ecosystem level in terms of distribution, composition & function[6].

❖ How to determine

By following changes in the temperature, humidity of air and soil and weather conditions (rainfall, wind direction) which concerns the timely (hourly, daily, monthly, yearly) variation values.

❖ Monitoring

To monitoring weather condition could be conducted using sensors system based on IoT technology (temperature, humidity, rainfall, wind speed).

❖ Score

[6] https://www.birdlife.org/projects/7-impacts-climate-change-biodiversity-and-ecosystem-services

With these indicators, the evaluation or score is based on relevant regional, national and organisation standards.

2.6.2.7 *Human activities*

❖ Why select it

Human activities lead to change in land used, management policies (use of pesticides for example) pollution of soil, water and air as well as noise and light. These changes affect productive viability of organisms, alter metabolism and cause pollution in the food chain. These may destroy some layers of the primary food chain, and thus have a negative effect on predator animal species. Small life forms may consume harmful chemicals which may then be passed in the food chain to larger animals, so this may lead to increased mortality rate and even animal extinction. Traffic noise has an impact on avian reproduction by smaller clutches and fewer fledged chicks. Light pollution affects many groups of animals and plants, especially bats, birds and nocturnal insects.

❖ How to determine

Evaluating the effects of human activities impact on the habitat of all species and ecosystem.

With change land used indicator, it is calculated by GIS, Fragstats software which shows the change over time of different land types such as forest, farm land, woodland, wetlandé Change in land used function often brings disadvantages to urban ecosystem, however, in some case, transformation from abandoned lands to parks or sport fields is a good sign. This indicator determined using GIS, Fragstats, Google map and satellite images

With pollution factors, to assess the effects of it on urban biodiversity need to base on results of the long-term monitoring.

❖ Monitoring

To monitoring these cause factors could be conducted using sensors systems with IoT technology (air quality, lighting, noise);

Taking samples (soil, water) to analyze the structures, properties, and composition;

Other parameters require field observation or image processing of videos or photos collected by cameras.

❖ Score

Based on the score of the proportion of green areas indicator, the less of transformation from green to artificial areas such as building, road, waterproof, and the more benefits it brings to the urban ecosystem. So that the maximum score will be accorded to cities with transformation less than 1% of the total city area.

0 points: > 20.0%

1 point: 14.0% ï 20.0%

2 points: 7.0% ï 13.9%

3 points: 1.0% ï 6.9%

4 points: < 1.0%

With the indicators like pollution factors, the evaluation or score is based on relevant regional, national and organisation standards.

2.6.2.8 *Number of Agencies/Private Companies/NGOs/Academic Institutions/International Organizations with which the City is Partnering in Biodiversity Activities, Projects and Programs*

❖ Why select it

Measures the extent of informal and/or formal partnerships, or collaboration with other entities. As it is impossible for any single agency to carry out all the activities, responsibilities, projects and programs that have biodiversity implications, hence, engagement of all levels of the population must be facilitated. These include the city officials in various departments, other spheres of government, the public, private sector, NGOs, etc.

❖ How to determine

The number of agencies / private companies / NGOs / academic institutions / international organizations with which the city is partnering in biodiversity activities, projects and programs.

❖ Monitoring

The data from city councils

❖ Score

0 points: No formal or informal partnerships

1 point: City in partnership with 1-6 other national or subnational agencies/private companies/NGOs/academic institutions/international organisations

2 points: City in partnership with 7-12 other national or subnational agencies/private companies/NGOs/academic institutions/international organisations

3 points: City in partnership with 13-19 other national or subnational agencies/private companies/NGOs/academic institutions/international organisations

4 points: City in partnership with 20 or more other national or subnational agencies/private companies/NGOs/academic institutions/international organisations (Chan et al., 2014)

2.6.2.9 *Budget for urban biodiversity projects*

❖ Why select it

This indicator indicates the financial commitment of city governments towards biodiversity. It is recognized that there are numerous other factors affecting the amount allocated towards biodiversity, but in general the greater the proportion of the total city's budget allocated, the greater the level of commitment by the city.

❖ How to determine

(Amount spent on biodiversity-related administration)/ (Total budget of city) × 100%

❖ Monitoring

Data are collected from concerned departments and bodies.

❖ Score

The following points are awarded for the respective proportions of the city budget allocated to biodiversity (Chan et al., 2014):

0 points: < 0.4%

1 point: 0.4% - 2.2%

2 points: 2.3% - 2.7%

3 points: 2.8% - 3.7%

4 points: > 3.7%

2.6.3 Monitoring implementation

The smart biodiversity monitoring is based on the solution presented in the figure 2.4 (Isam Shahrour et al., 2017). It includes both the use of digital technology and citizens involvement. Monitoring tasks are coordinated by a unique platform. Access to any task is possible only via the platform.

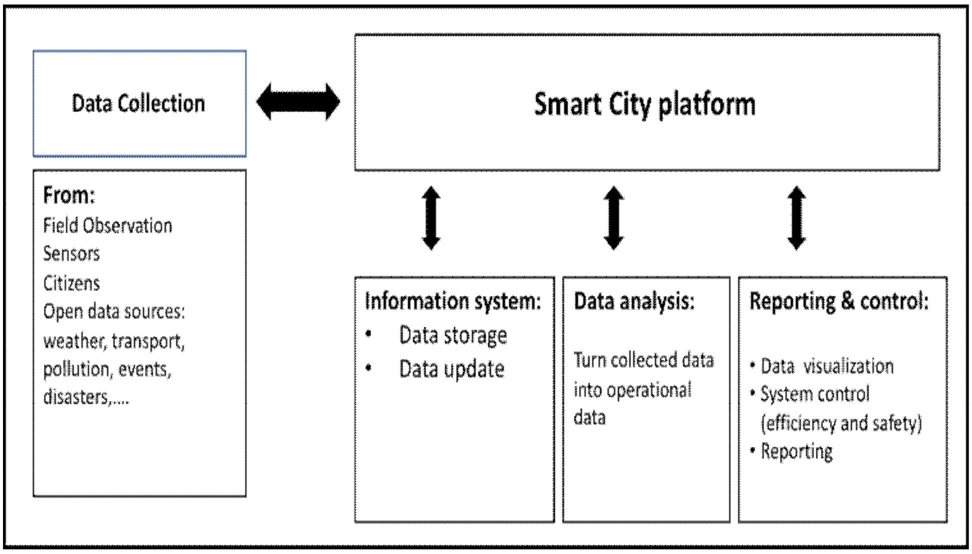


Figure 2.4: Smart City solution organization (Shahrour et al., 2017)

According to Talari et al. (2017), the smart monitoring includes four layers: perception layer, network layer, database layer and application layer (Figure 2.5). The perception layer includes a group of Internet-enabled devices that perceive, detect objects, gather information, and exchange information with other devices through communication networks. Cameras, sensors, Global Positioning Systems (GPS) are included in the perception layer. Forwarding data from the perception layer to the application layer under the constraints of devicesô capabilities, network limitation and the applicationsô constraints is the task of the network layer. Communication technologies such as Wi-Fi, 2G, 3G, 4G, 5G transmit the information over long and short distances. The database layer with the database management system (DBMS), are used for data storage and analysis. The application layer includes tools and applications for data use in biodiversity monitoring.

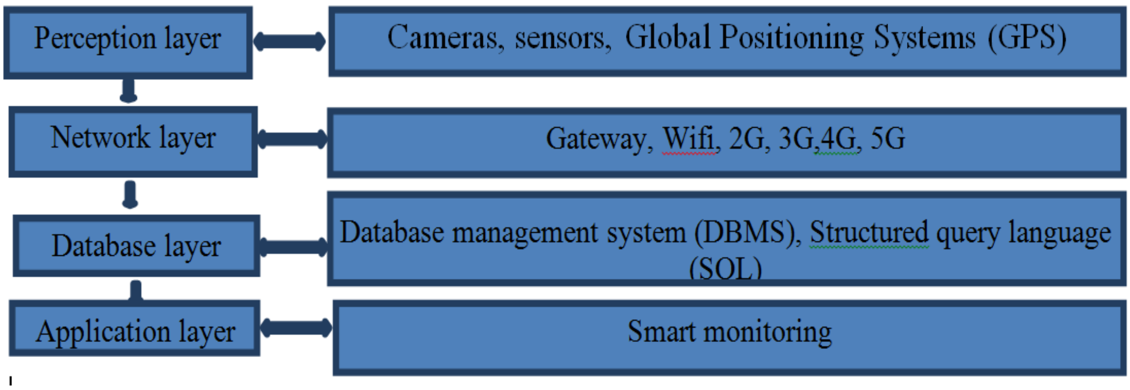


Figure 2.5: Smart monitoring layer (T. H. Y. Pham et al., 2019)

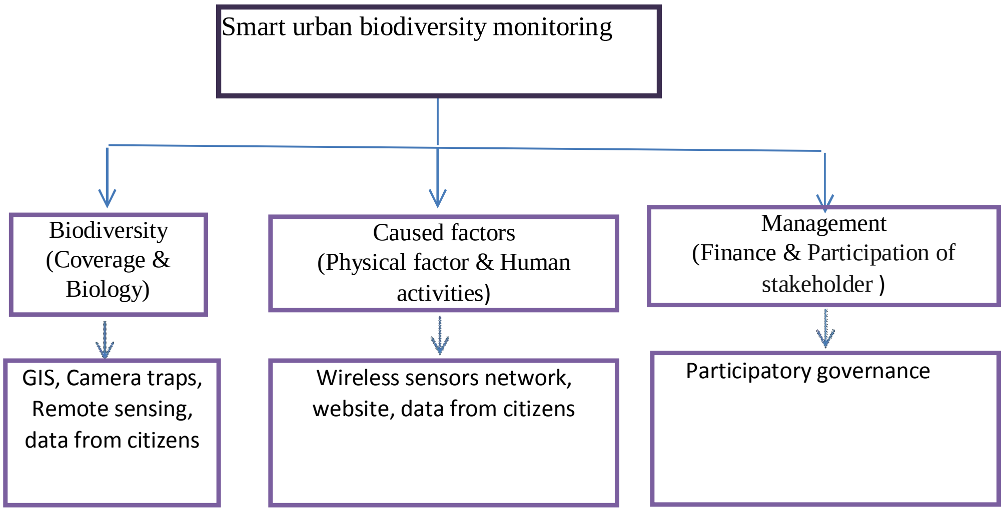


Figure.2.6: Application of smart technology for urban biodiversity monitoring (T. Pham et al., 2020)

2.6.4 Data collection and management

This task includes collection in a digital format of urban data such as urban infrastructures and buildings, urban services, population profile. These data could be collected and stored using the GIS system. It also includes data from sensors, which are used to monitor urban infrastructures and services as well as the environment. These sensors record and transmit in real-time data about urban system functioning. It also includes data from citizens, who can send data and information about their observations and suggestions. The platform also collects data from open-sources such as the weather, transportation, pollution and events related to urban hazards. All these data are stored in the smart city information system and updated regularly.

The application of the Smart City solution on urban biodiversity protection requires adaptation of the concept presented earlier to topics related to urban biodiversity such as urban species, habitat, weather, pollution, urban hazards and human activity. The objective is to develop a long-term information system that includes the evolution of urban species as well as major factors that affect this evolution. This approach faces a major difficulty, which is related to the time scale. Indeed, some events are rapid such as flood and weather variation, while the evolution of species could be perceptible at long time scale, except situation of major hazards, which could have a short-time impact on species. Table 2.4 shows the categories of data to be collected. It includes the following categories.

- Urban species; this category includes urban species and habitat with more details on specific species (witness species), alien species and species activity and health. Data are collected by field visit, by cameras installed at significant locations and from citizens involved in the project. The observation time should be established for each species, considering weather change or major events related to natural or human-made hazards.

- Weather conditions; this category concerns the hourly variation of the temperature, humidity, air quality, rainfall intensity and wind speed and direction.
- Human activity, with a focus on construction maps, changes in land use, pollution of soil and water, noise pollution and light pollution.
- Urban hazards such as flood, storms, earthquakes, fire and industrial
- The collection of these data could be conducted using sensors (temperature, humidity, air quality, lighting, noise, rainfall, wind speed); other parameters require field observation or image processing of videos or photos collected by cameras.

Table 2.4: Data for urban biodiversity preservation

Urban species	Weather conditions	Human activities	Urban hazards
Inventory	Temperature	Construction	Flood
Witness species	Humidity	Noise pollution	Storms
Alien species	Air quality (pollution,...)	Light pollution	Earthquakes
Species habitat (Location, continuity,é)	Rainfall	Soil, water pollution	Fires
Species activities	Wind	Air pollution	Industrial
Species health		Changing in land use	

2.6.5 Data analysis

Data analysis includes the use of engineering, environmental, safety and information technology tools such as Artificial Intelligence (AI) to transform real-time and historical data into operational data with the objective to reinforce the efficiency and safety of urban systems and to improve the quality of life of citizens. Today, the use of AI becomes popular, because it allows learning from real data, to establish patterns of complex system behaviour, to detect rapidly abnormal events, to take mitigation measurements and to improve the system efficiency.

Data analysis includes the following:

- Analysis of species patterns, including their health and activity at a regular time interval and specific critical events (hazards). This analysis concerns species spatial distribution as well as habitat connectivity. Change in pattern should be visualized using spatial maps (GIS) as well as quantitative indicators.
- Analysis of causal factors (weather conditions, human activity, urban hazard) using statistical methods or more advanced methods such as AI in order to identify ñabnormalò as well as their amplitude and duration. These events could be characterized according to their impact by an intensity factor, which will be used in the following step.
- Correlation and causal analyses to establish relationships between the evolution of species patterns and causal factors, characterized by their intensity.

2.7 Conclusion

This chapter presented the importance of urban biodiversity monitoring and how the use of the Smart City solution could help in improving this monitoring. Urban biodiversity monitoring includes aims at collecting at different time and spatial scales data concerning urban spices and their habitat as well as factors that impact these species. Analysis of these data results in an enhanced understanding of threats on biodiversity and then in establishing strategies for urban biodiversity protection.

The proposed methodology for biodiversity monitoring includes the following stages (Table 2.5):

1) Stage 1: Determination of the objectives and expectation of the biodiversity monitoring program of the concerned area. This phase requires discussion with policymakers, citizens, civil society and experts. It results in a document ñObjectives and roadmap of the biodiversity programò, which should be approved by the concerned institutions.
2) Stage 2: Collection of general data of the site such as soil use, green areas, water areas, species, soil and air pollution, weatheré These data should be stored in a GIS system, and analyzed in order to understand the real situation of the concerned

area and its challenges. The outcome of this phase includes GIS maps with collected information.

3) Stage 3: Determination of indicators to be monitored, based on section 2.4 of this chapter and the results of stages 1 and 2. The outcome of this phase will be presented in a document ñMonitoring programò which includes the indicators and the way of monitoring each indicator.
4) Stage 4: Implementation of the monitoring program. It includes the construction of the smart platform, the installation of sensors and methods for data collection from different sources, data communicationé A report ñImplementation of the smart monitoringò will present detailed information about the monitoring program, guides and manuals about sensors, difficulties and awareness, maintenance of devices,é
5) Stage 5: Data analysis. It includes implementation of tools for analysis and visualization of data, such as statistic tools, AI tools. A document ñAnalysis toolsò should present the tools used in the system, as well as manuals for their use with some examples.
6) Stage 6: Reporting. This phase includes the reporting activity at different periods. Short period for the daily/weekly observation, monthly period with more detailed information and yearly period with extensive results and analysis.
7) Stage 7: Improvement of the monitoring program. It includes a continuous improvement of the monitoring system based on observations reports.

The next chapter will present the application of this methodology on the biodiversity monitoring of the Campus of Lille University in the North of France.

Table 2.5: Methodology for the biodiversity monitoring

Stage	**Tasks**	**Outcome**
Stage 1	Objectives and expectation	Report ñObjectives and roadmap of the biodiversity programò
Stage 2	Collection of general data	Report ñGIS maps with collected informationò
Stage 3	Biodiversity indicators	Report ñlist of indicators, methods of monitoring,..)
Stage 4	Implementation of the monitoring program	Report with detailed information about the monitoring program, guides and manuals difficulties, maintenance
Stage 5	Data analysis	Report with analysis and visualization tools, manuals, some examples.
Stage 6	Reporting	Reports at different periods (short, medium and long) with major observations and recommendations.
Stage 7	Improvement	Improvement of the monitoring system based on observations reports,

3 Chapter 3:

Application on the biodiversity monitoring of the Scientific Campus of Lille University

3.1 Introduction

This chapter presents the application of the methodology presented in chapter 2 to the scientific campus of Lille University. This campus is located in the city of Villeneuve d'Ascq in the North of France. It has an area of around 110 hectares. Since the area of the campus is very small to be considered as an ecosystem for the biodiversity evaluation, this application aims at exploring the application of the methodology presented in the second chapter. More generally, the objectives of this work aims to (i) Identify the biodiversity profile of the campus, (ii) Identify, locate and track species on the campus, (iii) Track changes in land used, (iv) Assess the pollutions on the campus including air and soil quality, noise and light, (v) Analyze the relationship between causal factors and the biodiversity and (vi) Raise awareness of biodiversity conservation.

The chapter presents successively the scientific campus, the indicators used in this work, data collection and analysis and finally the main outcome of this work and recommendations for the preservation of the biodiversity at the scientific campus.

3.2 Presentation of the Scientific campus

The Scientific campus of Lille University is located near the North of France. The campus stands for a small town with an area of 110 hectares and about 25,000 users including students, faculty members and technical and administrative staffs. It was constructed between 1964 and 1966. Later on, some buildings were renovated, while others were constructed. The campus includes 145 buildings with a total construction area of 325,000 m^2. Buildings are used for research, teaching, administration, studentsô residences and entertainment activities. The campus is deserved by 100 km of urban networks: drinking water, stormwater, sanitation, electrical grid, public lighting, district heating and roads. Figure 3.1 shows the. Google earth illustration of the Scientific campus

Figure 3.1: The Scientific campus - Villeneuve d'Ascq (Google earth)

3.3 Biodiversity indicators

Tables 3.1 to 3.3 resume the indicators used for the biodiversity monitoring of the scientific campus. Table 3.1 provides the details of the set of state biodiversity indicators. They include (i) the proportion of green area as well as their connectivity and (ii) the localization and distribution of species selected in this study including birds and plants. Data about birds come from the studentsô associate of environment protection on the Scientific campus - University of Lille and city of Villeneuve Dôascq, while data about the plants are provided by Lille University. Unfortunately, some indicators such as the change in the number of native species and the proportion of invasive alien species are missing.

Table 3.2 provides indicators related to the causal factors. They include the temperature and humidity, which are measured by sensors installed within this work and from the weather data of METEO France as well as the precipitations, which are obtained from METEO France. Human activity is monitored through change in land used, air pollution, soil pollution, noise and light pollution. Change in land use is provided by the university. Data about air pollution are collected from the air quality monitoring station ATMO[8]. Data about Noise pollution, soil pollution and light pollution are missing.

Table 3.1: Set of state biodiversity indicators

Indicators		Type of data	Source
Coverage	Proportion of green areas	Green area	Google maps and satellite images
	Connectivity/Fragmentation of green areas		
Biology	Abundance and distribution of selected species (selected by city)	Plants	http://biologie-enligne.univ-lille1.fr/campus
		Birds	City of Villeneuve D'ascq and MERLE (Movement of Students Reunited for the Eco-Citizen Struggle and environment protection on the Scientific campus - University of Lille)
		Insects	Biology department - University of Lille
	Change in native species		Missing
	Invasive alien species		Missing

Table 3.2: Set of biodiversity causal indicators

Indicators		Type of data	Source
Physical factors	Temperature, Humidity of soil	T, H	sensors system
	Weather conditions	Temperature	Meteo France (http://www.meteofrance.com)
		Humidity	
		Precipitation	
Human activities	Changing in land used	land used	Satellite images
	Air pollution	Nitrogen dioxide (NO_2)	Atmo (https://www.atmo-hdf.fr/)

[8] https://www.atmo-hdf.fr

		Nitric oxide (NO)	
		Ozone (O_3)	
		PM10	
		PM2.5	
	Soil pollution		Missing
	Noise pollution		sensors system
	Light pollution		Missing

Table 3.3 provides the details about the indicators of the biodiversity management. They include data about the budget for the biodiversity preservation and data about the collaboration of the university with external partners.

Table 3.3: Set of biodiversity management indicators

Indicators		**Source**
Finance	Budget for urban biodiversity projets	Durable development ï University of Lille
Participation of stakeholder	Number of connections with agencies/private companies/NGOs/Academic or Institutions	Durable development ï University of Lille

For the evaluation of the biodiversity, we use a qualitative score system including 5 levels (Table 3.4). Level four is the highest (Excellent), while level one is the lowest score (Very bad).

Table 3.4: Score system used for the assessment of biodiversity indicators

Score	Description
0	Very bad
1	Bad
2	Medium
3	Good
4	Excellent

3.4 Data collection

3.4.1 State biodiversity indicators

3.4.1.1 *Coverage indicator*

The coverage indicator is described using two indicators: proportion of green areas and connectivity of these areas. These indicators are determined from field observations and the use of GIS system.

Figure 3.2 shows the distribution of the green area in the campus. It shows a distribution of zones with different size all over the campus. The calculation of the proportion of green area gives: 50%. This ratio indicates a good ratio for the campus, when compared to urban area. According to the scoring system presented in table 3.4, the qualitative score for this indicator is "Good".

Figure 3.2 shows that the green area zones are disconnected by roads and construction. The indicator was calculated by GIS and Fragstats software with its value is 10 ha. According to the qualitative evaluation score (Table 3.4), the score of this indicator is "Bad". However, if we consider this indicator for abundance and distribution of selected species (insects, birds, and plants), these "discontinuities" disappear and the score in this case is "Excellent".

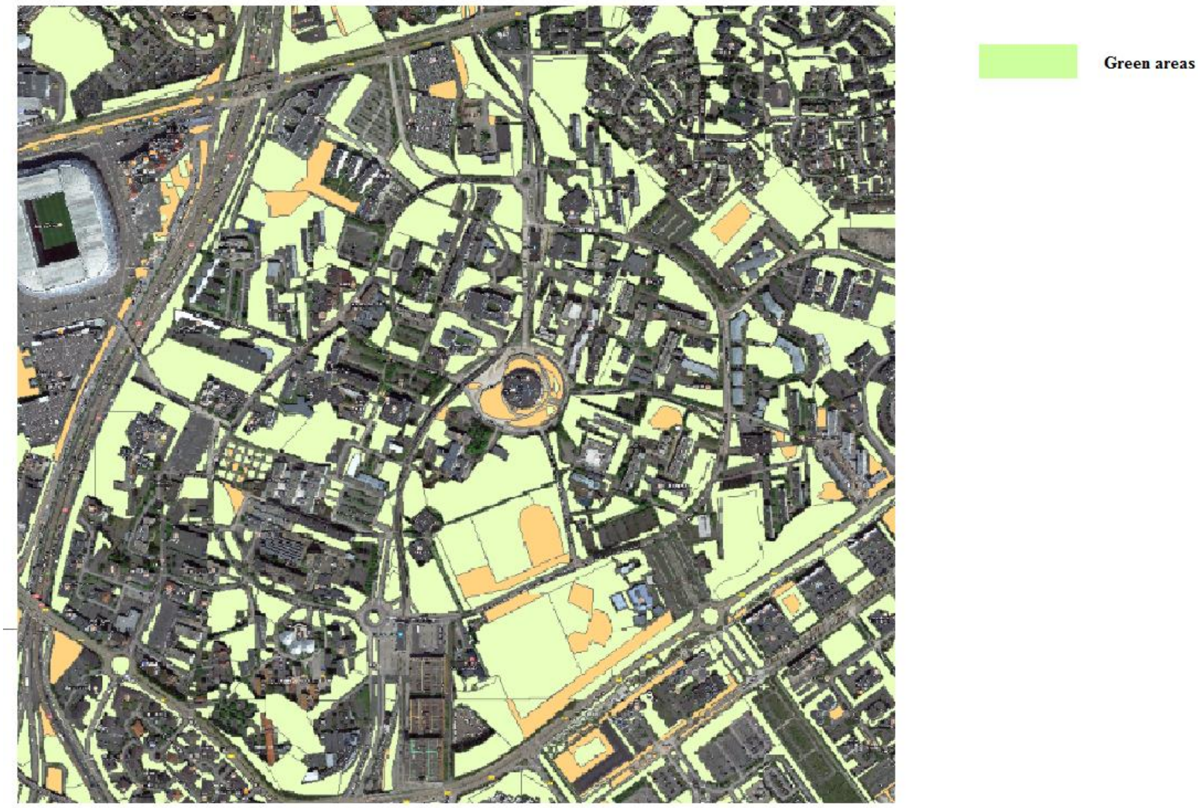


Figure 3.2: Green area in the Scientific Campus

3.4.1.2 *Abundance and distribution of selected species*

The abundance and distribution of selected species are described using three indicators: birds, insect and plants. Unfortunately, we did not succeed to collect information about other species.

Birds

Figure 3.3 shows data collected about birds on the campus for the period 30/01/2013 to13/04/2013. It shows the presence of 38 species. According to the French red list of threatened species[9], 2 of these species are vulnerable, 4 are in a threaten state and 29 are classified with low trouble state (Figure 3.4). It can be seen that those of Villeneuve d'Ascq and the Citadelle of Lille in 2002 ï 2003 (Figures 3.5 and 3.6). It can be observed that the number of birds in "low trouble state" in the campus is about 25% of that in Villeneuve d'Ascq and 32% of that in Lille Citadel in 2002-2003. This result indicates a deterioration in this number in about 10 years. However, this could be explained that Villeneuve d'Ascq is a big city with 20 times the area of the Scientific campus and Citadelle park is built as an ecological zone of Lille. Base on the score for this indicator, "Medium" is given for this indicator.

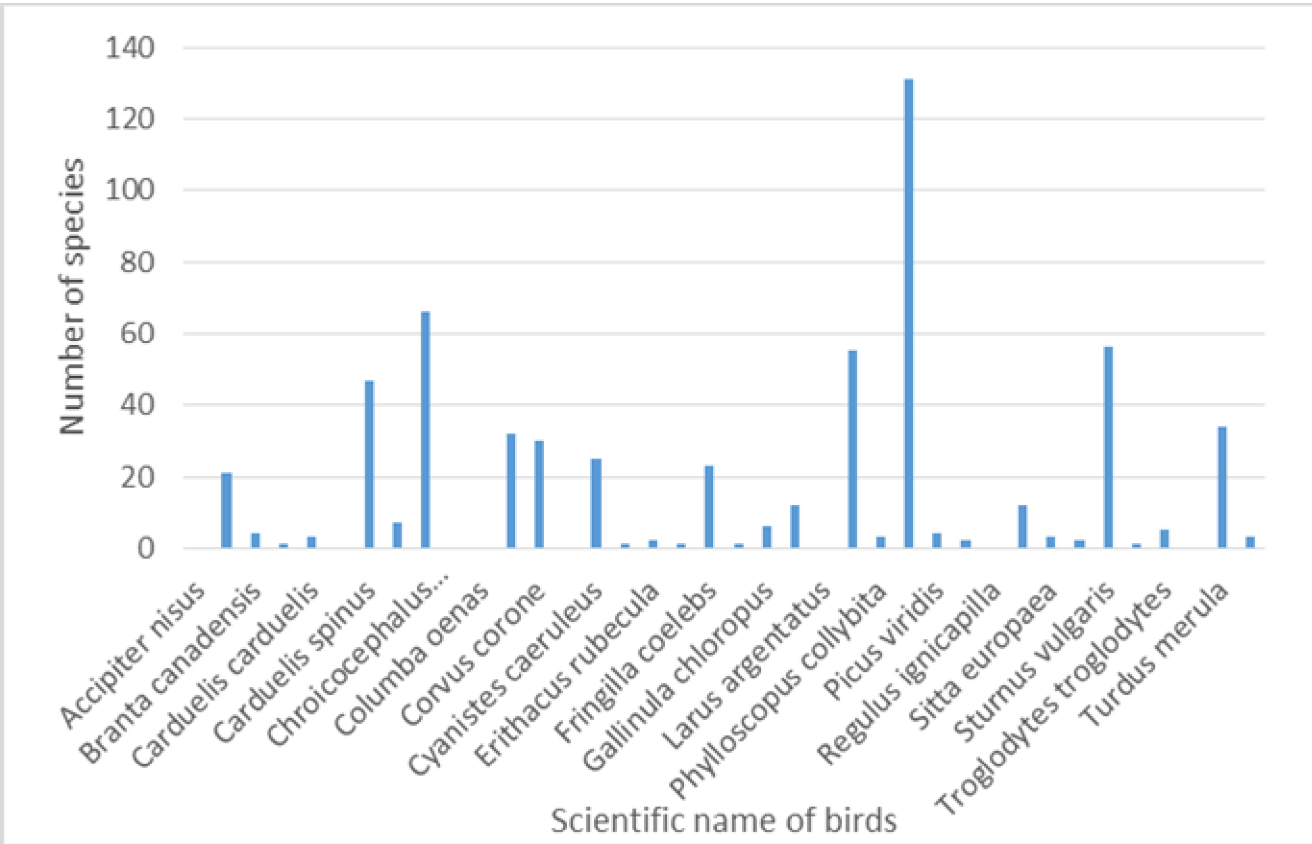


Figure 3.3: Birds observed in the Scientific campus during the period (30/01-13/04/2013)

9 https://inpn.mnhn.fr/docs/LR_FCE/Liste_rouge_France_Oiseaux_de_metropole.pdf

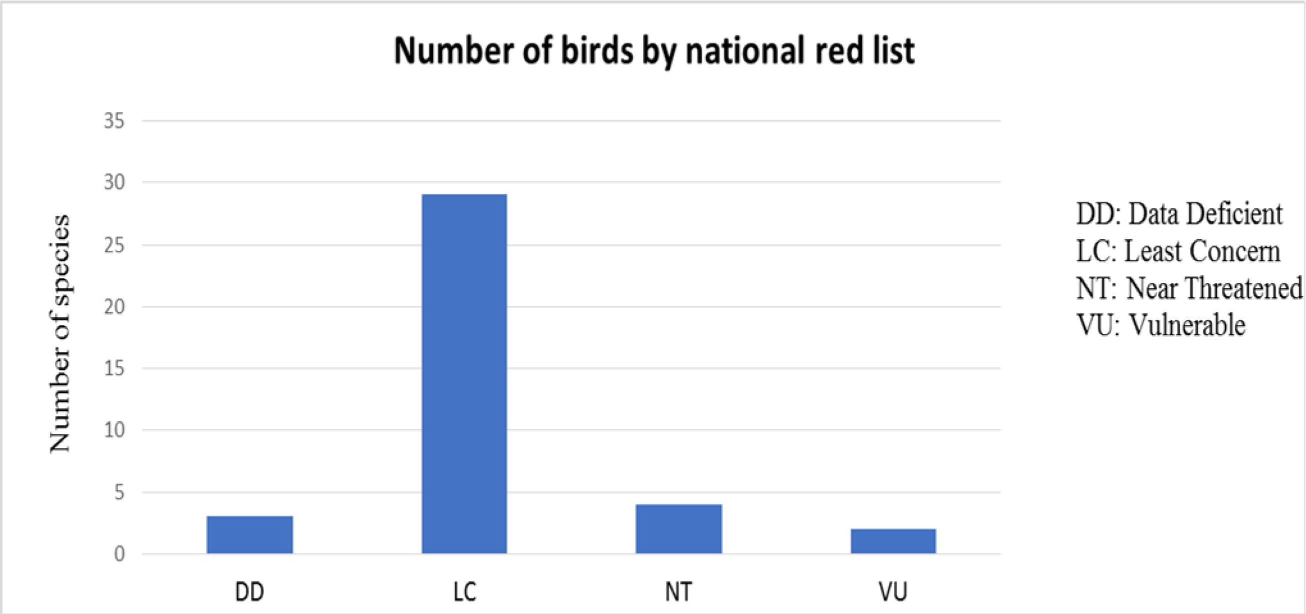


Figure 3.4: Number of birds observed according national red list in the Scientific Campus during the period (30/01-13/04/2013)

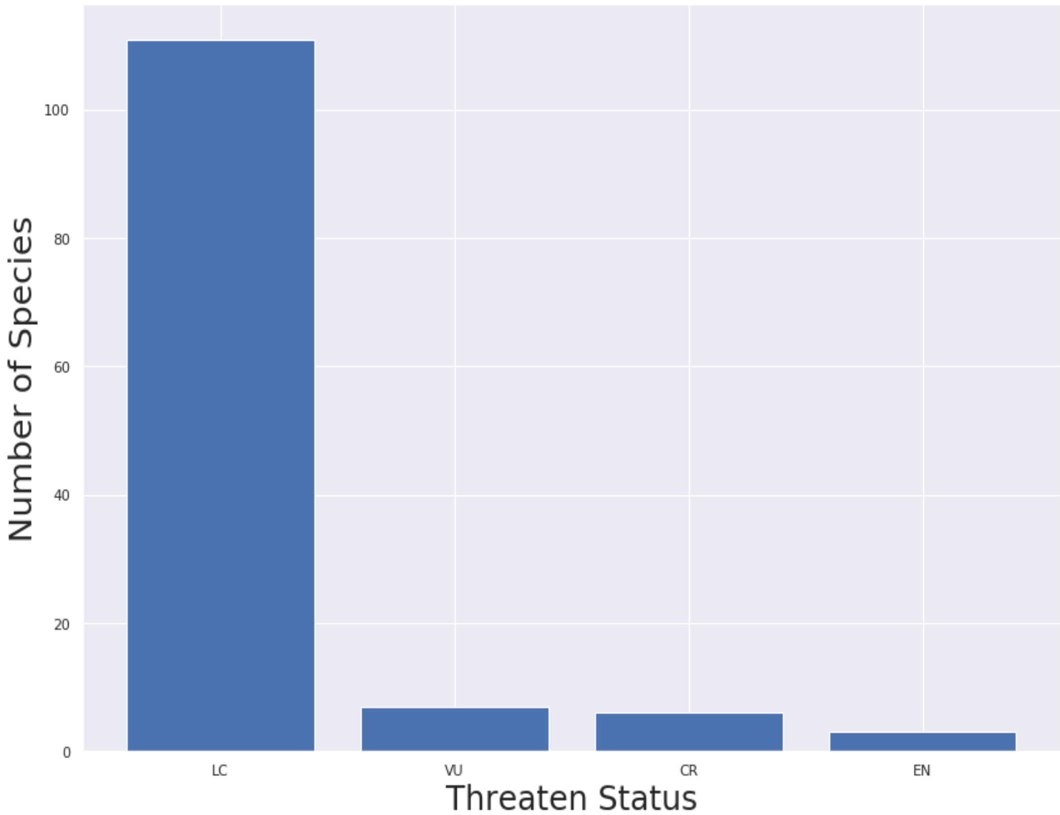


Figure 3.5: Classification of birds according National red list in Villeneuve d'Ascq (2002 - 2003)

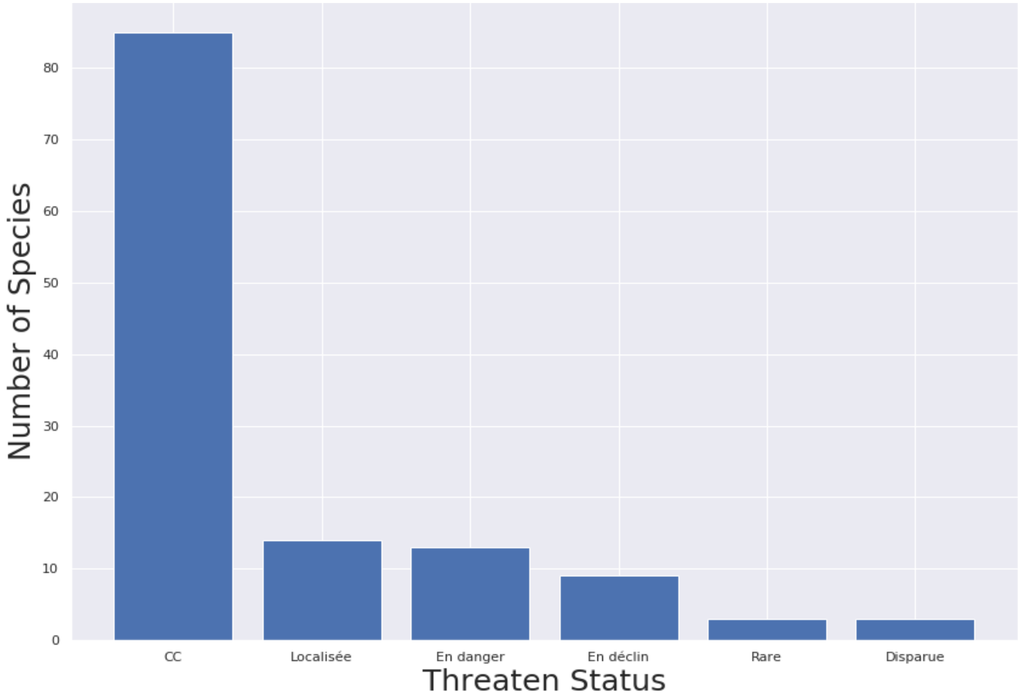


Figure 3.6: Classification of birds according Regional red list in the Citadel of Lille (2002 - 2003)

Insects

Figure 3.7 shows data collected about insects on the campus in May 2019, it shows the presence of 18 species which are in a group of insects that form the order Coleoptera. They are found in almost every habitat except the sea and the polar regions, they interact with their ecosystems in several ways: beetles often feed on plants and fungi, break down animal and plant debris, and eat other invertebrates. Some species are serious agricultural pests, such as the Colorado potato beetle, while others such as Coccinellidae (ladybirds or ladybugs) eat aphids, scale insects, thrips, and other plant-sucking insects that damage crops. Base on the score for this indicator in chapter 2, with 18 species observed in campus, based on the score of this indicator is ñbadò

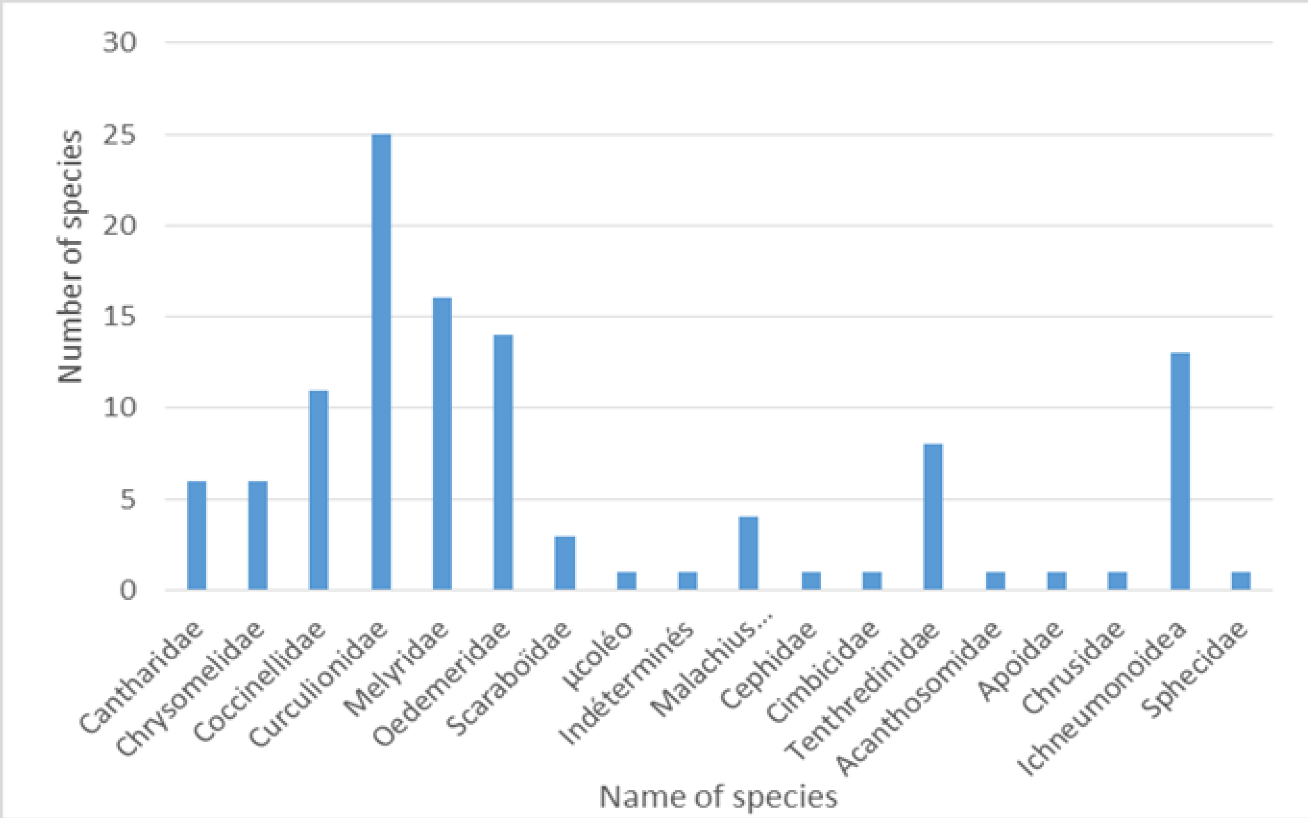


Figure 3.7: Insects observed in the Cite scientific Campus (05/2019)

Vegetations

Data about vegetation in the campus come from the course "Vegetation in the scientific campus of Bouchet et al. (2018) [10] . Around 313 species are reported in the campus. The majority is related to the construction of the campus in the 1960s. These species are classified into 11 categories, which are summarized in table 3.5 and the appendix. Data show an important variety in the vegetation, which has been conserved over time. For this reason, a score "Good" is given for this category.

10 Marie-Hélène Bouchet, Michel Descamps, Marie-Chantal Fabre (2018) Course vegetation in the scientific campus, Lille University, https://biologie-enligne.univ-lille.fr/campus/co/000_module_vegetation_campus.html.

Table 3.5 Main categories of vegetations in the campus (Data source[11])

Category	Number of species
Trees of the beech forests	21
Natural trees in the North	15
Ornamental shrubs	31
Shrubs and bushes of oak-beech	33
Ornamental shrubs	38
Plants of traffic areas	10
The lawns mowed regularly	14
The "weeds" of the flower beds	48
Waste land plants	96
In the basin	5
Mosses and lichens	2
Total	313

3.4.2 Causal factors

The causal factors include the following indicators: soil temperature and humidity, weather conditions, changes in land used and air pollution. and light and noise?

3.4.2.1 *Weather conditions*

Data about the weather are provided by the station Lesquin of Météo-France[12], which is close to the campus. Figure 3.8 shows data for the period 1973 - 2020 concerning the temperature variation. The continuous line in green shows the variation of the yearly mean temperature. Despite some fluctuation, it shows an increase of about 2°C during the period 1973 - 2020. The continuous lines in red and in bleu show the variation of the yearly mean maximum and mean minimum temperature, respectively. Despite some fluctuations, they

12[1] (http://www.meteofrance.com)

show an increase of about 3°C in both temperatures during the period 1973 - 2020. The discontinuous line in red shows the variation of the yearly extreme maximum temperature. Despite some fluctuation, it shows an increase of around 11°C. The discontinuous line in bleu shows the variation of the yearly extreme minimum temperature. Despite some fluctuation, it shows stabilization. It shows also some extreme values such as in 1982, where this temperature dropped down to -20°C.

Figure 3.9 shows the number of days per year where the temperature exceeded 20°C (bleu), 25°C (green) and 30°C (red). Despite some fluctuations, the number of days with a temperature exceeding 30°C increased by around 14 days, while that with a temperature exceeding 25°C increased by around 35 days.

Figure 3.10 shows the number of days per year where the temperature was inferior to 0°C (green), -5°C (black) and -10°C (bleu). It shows that despite important fluctuations the number of days per category decreased over the period 1973 - 2019. The observations concerning the number of days concerned by extreme values of the temperature are confirmed by figure 3.11.

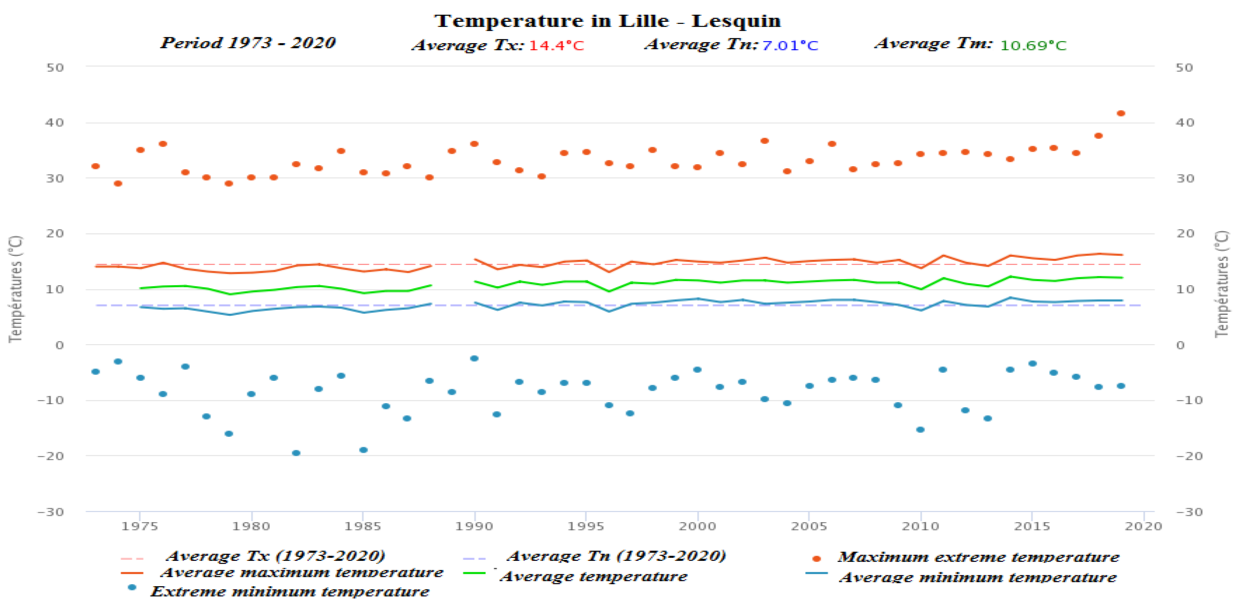


Figure 3.8: Variation of the temperature at Lille - Lesquin station - period 1973 - 2020
Data sources: Info climat https://www.infoclimat.fr/mon-compte-infoclimat-messagerie-privee.html

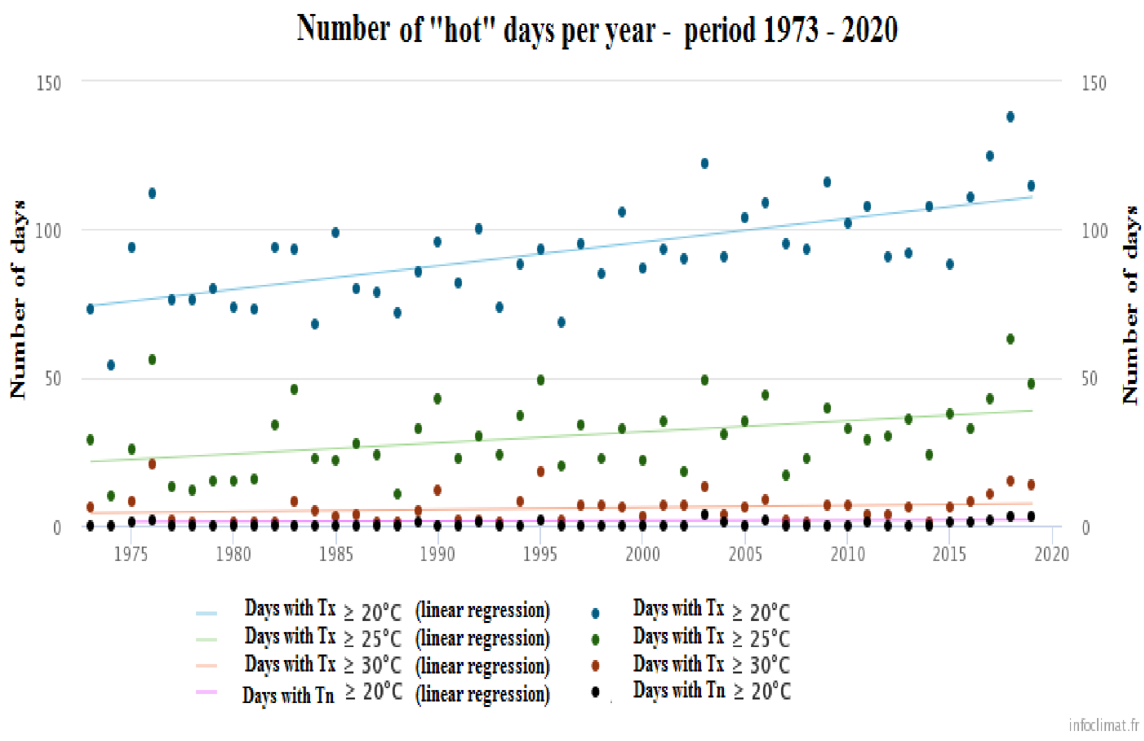


Figure 3.9: Variation of the number of "hot" days per year - period 1973 - 2020
***Data sources: Info climat** https://www.infoclimat.fr/mon-compte-infoclimat-messagerie-privee.html*

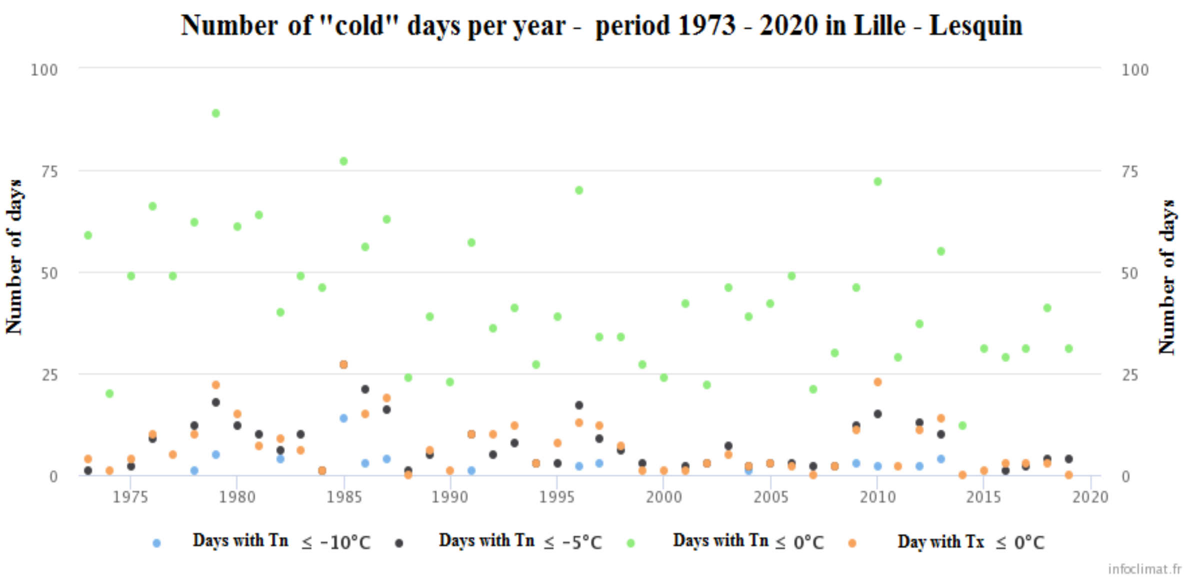


Figure 3.10: Variation of the number of "cold" days per year - period 1973 - 2020
***Data sources: Info climat** https://www.infoclimat.fr/mon-compte-infoclimat-messagerie-privee.html*

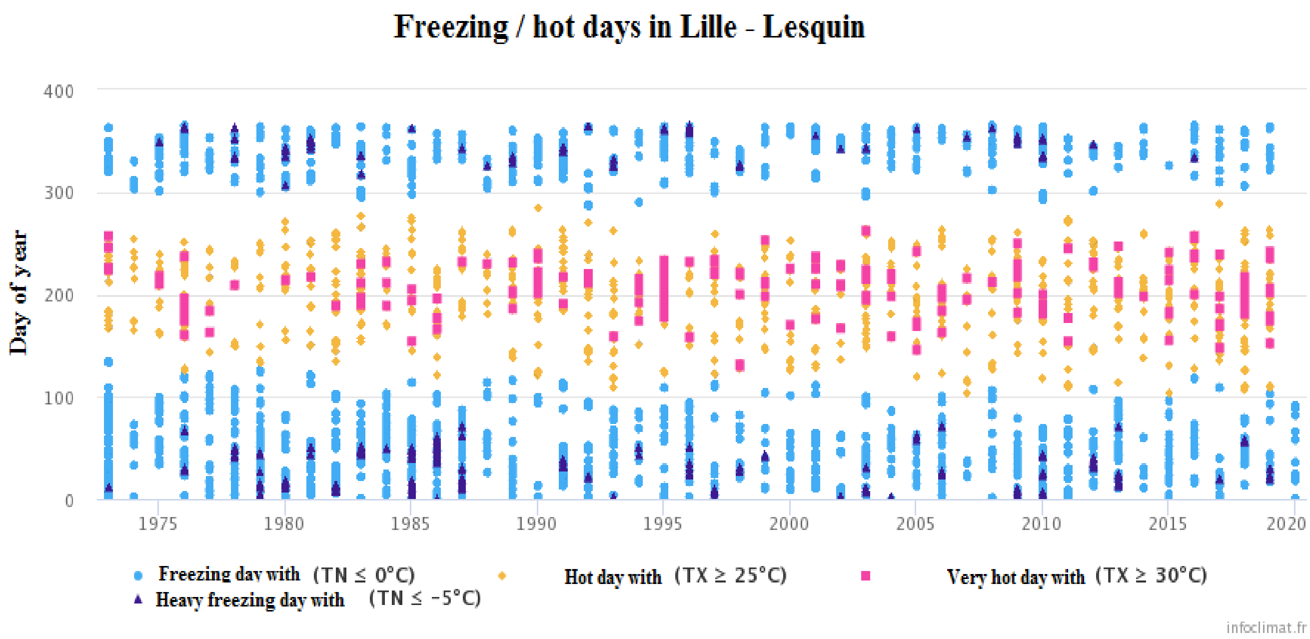


Figure 3.11: Variation of the repartition of days according to the temperature level
Data sources: Info climat https://www.infoclimat.fr/mon-compte-infoclimat-messagerie-privee.html

Figure 3.12 shows the variation of the monthly mean humidity for the period 2010 - 2019. It shows fluctuation around a mean value of 80%. The maximum mean value of the humidity is around 91%, while the minimum value is around 65%, except two values in 2015 and 2018. Globally, the humidity in Lille is high.

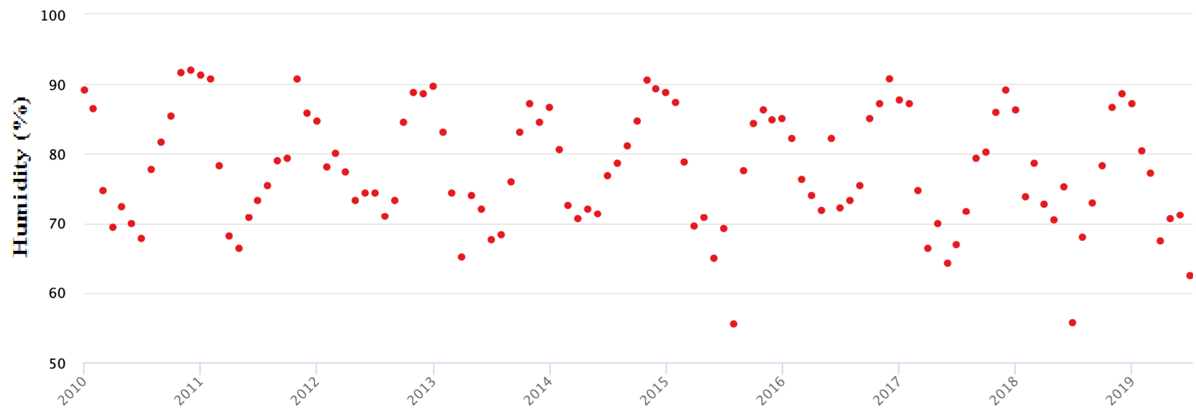


Figure 3.12: Variation of the monthly mean value of the humidity (2010 - 2019)
Data sources: Info climat https://www.infoclimat.fr/mon-compte-infoclimat-messagerie-privee.html

Figure 3.13 shows the variation of the annual precipitation (AP) during the period 1973 - 2019. It shows an important variation with a minimum of 470 mm in 1976 and a maximum of 1150 mm in 1992. In the last three years, we observe low values of AP (around

630 mm). Figure 3.14 shows the variation of the number of days per year with daily precipitation (DP) exceeding 1mm (bleu), 5 mm (black) and 10 mm (green). It shows some peaks in the 1990th. In the last years, we observe a stabilization around the values: 20 days for DP >= 10 mm, 50 days for DP >= 5 mm and 120 days for DP >= 1 mm,

Globally, we observe a deterioration in the weather conditions with a global heating of around 2°C since 1973. For this raison, a score of "Medium" is given for the weather.

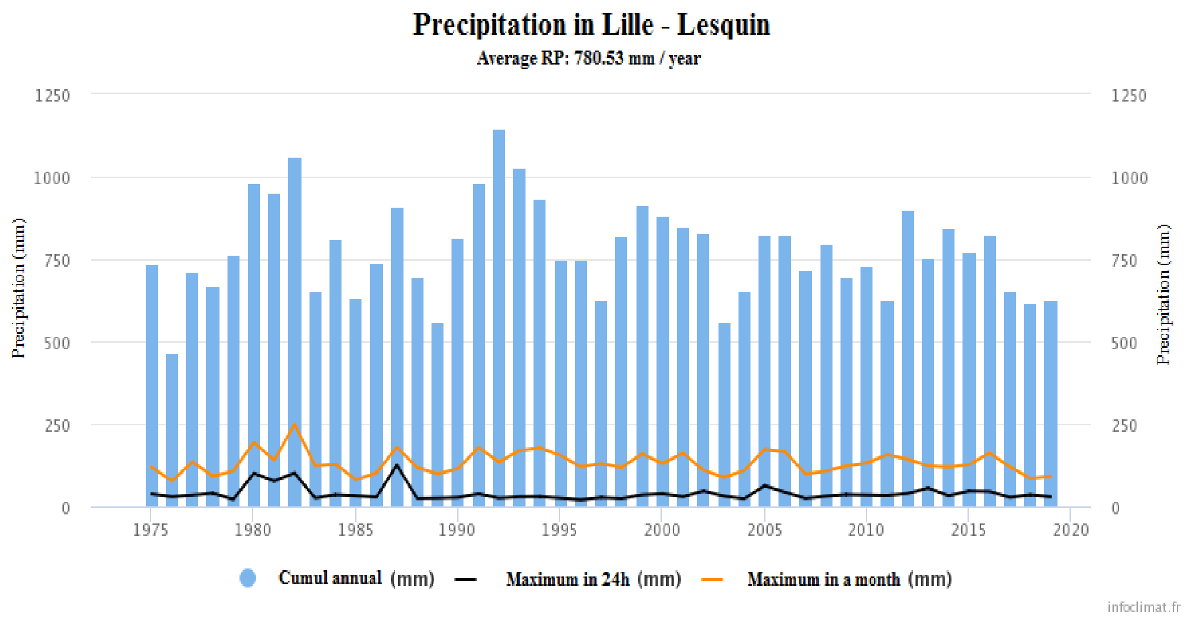


Figure 3.13: Variation of the precipitation monthly mean (1973 - 2019)
Data sources: Info climat ***https://www.infoclimat.fr/mon-compte-infoclimat-messagerie-privee.html***

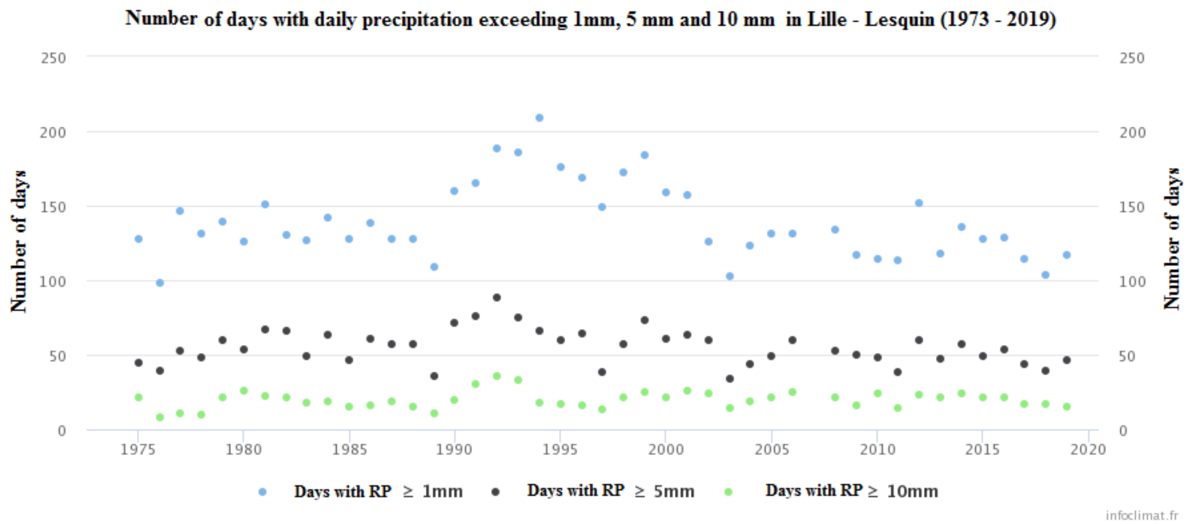


Figure 3.14: Variation of the number of days with daily precipitation exceeding 1mm, 5 mm and 10 mm (1973 - 2019)

Data sources: Info climat https://www.infoclimat.fr/mon-compte-infoclimat-messagerie-privee.html

3.4.2.2 *Land use*

The main land use in the campus includes buildings and green area that include woodland and grassland. Data were collected from satellite images. Looking back at the campusôs construction from satellite images, it can be seen that before 1960s, this place was only agricultural plots or abandoned land. The strong construction process began in the 1960s to 1980s and continues to this day which leads to a dramatic change in land use here. Figure 3.15 shows the variation in the land use between 1997 and 2018. It shows an important reduction of total green area. In 1997 the green area accounted for 68% of the campus surface, this percentage decreased to 57% in 2008 and then to 49% in 2018. However, this change has a positive point that the wasteland is converted into woodland from 0% to 11% and this ratio has maintained throughout the planning process until now. **This variation indicates a degradation in the land use with regard to the biodiversity, a score of "Medium" is given for this indicator.**

Figure 3.15: Change in land used in the Scientific campus

3.4.2.3 *Air quality*

Air pollution constitutes one of the main environmental threats for the biodiversity. According to the European Environment Agency, the air pollution monitoring should focus on the following pollutants: nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3) and particulate matter. Road traffic and fossil energy production constitute the major cause of NO_2, while SO_2 is mainly emitted by the industrial activity. O_3 is formed from oxides of nitrogen (NOx) and volatile organic compounds (VOCs) under the action of light. Its concentration in urban area is lower than that in rural area, because it vanishes when it reacts with other pollutants (Pasquier & André, 2017). Particulate matter refers to solid and liquid particles in the air. It is produced by both human activity (traffic, domestic combustion, industry, construction activity) and natural activity (windblown dust, wildfires and volcano eruptions activities. Table 3.6 summarizes the EU references values and WHO (World Health Organization) quality guidelines (AQGs) for main air pollutants. It shows that the WHO quality guidelines are mostly stricter than that of the EU, in particular for PM2.5, PM10 and SO_2.

Table 3.6: French and EU standards for the air pollution

Pollutant	EU reference values ($\varepsilon g/m^3$)	WHO air Quality Guidelines (AQGs) ($\varepsilon g/m^3$)
PM2.5	25 (annual mean)	10 (annual mean) 25 (24-h mean)
PM10	40 (annual mean) 50 (24-h mean) (not to be exceeded on >35 days/year	20 (annual mean) 50 (24-h mean)
NO_2	40 (annual mean) 200 (1-h mean)	40 (annual mean) 200 (1-h mean)
O_3	120 (8-h mean)	100 (8-h mean)
SO_2	125 (4-h mean) (not to be exceeded on >3 days/ year)	20 (24-h mean) 500 (10-min mean)

Since air pollution is dependent on human activity, its concentration could have important spatial and time variation. In order to explore this variation, air pollution was measured at different locations (figure 3.16) in the scientific campus (Dung, 2018) in May of 2018. Figure 3.17 shows the NO_2 concentration in the campus. The highest values are recorded at the 4 cantons and IMT locations, which are close to the traffic axes. The mean value is around $27\varepsilon g/m^3$, while the maximum value is equal to 50 $\varepsilon g/m^3$. These values are accepted for human health according to the French and European standards.

Figure 3.18 shows the PM10 concentration in the campus. The highest values are also recorded also at the 4 cantons and IMT locations. The mean value is around 20εg/m^3, while the maximum could reach 160εg/m^3. However, these values are accepted for human health according to the French and European standards.

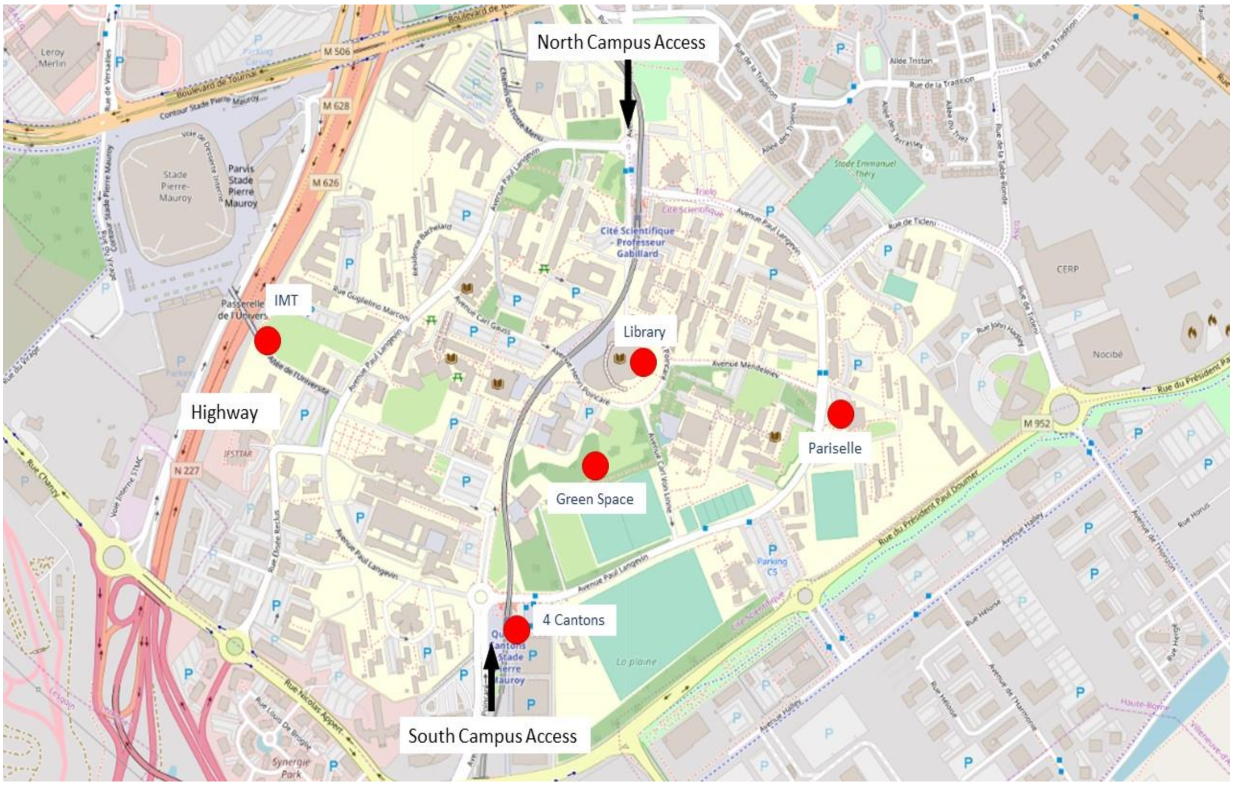


Figure 3.16: Position of monitoring points in the campus

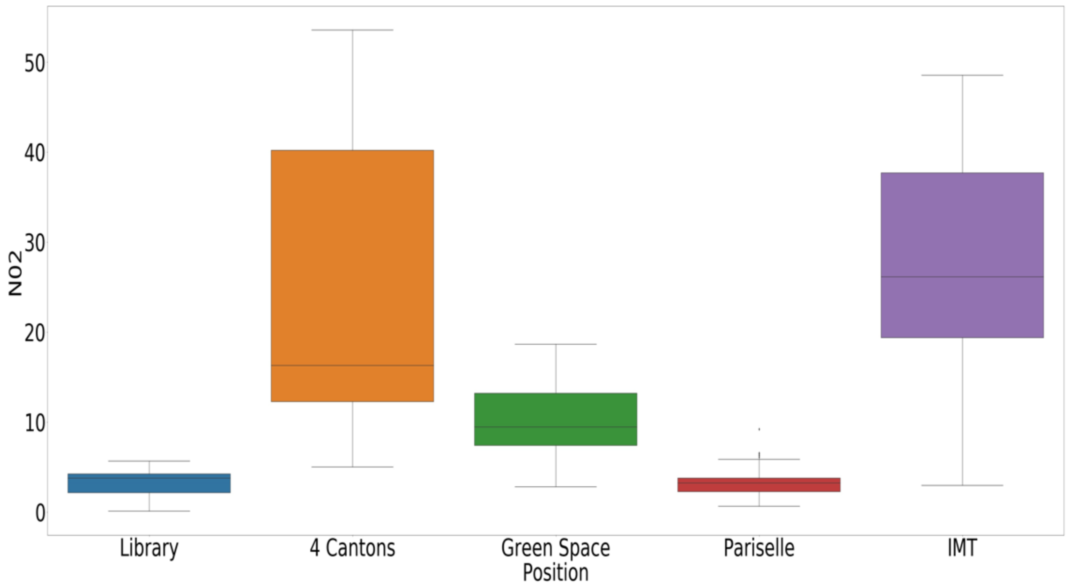


Figure 3.17: NO_2 concentration in the campus (5/2018)

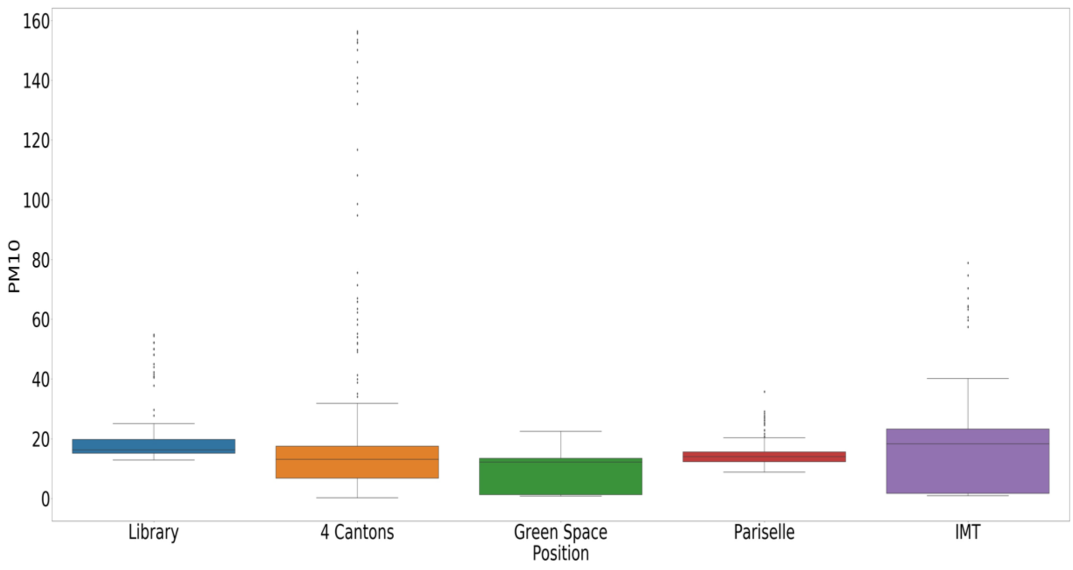
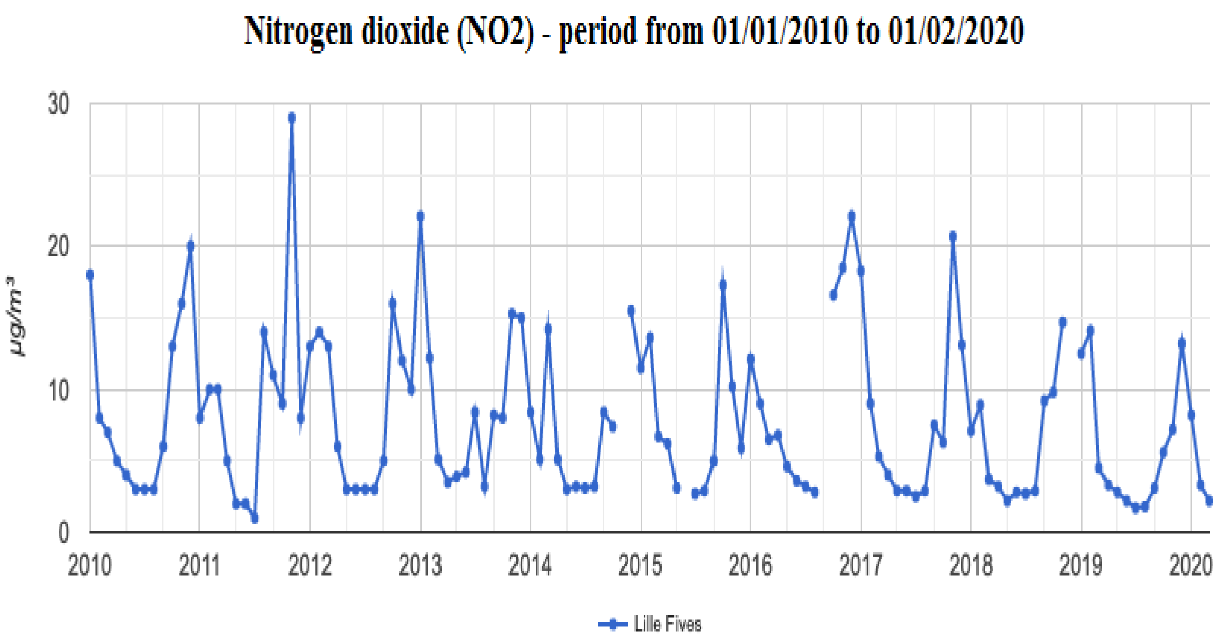
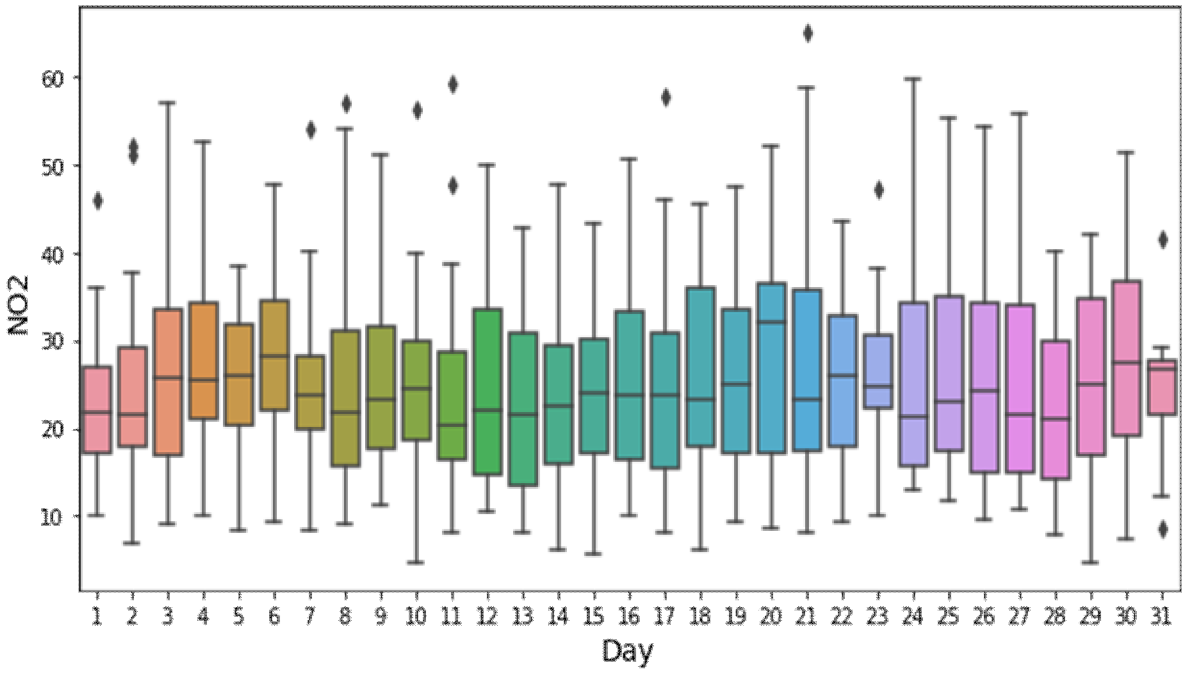


Figure 3.18: PM10 concentration in the campus (5/2018)

Data of air quality were also collected from the ATMO air quality station located in Lille Fives, which is about 4 km from the Scientific Campus (https://www.atmo-hdf.fr/). Figure 3.19 shows the variation of the monthly mean value of the Nitrogen dioxide (NO_2) in the period 2010 - 2020. It shows a variation between 1 and 30 (ε g/m^3). These values are accepted according to the French and European standards.



(a)

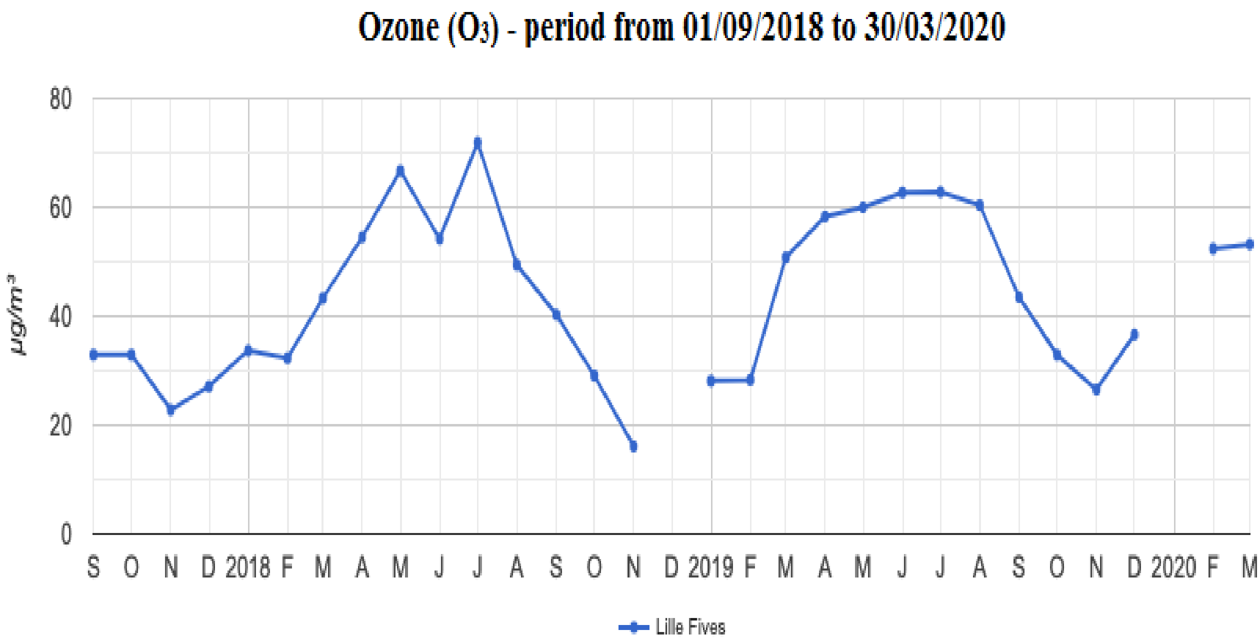


(b)

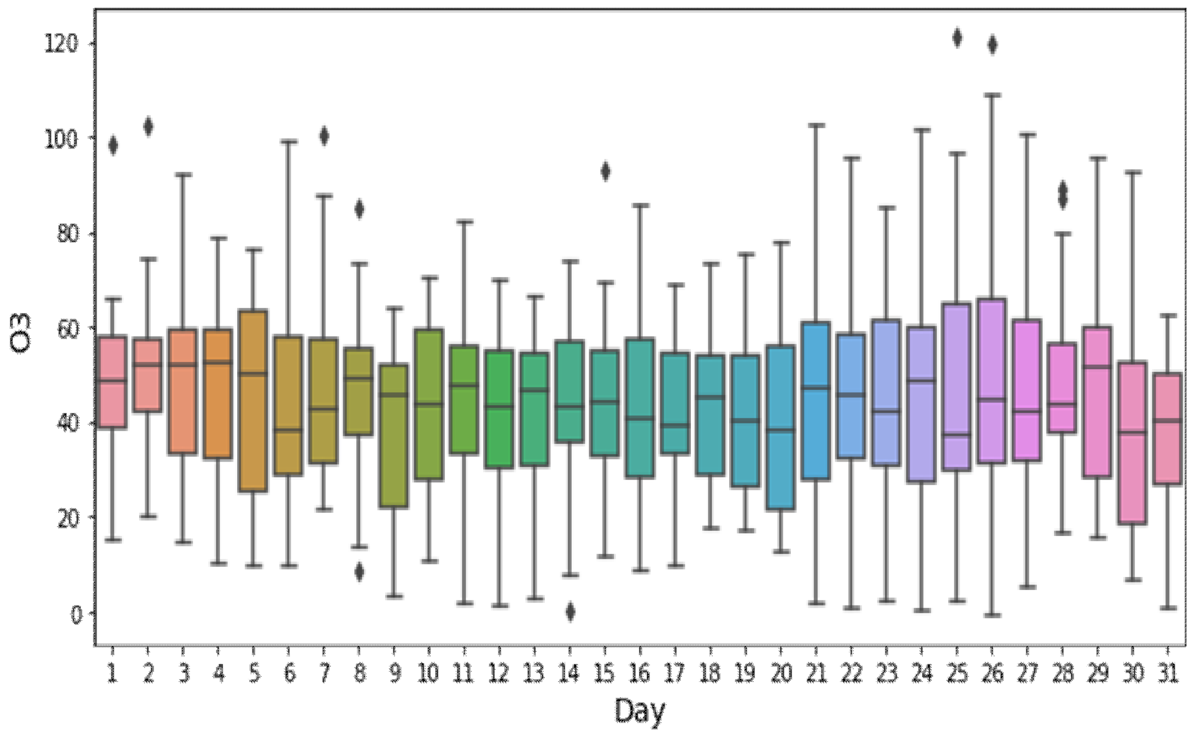
Figure 3.19: Variation of nitrogen dioxide (NO2) at ATMO Lille-Five station
a) Monthly mean of (period 2010 - 2020) b) Daily mean (2018-2019)

Data Source: ATMO (https://www.atmo-hdf.fr/).

Figure 3.20 shows the variation of the monthly mean value of the ozone (O_3) in the period 2018 - 2020. It shows a variation between 15 and 70 (εg/m^3). These values are well accepted according to the French and European standards.



(a)



(b)

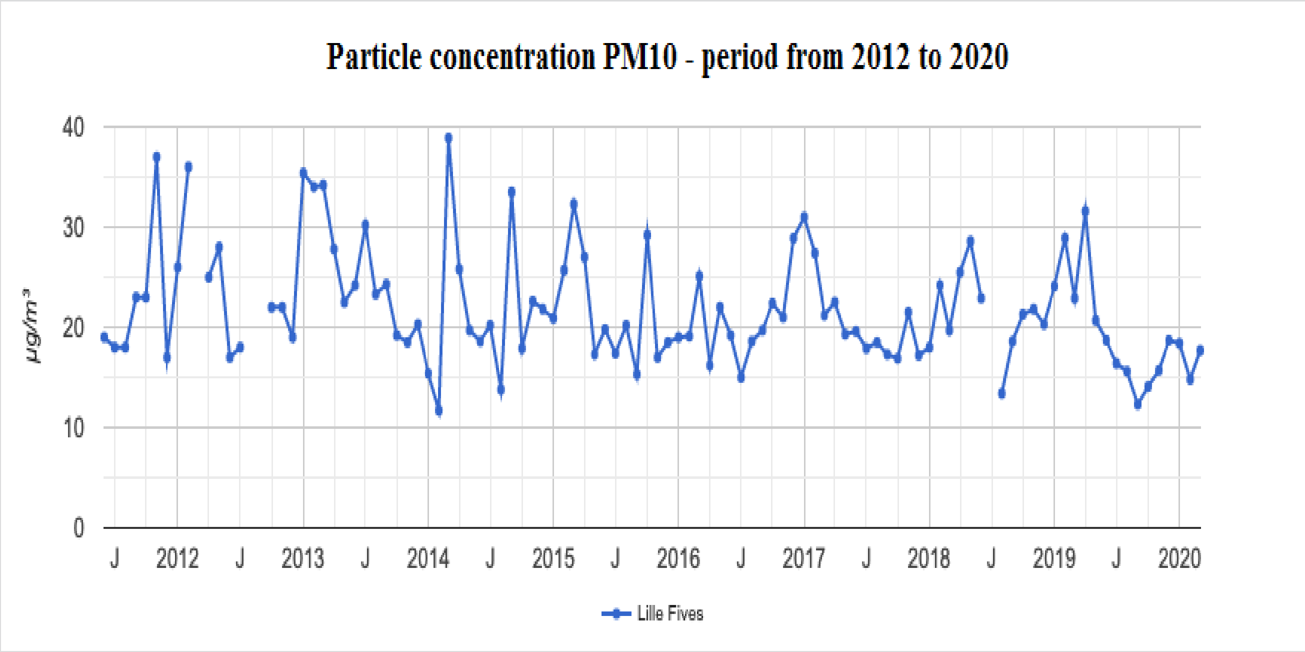
Figure 3.20: Variation of the monthly mean of the Ozone (O_3) at ATMO Lille-Five station a) Monthly mean (period 2018 - 2020) b) Daily mean (2018-2019)

Data Source: ATMO (https://www.atmo-hdf.fr/).

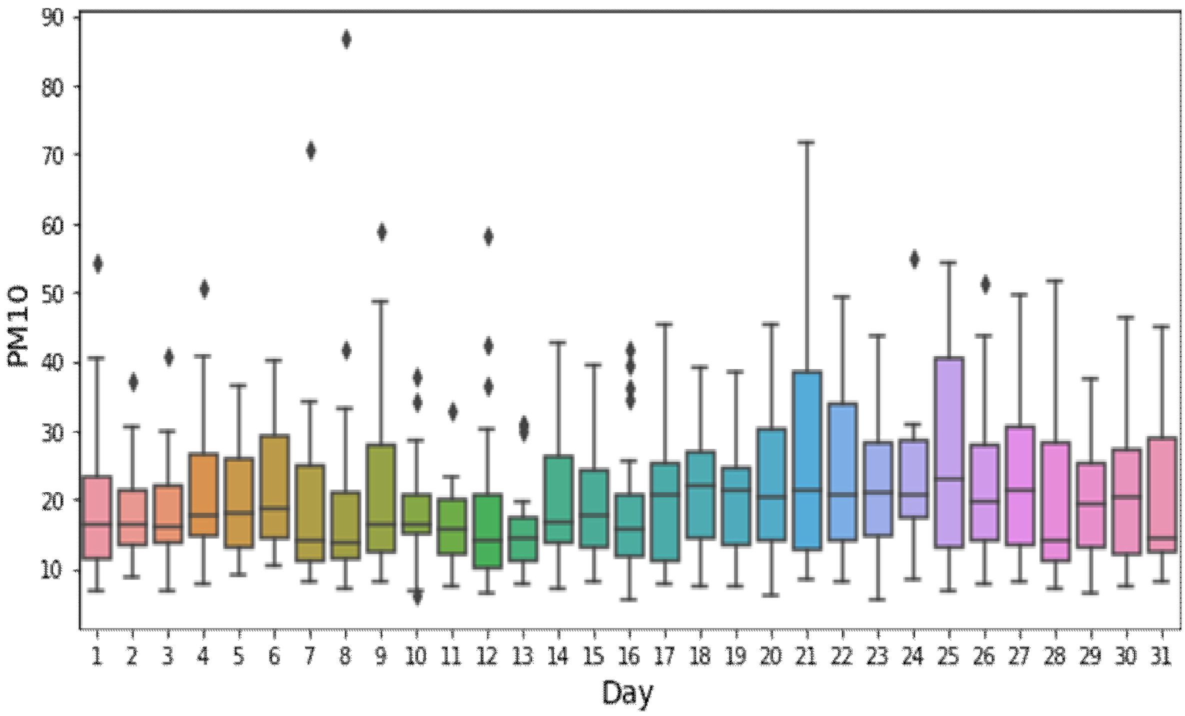
Figure 3.21 shows the variation of the monthly mean of the particle concentration PM10 in the period 2012 - 2020. It shows a variation between 10 and 40 (εg/m^3). These values are under the French and European standards.

Figure 3.22 shows the variation of the monthly mean of the particle concentration PM2.5 in the period 2010 - 2020. It shows a variation between 7 and 40 (εg/m^3). However, the yearly mean concentration is inferior to the French and European thresholds (20 εg/m^3).

Globally, the concentration of the air pollution at the campus is acceptable according to French and European standards. Consequently, the score for the air quality indicator could be considered as "Good".



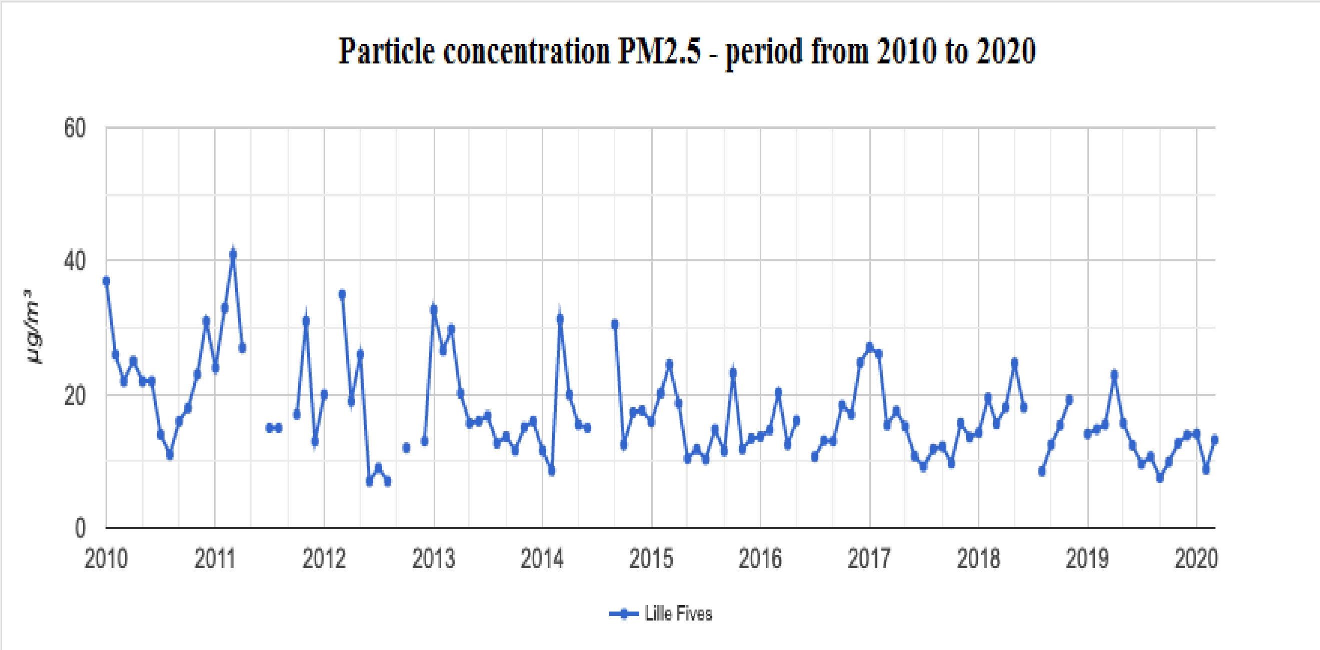
(a)



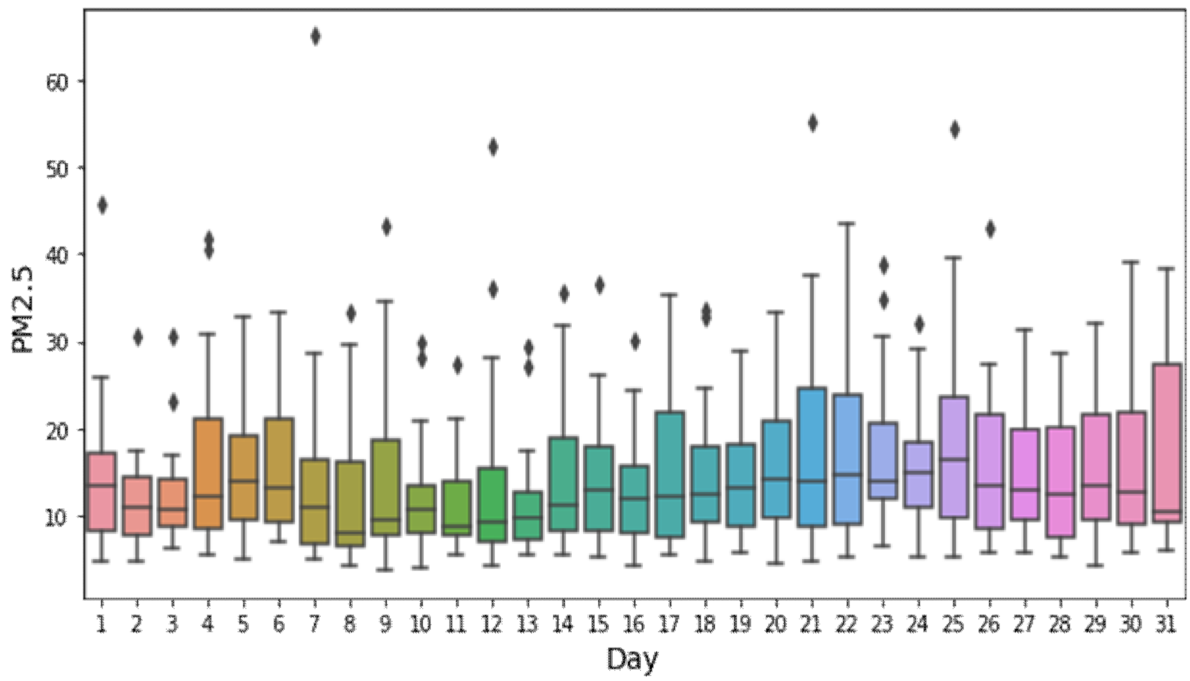
(b)

Figure 3.21: Variation of the monthly mean value of the particle concentration PM10
a) Monthly mean (period 2010 - 2020) b) Daily mean (2018-2019)

Data Source: ATMO (https://www.atmo-hdf.fr/).



(a)



(b)

Figure 3.22: Variation of the monthly mean value of the particle concentration PM2.5
a) Monthly mean (period 2010 - 2020) b) Daily mean (2018-2019)

Data Source: ATMO (https://www.atmo-hdf.fr/).

3.4.2.4 *Indicators for the biodiversity management*

Indicators for the biodiversity management include data about the budget for the biodiversity for the scientific campus and the local, national and international cooperation in the field of preservation of the campus biodiversity.

According to the durable development commission of university of Lille, in 2019, the budget allocated to biodiversity protection measures and environmentally friendly maintenance practices amounted to ú 23,000 including tax (rounded). Among this budget, the provision of ecological pasture represents approximately 50%. This amounts to about 0.7% of total annual campus budget thus the score for this indicator is ñMediumò

Currently, the durable development commission of university of Lille has the cooperation regularly with other partners following:

- Le Merle student association
- Les Blongios association
- UnisCité association
- Groupe Ornithologique of Nord association (GON)
- Coordination Mammalogique of Nord in France association (CMNF)

With this cooperation, the score is ñMediumò

The global score for both indicators is "Medium".

3.4.3 Synthesis

The table 3.7 summarizes the score for the different indicators as explained in previous sections. The state of biodiversity is considered "Medium to Good". However, data are still missing about "animal» species. This score requires yet additional information. The score "Good" is given for the green space and air quality; however, the reduction in the green space is worrying, a score "Bad" is given for the strategy of land use. The score of the weather is "Medium", because of the global heating. The score for the biodiversity management is "Medium", because of a deficiency in financial support and cooperation in this area.

Table 3.7: Score of biodiversity indicators

	Indicator		**Score**
Biodiversity	Coverage indicator	Proportion of green areas	***Good***
		Connectivity/Fragmentation of green areas	***Bad***
	Biology	Abundance and distribution of selected species	***Medium (Birds)*** ***Bad (insects)*** ***Good (vegetation)***
Cause factors	Physical factors	Weather conditions	***Medium***
	Human activities	Changing in land used	***Medium***
		Air pollution	***Good***
Management indicators	Finance	Budget for urban biodiversity projects	***Medium***
	Participation of stakeholder	Number of Agencies/Private Companies/NGOs/Academic Institutions/International Organizations with which the City is Partnering in Biodiversity Activities, Projects and Programs	***Medium***

3.5 Conclusion

This chapter presented the application of the methodology of biodiversity monitoring proposed in in chapter 2 to the scientific campus of Lille University. This campus was selected for an ease of data access. Area of this campus presents a mosaic of ecosystems and can, therefore, be considered as a small city for the biodiversity assessment. The application aimed at exploring the application of the methodology proposed in this work.

The collection of general data was relatively easy, but the collection of data concerning the state of biodiversity was very difficult. A lot of data is missing about the presence of different species and their evolution. However, some fragmented data were collected about insects and birds. Data about the vegetation were obtained from a course at Lille University. In the future, Lille University should establish a rigorous program for the identification of biodiversity species as well as their evolution.

Data about the causal factors are available. Meteo-France provides extensive data about the weather, while ATMO provides good information about the air quality. Analysis of weather data shows some deterioration for the biodiversity, because of a global heating of about 2 °C. Data about the air quality indicates good air quality in the campus. Local monitoring of the air quality confirms the observation of ATMO station. The land use in the campus results in a reduction of the green area. Although this reduction is negative for the biodiversity preservation but they have made a great efforts to maintain the ratio of woodland in a long time. However, because of lack of data, it is very difficult to quantify its impact on the biodiversity.

Although the budget allocated to biodiversity conservation on campus is not high, it has been stable in recent years. The establishment of the campus biodiversity commission is underway and has the cooperation with regional and local associations but also with local research laboratories working on biodiversity. Monitoring is in progress, in particular entomological monitoring. As the data are still partial, they could not be used in this work. Considering the importance of the management in the biodiversity preservation, the university should pay more attention with more engagement in this issue.

4 Chapter 4

Open data

4.1 Introduction

Biodiversity monitoring is a long, complex and costly process, timewise and financially. Biodiversity data collection faces a multitude of barriers, which are related to the wide field of the biodiversity, the high number of stakeholders, the absence of cooperation among stakeholders and the large time scale of the biodiversity. This chapter investigates how the open data could help in the biodiversity data collection.

Open data is considered as the ónew raw material of the twenty-first centuryô and governments around the world are increasingly alert to the potential of releasing data. It is now a worldwide movement. It has, as the 2016 Open Data Barometer (ODB) report puts it, óentered the mainstreamô. More than half of the countries surveyed by the ODB in 2015 have an Open Data initiative. In 93% of countries surveyed, even in countries where data is not yet fully open, civil society and the technology community are using government data. Open data Soft estimates that there are more than 2,600 Open Data portals worldwide. As open data moves from being a new initiative to business, it becomes a long term is a top priority for many countries (European Commission Project team, 2017).

Open data is provided by public entities to be accessed and reused. Publishing open data is an excellent way to improve an organizationôs transparency and provide insight into the value of the organization. Getting started with open data involves identifying key open data resources, identifying library information that would be beneficial to publish and creating programs that provide digital literacy training and create opportunities for patrons to engage with open data in new and creative ways (Ayre & Craner, 2017).

4.2 Use of open data

ñOpen Dataò refers to data collected and shared with others to use as they wish, without restrictions on copyright or usage. Traditional examples of open data include government-collected data (e.g., weather reports, crime incident reports, postal or Zip codes) as well as some academic sources (e.g., open-access journals, raw polling and survey data, scientific experiment results). Businesses are also realizing the benefits of sharing data and making it available for use. Whatôs being done with all of this data? Local, state and national government agencies - including libraries - use shared data to lower costs and improve services they deliver to their constituents. Non-profit and community groups use valuable government data to better target services. Businesses rely on government economic statistics, maps and commercial reports to structure their operations

In 2007, Larry Lessig and 29 other ñopen data pioneersò established a set of values articulating how the government could provide data in a manner that would empower others to review, analyze, and act on the data; the ultimate goal was to further improve government operations. They argued that data should be complete, primary, timely, accessible, machine-processable, non-discriminatory, non-proprietary, and license-free (although now an explicitly open license is preferred to unlicensed releases) (Ayre & Craner, 2017).

In 2013, President Obama signed an executive order which resulted in the establishment of an Open Data Policy and the data.gov website, the nationôs first federal government data portal. The Order stated as follows: Openness in government strengthens our democracy, promotes the delivery of efficient and effective services to the public, and contributes to economic growth. As one vital benefit of open government, making information resources easy to find, accessible and usable can fuel entrepreneurship, innovation, and scientific discovery that improves Americansô lives and contributes significantly to job creation (Ayre & Craner, 2017).

Two important qualities make data ñopen.ò Data must be ñlegallyò open, which means it is unrestricted by restrictive copyright terms and can be legally shared and used by individuals, businesses, academia, nonprofits and others. Data must also be open in the ñtechnicalò sense of the word, which refers to the delivery of the data in a standard, well-defined format, usually via the Internet. A current definition of open data is provided by Open Definition:

Open data that can be freely used, re-used and redistributed by anyoneð subject only, at most, to the requirement to attribute and share alike (https://opendefinition.org/od/2.1/en/).

Open data is data that anyone can access, use and share. Governments, businesses and individuals can use open data to bring about social, economic and environmental benefits (https://www.europeandataportal.eu/elearning/en/module1/#/id/co-01).

Open data offers numerous benefits to public agencies. Project Open Data, another outcome from the 2013 Executive Order, is an ñonline, public repository intended to foster collaboration and promote the continual improvement of the Open Data Policy.ò They describe the benefits as follows:

ŏ Save time and money when responding to Freedom of Information Act requests.

ŏ Avoid duplicative internal research.

ŏ Use complementary datasets held by other agencies.

ŏ Empower employees to make better-informed, data-driven decisions.

ŏ Attract positive attention from the public, media and other agencies.

ŏ Generate revenue and create new jobs in the private sector.

ŏ The power of open datað like any other use of datað is its ability to drive and support intelligent decision-making, from individuals to organizations to entire communities and nations. The ñopennessò of open data reduces friction and increases the ability of people and organizations to use that data effectively (Ayre & Craner, 2017).

Open data used in public services, urban infrastructure public officials, local initiatives, and other features of urban governance (licenses and building permits), and open data helps develop the innovation potential of governments, businesses and entrepreneurs that can provide economic, social and scientific gains. We can use open data in education, transportation, health care, electricity, consumer products, consumer finance, economics, and social issues. Governments and public agencies are liberating their data, and they want open data to be used to solve problems and to create and improve products and services, it can be generated new business opportunities and fostering entrepreneurial initiatives. The impact of open data is visible in science, business, government and civil society. Moreover, there are literature reviews about open innovations like mapping service collects data that related to barriers and urban environment via crowd sourcing and understanding (Corrales-garay & Ortiz-de-urbina-criado, 2020). There are many use for open data, such as ecology, healthcare, energy, transportation, economics and education (Lv et al., 2018).

4.3 Open data for biodiversity

4.3.1 Presentation of open data sources for biodiversity

Open data is an exciting development for ecology. It opens a number of doors for researchers, allowing studies across huge areas, creating more context for field studies and building credibility with the broader public and with each other. It adds an extra set of requirements, which create another task for already busy researchers, but at the same time it creates opportunity. Key requirements for open data include appropriate repositories, clear standards, and financial support for the additional effort and these requirements are increasingly being met (Schimel, 2017).

A list of Open data sources for biodiversity could be identified using internet research with the key words "Open data biodiversity". The following section presents briefly the major resources of open data for biodiversity.

Source 1: GBIFð the Global Biodiversity Information Facility (www.gbif.org/)

This open data source is managed by an international network and research infrastructure, which is funded by the world's governments. It provides providing open access to data about all types of life on Earth for anyone and anywhere.

Source 2: Europa Biodiversity (biodiversity.europa.eu/data):

This open data portal is related to biodiversity in Europe. It is supported by the European Union. It provides access to data and information on species, habitat types and sites of interest in Europe and to related products for biodiversity indicators and assessments. Priority is given to policy-relevant data and information for European and national institutions, professionals, researchers and the public. The data set is managed by The European Environment Agency (EEA), which aims to support sustainable development in Europe. The portal includes important data related biodiversity in Europe, in particular about:

- The population trends of farmland, forest and all common bird species 1990-2016
- The population trends of butterfly species 1990-2016
- Number of species survival in Red list (1994-2004)
- The impact of climate change on widespread bird populations has increased strongly in the past twenty years (1980-2005)
- Cumulative number of alien species established in freshwater environment in 11 countries (1900-2008)
- Cumulative number of alien species established in terrestrial environment in 11 countries (1900-2008)
- Alien species in European marine/estuarine waters (1900-2008)

- Yearly land take per major land cover category in the EU-28 for all Corine Land Cover observation periods (2000-2018)(Arable land and permanent crops, Forests and transitional woodland shrub, Natural grassland, heathland, sclerophylous vegetation, Pastures and mosaic farmland, Wetlands)
- Average contribution of Life Nature to projects in 18 EU countries (2000ï 2006)
- Percentage of total EU expenditure on the Life project from 1995 to 2006
- Statistic the number of burnt forest in 5 countries: Portugal, Spain, France, Italy, Greece (1980-2018)
- Survey recognition and understanding of the term 'biodiversity' in the European Union by interviewed EU citizens have heard of biodiversity and what it means (2007-2018).

Source 3: World open data (https://data.world)

This open data portal proposes supports and services related to the classification, integration storage and analysis of open data as well as their share around the world.

Source 4: DataOne (https://www.dataone.org)

This open data portal is supported by the U.S. National Science Foundation (NSF). It is managed by the Observation Network for Earth (DataONE) for the collection and share of science data. It ensures the preservation, access, use and reuse of multi-national earth observational data.

4.3.2 Difficulties and barriers for biodiversity open data

Biodiversity open data faces various challenges. Some of these challenges are specific for the biodiversity field, while others are common with other fields. Data on endangered species are often shielded to some degree by law, and common sense. Many ecologists make use of data ï collected by management agencies ï that are partly protected for privacy and commercial concerns, such as fisheries landings or forest data on private land. Usually, this information can be shared after some degree of processing, or after the original request for raw data is properly modified so as to ensure that confidentiality isnœt compromised. In the international community, some nations share environmental data for research, but do not allow redistribution of the raw data. Additional restrictions could be applied for future replication. Biodiversity open data suffers also from lack of standards for data preservation and processing. It is then important to set up some standards in this field as well as for the quality control of these data to guarantee their good use as well as ease share. When the analytics are applied to the data, or when the raw data are transformed into an analyzed product, it is as important to archive and document those analytics, and the Societyôs journals also encourage or require this (Schimel, 2017).

4.4 Presentation of open datasets for the biodiversity

4.4.1 Europe biodiversity datasets

The European biodiversity portal included important data about the biodiversity in Europe.

The figure 4.1 shows the data of EU ï Number of common birds population in 28 countries in Europe or EU 28 (Austria, Belgium, Bulgaria, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom) during the period from 1990 to 2013.

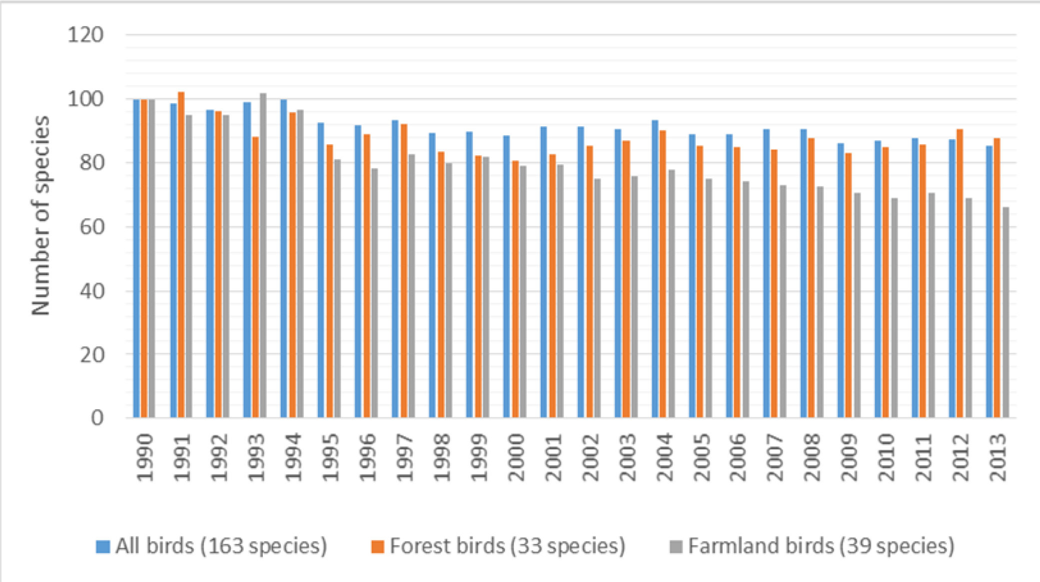


Figure 4.1: EU - Common bird populations during the period from 1990 to 2013

Birds are sensitive to environmental change and their population numbers can reflect changes in ecosystems as well as in other animal and plant populations. Trends in bird populations can, therefore, be excellent barometers of the health of the environment. The status of birds has been the subject of long-term monitoring in Europe. The long term trends (over 25 years) revealed by monitoring schemes for common birds, in particular farmland birds, show significant declines, with no signs of recovery. Between 1990 and 2016, there was a decrease of 9 % in the index of common birds in the 28 EU Member States with bird population monitoring schemes. The decline in common farmland bird numbers was much more pronounced, at 32 % (EU). While this indicator takes 1990 as a starting point, it was warned that significant decreases had already occurred before this date. The long-term trends in common bird populations demonstrate that Europe has experienced a major decline in biodiversity. This has been primarily due to the loss, fragmentation and degradation of natural and semi-natural ecosystems, mainly caused by agricultural intensification, intensive forest management and land abandonment or urban sprawl.

The figure 4.2 shows the variation of the alien species established in terrestrial environment in 11 countries in Europe (Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland, Russia, Sweden) during the period from 1900 to 2008. It shows the cumulative number of three groups alien species includes: primary producers, invertebrates and vertebrates.

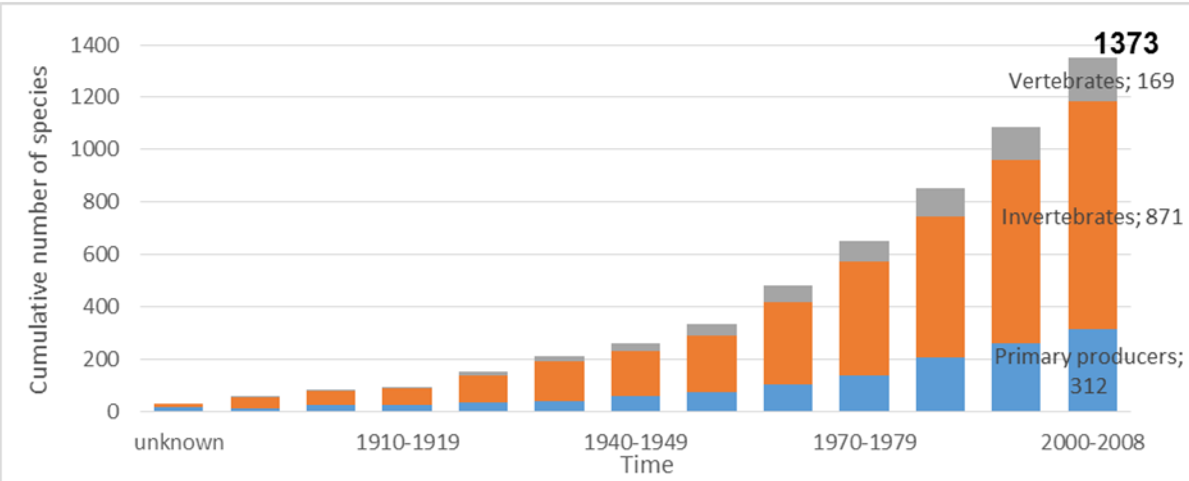


Figure 4.2: Cumulative number of alien species in Europe (1900-2008)

The trend in establishment of new species indicates that the problem is far from under control, with impacts on biodiversity expected to increase because of the growing number of species involved and an increasing vulnerability of ecosystems to invasions, which results from other pressures such as habitat loss, degradation, fragmentation, over-exploitation and climate change. For a nearly century from 1910 to 2008, a total of all alien species in Europe increased reach to 4360%. The situation is particularly worrying in marine and island ecosystems.

The figure 4.3 shows changing in land use in EU-28 during the period from 2000 to 2018.

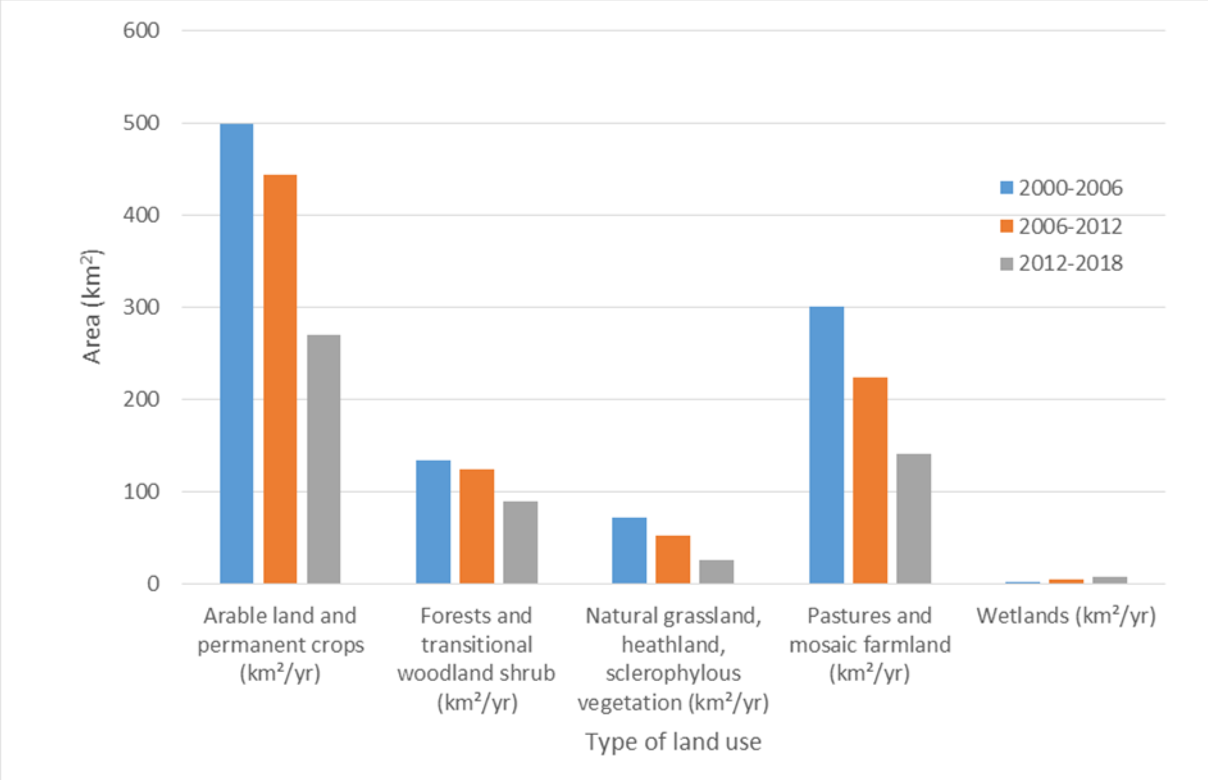


Figure 4.3: Change in land use in 28 countries in Europe (2000-2018)

Despite a reduction in the last decade (land take was over 1000km²/year between 2000-2006), land take in EU28 still amounted to 539km²/year between 2012-2018. The net land take concept combines land take with land return to non-artificial land categories (re-cultivation). While some land was re-cultivated in the EU-28 in the period 2000-2018, 11 times more land was taken. Between 2000 and 2018, 78 % of land take in the EU-28 affected agricultural areas, i.e. arable lands and pastures, and mosaic farmlands. From 2000 to 2018, land take consumed 0.6 % of all arable lands and permanent crops, 0.5 % of all pastures and mosaic farmlands, and 0.3 % of all grasslands into urban areas.

The main drivers of land take during 2000-2018 were industrial and commercial land use as well as extension of residential areas and construction sites.

The figure 4.4 shows the percentage of total EU expenditure for Life Nature project in the EU-28 during the period from 1995 to 2006.

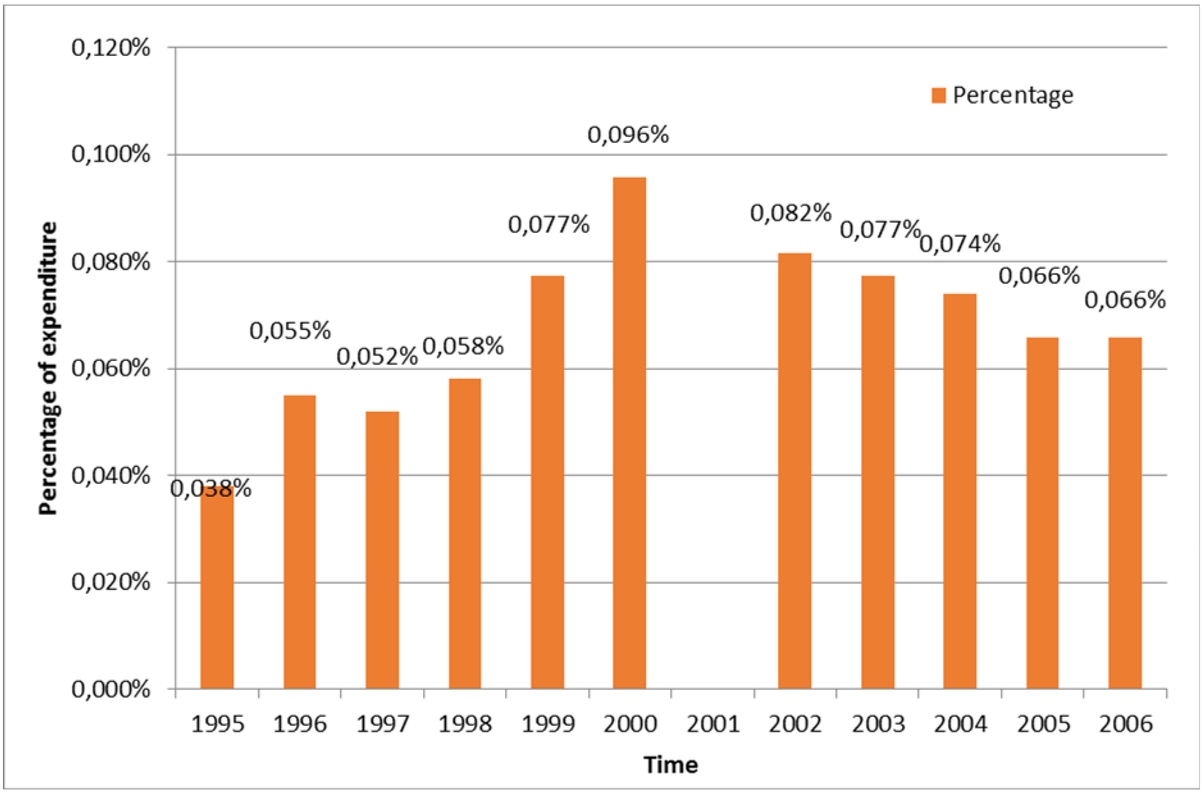


Figure 4.4: Percentage of total EU expenditure for Life Nature project of 28 countries in Europe (1995-2006)

The data of this indicator currently has a limited scope and only contains information from EU funding of projects using the LIFE financial instrument for the environment. The amount of the EU contribution per LIFE project varies significantly among Member States. European funding benefiting biodiversity may also be 'hidden' in budget lines within other policy areas such as agriculture, rural development and research. Finally, the indicator currently does not show national funding for biodiversity.

The figure 4.5 shows the results of survey about recognition and understanding of the term 'biodiversity' in the European Union by interviewed EU citizens during the period from 2007 to 2018. It was conducted in the EU-2828 countries by interviewing EU citizens with 4 options of the term 'biodiversity':

- I've heard of it but I do not know what it is
- I've heard of it and I know what it is
- I have never heard of it
- Don't know `

The results of the latest Special Eurobarometer survey, conducted in December 2018 and published in May 2019, show an increased recognition and awareness of the term 'biodiversity' (71 %) since 2015, while almost half of the respondents (41 %) know what 'biodiversity' means (plus 11% compared to 2015). This increased awareness may be a result of European Commission efforts to further communicate the concept of biodiversity since the 2015 Eurobarometer and may explain the decrease in the number of respondents calling for the EU to better inform citizens about the importance of biodiversity.

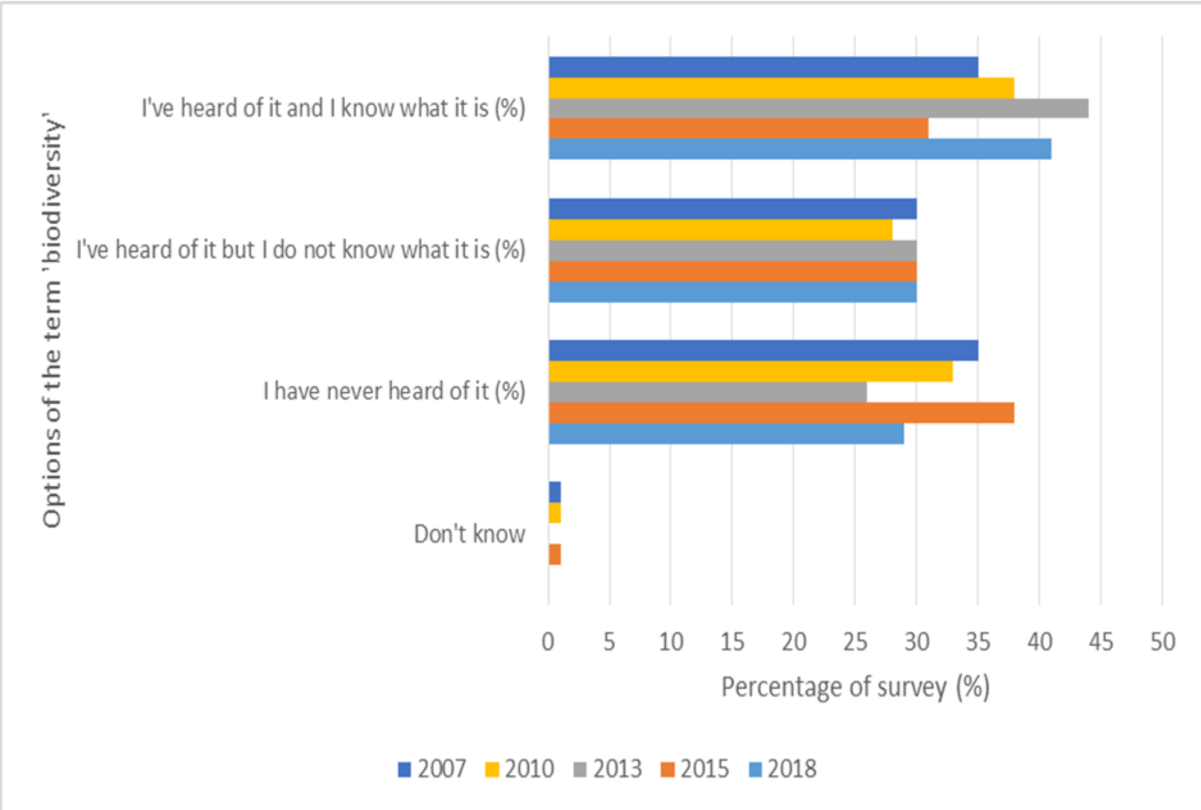


Figure 4.5. Survey recognition and understanding of the term 'biodiversity' in the European Union by interviewed EU citizens (2007-2018).

The figure 4.6 shows the data of the burnt area for each of the five southern European countries for which long time series are available (southern France, Greece, Italy, Portugal, Spain; EUMED5; starting in 1980) and for all other countries in Europe together (starting in 1992). The burnt area for the EUMED5 countries shows a slightly decreasing trend since 1980, with the exception of Portugal. However, there is a large variability from one year to the next, which is determined strongly by the seasonal meteorological conditions. This variability is illustrated also by the last two years on record. The burnt area in 2017 was the second largest on record, due in particular to unprecedented forest fires in Portugal, whereas the burnt area in 2018 was the lowest on record. At the same time, more European countries suffered from large forest fires in 2018 than ever before, including in central and northern Europe. Both fire seasons coincided with record droughts and heat waves in the spring and summer of these years in the most affected regions.

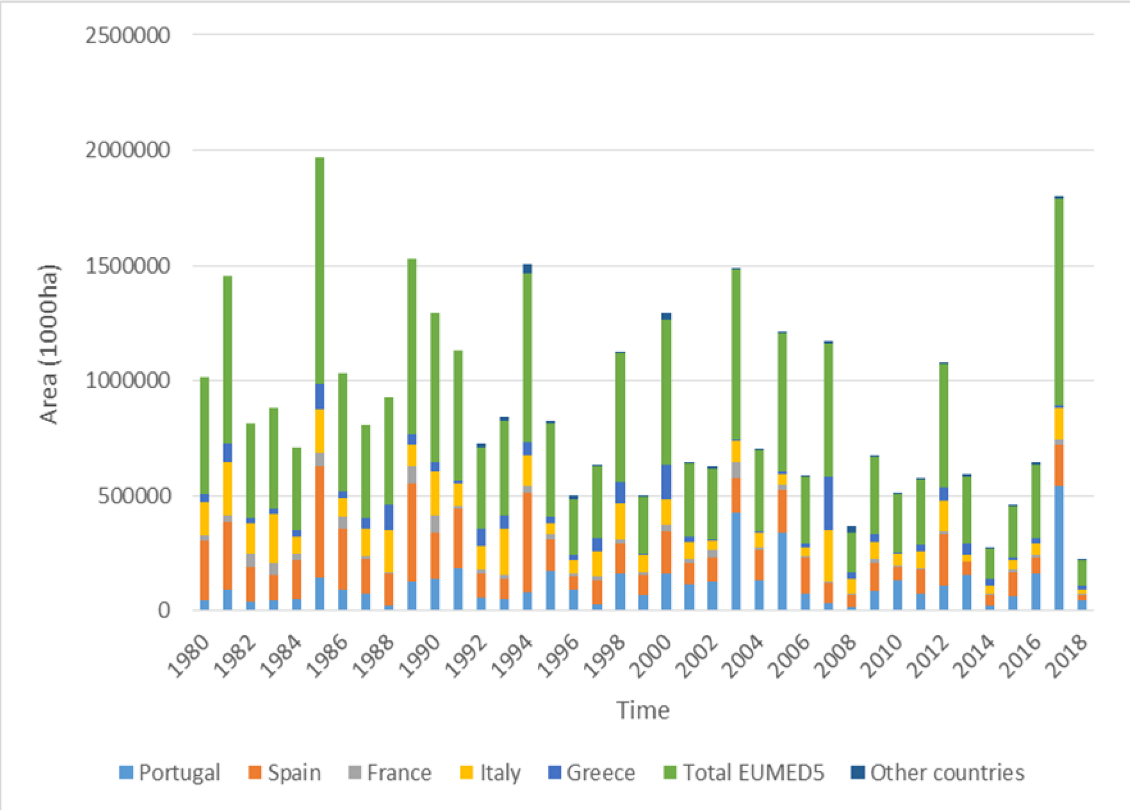


Figure 4.6. Burnt forest areas in EUMED5 and other countries during the period from 1980 to 2018

The figure .4.7 shows the data of the Climatic Impact Indicator (CII) measures the divergence between the population trends of bird species projected to expand their range and those predicted to shrink their range due to climatic change. The indicator is based on a combination of observed population trends monitored from 122 common bird species in 20 European countries over 26 years (1980-2005), and projected potential shrinkage or expansion of range size for each of these species at the last part of this century (2070 - 2099), derived from climatic envelope models. The ensemble in this case is the average climate envelope forecast based on six differing future scenarios.

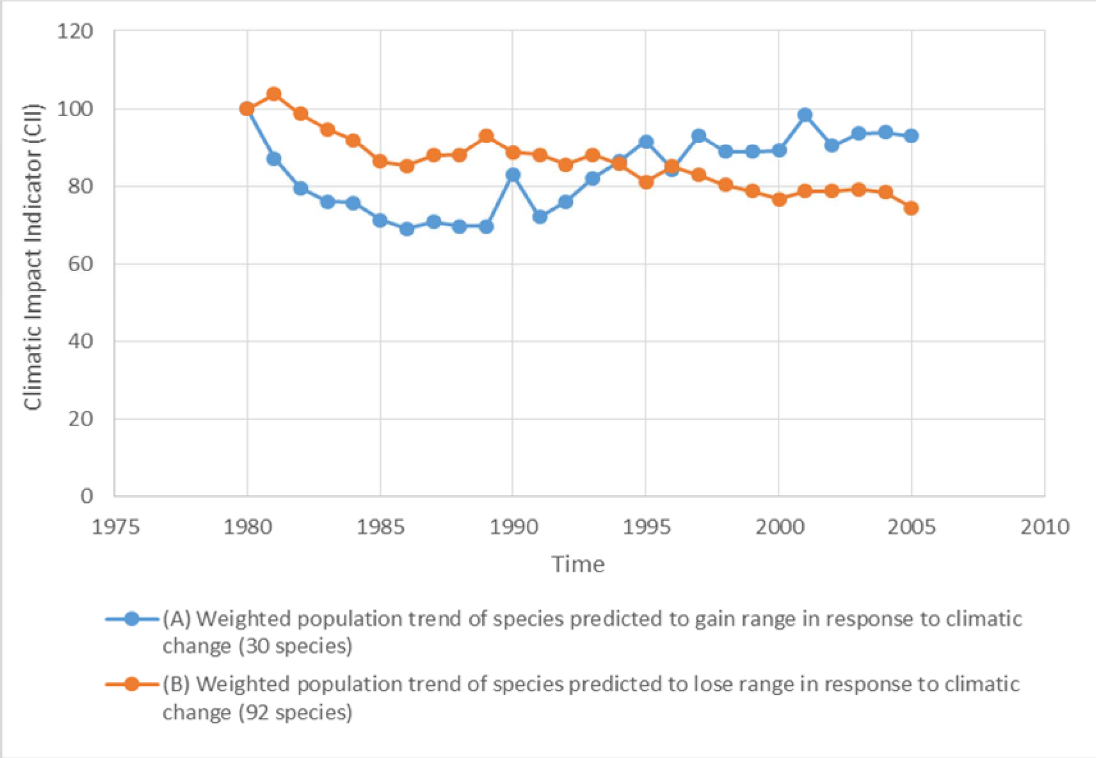


Figure 4.7 Climatic Impact Indicator on birds (1980-2005)

The general trend of the CII is clearly upwards indicating that climatic change is having an increasing impact on bird populations. Where the trend is downwards, this means that the impact of climate warming on bird populations is being overridden by other pressures in the environment; these could be man-made pressures, or natural ones, such as cold winter weather. The CII demonstrates unequivocally and for the first time that climatic change has affected bird populations at a European scale. It shows conformity between observed population trends and modelled projections of how each species should respond to climatic warming.

Although the indicator provides a simple visual depiction of the impacts of climatic change on bird populations through time, the underlying modelling of bird trends and climatic envelopes for species are complex (although fully documented in a peer-reviewed paper). Climatic warming has led to a small number of bird species increasing in number in Europe, but a much larger number declining in number, so overall climatic change poses a threat to biodiversity, but individual species might still benefit from a warming environment.

The CII fell in the 1980s reflecting the influence of cold winter weather events during this time (especially around 1980 and 1985 when such events significantly increased mortality in small birds) combined with other known drivers, such as land use change and agricultural intensification, which acted to depress bird populations.

4.5 Conclusion

From the collected data can be seen the overall picture of biodiversity of European countries. Generally, the green areas are shrinking due to changing in land use, the diversity of some species is threatened. Moreover, cause factor such as pollution issues, climate changeé are increasingly affecting a number of surveyed species (birds). There is a positive signal, it is encouraging that the awareness and interest of the community in conserving biodiversity has increased significantly.

It continues to be a challenge to achieve the wide and effective deployment of conservation measures in European policies which can help populations recover at national and European scales. It is also difficult to forecast how soon biodiversity, as illustrated by the abundance of bird populations, will recover, as their state is influenced by a complex combination of environmental factors and policy measures.

However, the datasets are not consistent in term of time and scale monitoring for all indicators, for example: the data of the burnt area only for each of the five southern European countries (southern France, Greece, Italy, Portugal, Spain) or the data of the alien species established in terrestrial environment in 11 countries in Europe (Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland, Russia, Sweden) and the other data for 28 countries in different time, so it is difficult to assess the correlation between them. On the other hand, the data of some indicator cannot access.

It can be seen that Open Data Portals are a critical part of data infrastructure: they connect data holders with data users, who in turn create services that citizens and businesses benefit from and rely on. The availability of data supporting scientific publications is becoming more and more critical to the ecological community. Open data is an exciting development for ecology. It opens a number of doors for us as researchers, allowing studies across huge areas, creating more context for field studies, and building credibility with the broader public and with each other. It does add an extra set of requirements, which creates another task for already busy researchers, but at the same time it creates opportunity.

Despite this, due to the complexity of biodiversity data so application of open data still has certain limitations. To create services that more advantages, data users need a reliable and consistent data supply.

Conclusion

The digital revolution and the emergence of the Smart City concept offer new capacities to monitor at large scale the urban environment, including the biodiversity as well as to analyse the collected data using powerful tools such as the Artificial Intelligence. The use of these new capacities will help to understand the complex urban biodiversity and to take relevant decisions for its preservation. This work aims at contributing to this goal.

The importance of urban biodiversity monitoring framework based on the Smart City solution, for the urban biodiversity monitoring including data collection at different time and spatial scales concerning urban spices and their habitat as well as factors that impact these species. Analysis of these data will help to understand the menace on biodiversity and to establish a protection and resilient strategy for urban biodiversity.

This preservation requires adequate monitoring to understand biodiversity evolution as well as the causal factors and their impact on biodiversity. Smart monitoring will help to take the right measurements to stop biodiversity degradation and even more to ensure its development. This work presented the monitoring indicators related to biodiversity, causal factors and management system as well as an advanced monitoring system based on the use of camera traps, remote sensing, sensors networks and citizens observations.

An application of the methodology of biodiversity monitoring is proposed in chapter 3 to the scientific campus of Lille University which aimed at exploring the application of the methodology proposed in this work.

Thanks to the development of smart technology, the collection of some data of coverage and cause factors indicators was relatively easy. However, due to lack of biological profile of campus which leads to difficult to quantify the state of the presence of different species and their evolution and the impact on biodiversity.

The lack of data about biological profile of the study area is not only for the campus but it is also a common situation when assessing the status of urban biodiversity around the word. It need a strategy to collect the biological data for city such as:

- Building and expanding the platform from science citizen
- Integration data from different sources
- Take advantages of smartphone technology to develop some apps collect the urban biodiversity

The development of Open data which has opened a number of doors for researchers in biodiversity domain, allowing studies across huge areas, creating more context for field studies, and building credibility with the broader public and with each other.

It also can be considered as a useful solution for the problem of missing of data. However, it is necessary to overcome difficulties when exploiting open data to improve the quality of data and easier in accessing.

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Appendix

The trees of the beech forests (21)

Name of species	**Scientific name**	**Family**
Hêtre	*Fagus sylvatica*	Fagaceae
Chêne pédonculé	*Quercus robur*	Fagaceae
Chêne sessile	*Quercus petraea*	Fagaceae
Bouleau pubescent	*Betula pubescens*	Betulaceae
Bouleau verruqueux	*Betula pendula*	Betulaceae
Charme	*Carpinus betulus*	Betulaceae
Aulne glutineux	*Alnus glutinosa*	Betulaceae
Érable sycomore	*Acer pseudoplatanus*	Sapindaceae
Érable plane	*Acer platanoides*	Sapindaceae
Frêne	*Fraxinus excelsior*	Oleaceae
Tilleul	*Tilia cordata*	Tiliaceae
Peuplier tremble	*Populus tremula*	Salicaceae
Saule blanc	*Salix alba*	Salicaceae (espèce du bord des eaux)
Alisier blanc	*Sorbus aria*	Rosaceae
Sorbier des oiseleurs	*Sorbus aucuparia*	Rosaceae
Aubépine à deux styles	*Crataegus laevigata*	Rosaceae
Merisier	*Prunus avium*	Rosaceae
Houx	*Ilex aquifolium*	Aquifoliaceae
Néflier	*Mespilus germanica*	Rosaceae
Poirier	*Pyrus communis*	Rosaceae
Pommier	*Malus sylvestris*	Rosaceae

Natural trees in the North (15)

Épicéa	*Picea abies*	Pinaceae
Mélèze	*Larix decidua*	Pinaceae
Pin noir	*Pinus nigra*	Pinaceae
Pin sylvestre	*Pinus sylvestris*	Pinaceae
If	*Taxus baccata*	Taxaceae
Platane	*Platanus hispanica*	Platanaceae
Noyer	*Juglans regia*	Juglandaceae
Châtaignier	*Castanea sativa*	Fagaceae
Peuplier blanc	*Populus alba*	Salicaceae
Peuplier noir	*Populus nigra ssp nigra*	Salicaceae
Peuplier d'Italie	*Populus nigra ssp pyramidalis*	Salicaceae
Peuplier grisard	*Populus canescens*	Salicaceae
Robinier faux acacia	*Robinia pseudacacia*	Fabaceae
Marronnier d'Inde	*Aesculus hippocastanum*	Sapindaceae
Marronnier rouge	*Aesculus carnea*	Sapindaceae

Ornamental shrubs (31)

Ginkgo	*Ginkgo biloba*	Ginkgoaceae Ginkgophytes
Sapin du Colorado	*Abies concolor*	Pinaceae
Cèdre de l'Atlas	*Cedrus atlantica*	Pinaceae
Pin de Lord Weymouth	*Pinus strobus*	Pinaceae
Épicéa bleu	*Picea pungens*	Pinaceae
Sapin de Douglas	*Pseudotsuga douglasii*	Pinaceae
Mélèze du Japon	*Larix kaempferi*	Pinaceae
Séquoia	*Sequoiadendron gigantea*	Taxodiaceae
Cryptoméria	*Cryptomeria japonica*	Taxodiaceae
Cyprès chauve	*Taxodium distichum*	Taxodiaceae
Cyprès de Lawson	*Chamaecyparis lawsonia*	Cupressaceae
Tulipier de Virginie	*Liriodendron tulipifera*	Magnoliaceae
Copalme d'Amérique+B:C	*Liquidambar styraciflua*	Altingiaceae
Noyer noir d'Amérique	*Juglans nigra*	Juglandaceae
Ptérocaryer du Caucase	*Pterocarya fraxinifolia*	Juglandaceae
Chêne des marais	*Quercus palustris*	Fagaceae
Chêne rouge d'Amérique	*Quercus rubra*	Fagaceae
Peuplier à feuilles de catalpa	*Populus lasiocarpa X Populus nigra*	Salicaceae

Saule pleureur	*Salix babylonica*	Salicaceae
Amelanchier	*Amelanchier ovalis*	Rosaceae
Cerisier du Japon	*Prunus serrulata 'Hisakura'*	Rosaceae
Cerisier de Virginie	*Prunus virginiana*	Rosaceae
Prunier myrobolan	*Prunus cerasifera*	Rosaceae
Prunier de Pissard	*Prunus cerasifera Pissardii*	Rosaceae
Arbre des pagodes	*Sophora japonica*	Fabaceae
Févier d'Amérique	*Gleditsia triacanthos*	Fabaceae
Arbre de Judée	*Cercis siliquastrum*	Fabaceae
Érable négundo	*Acer negundo*	Sapindaceae
Faux vernis du Japon	*Ailanthus altissima*	Simaroubaceae
Catalpa	*Catalpa bignonioides*	Bignoniaceae
Paulownia	*Paulownia tomentosa*	Paulowniaceae

The shrubs and bushes of oak-beech (33)

Épine-vinette	*Berberis vulgaris*	Berberidaceae (plante thermophile sur sol calcaire dans le nord)
Orme champêtre	*Ulmus campestris*	Ulmaceae
Noisetier	*Corylus avellana*	Betulaceae
Aulne glutineux	*Alnus glutinosa*	Betulaceae
Aulne blanc	*Alnus incana*	Betulaceae
Charme	*Carpinus betulus*	Betulaceae
Saule marsault	*Salix caprea*	Salicaceae
Groseillier rouge	*Ribes rubrum*	Grossulariaceae (peut se trouver dans les sous-bois des forêts humides)
Aubépine à un style	*Crataegus monogyna*	Rosaceae

Aubépine à deux styles	*Crataegus laevigata*	Rosaceae
Poirier	*Pyrus communis*	Rosaceae
Pommier	*Malus sylvestris*	Rosaceae
Néflier	*Mespilus germanica*	Rosaceae
Ronce	*Rubus fruticosus*	Rosaceae
Prunellier	*Prunus spinosa*	Rosaceae
Cerisier à grappes	*Prunus padus*	Rosaceae
Bois de Ste Lucie	*Prunus mahaleb*	Rosaceae (espèce méridionale naturalisée)
Merisier	*Prunus avium*	Rosaceae
Églantier = Rosier des chiens	*Rosa canina*	Rosaceae
Baguenaudier	*Colutea arborescens*	Fabaceae (espèce méridionale naturalisée)
Cytise	*Laburnum anagyroides*	Fabaceae (espèce méridionale naturalisée)
Genêt à balais	*Sarothamnus scoparius*	Fabaceae
Cornouiller sanguin	*Cornus sanguinea*	Cornaceae
Érable champêtre	*Acer campestre*	Sapindaceae
Petite pervenche	*Vinca minor*	Apocynaceae (plante rampante des sous-bois à tige radicante)
Troène	*Ligustrum vulgare*	Oleaceae
Sureau noir	*Sambucus nigra*	Adoxaceae
Viorne lantane	*Viburnum lantana*	Adoxaceae
Viorne obier ou boule de neige	*Viburnum opulus*	Adoxaceae
Les plantes grimpantes		
Clématite	*Clematis vitalba*	Ranunculaceae
Lierre	*Hedera helix*	Araliaceae

Chèvrefeuille des bois	*Lonicera periclymenum*	Caprifoliaceae
Vigne vierge	*Parthenocissus tricuspidata*	Vitaceae (ornementale sur les murs)
Ornamental shrubs (38)		
Épine-vinette rouge	*Berberis atropurpureum*	Berberidaceae
Mahonia	*Mahonia aquifolium*	Berberidaceae
Zelkhova	*Zelkova serrata*	Ulmaceae
Renouée ornementale	*Polygonum aubertii*	Polygonaceae
Saule chalef	*Salix eleagnos*	Salicaceae
Millepertuis ornemental	*Hypericum calycinum 'hidcote'*	Hypericaceae
Althéa	*Hibiscus syriacus*	Rosaceae
Groseillier à fleurs	*Ribes sanguineum*	Grossulariaceae
Deutzia	*Deutzia sp.*	Hydrangeaceae
Églantier ornemental	*Rosa rugosa*	Rosaceae
Spirée rouge	*Spirea japonica "dart red"*	Rosaceae
Spirée Vanhoutten	*Spiraea X vanhoutei (S. cantoniensis X S. trilobata)*	Rosaceae
Corète de japon	*Kerria japonica*	Rosaceae
Laurier cerise	*Prunus laurocerasus*	Rosaceae
Laurier du Portugal	*Prunus lusitanicus*	Rosaceae
Aubépine rouge	*Crataegus laevigatus ‘Paul's Scarlet'*	Rosaceae
Pyracantha	*Pyracantha coccinea*	Rosaceae
Cotonéaster de Dammer	*Cotoneaster dammeri*	Rosaceae
Cotonéaster horizontal	*Cotoneaster horizontalis*	Rosaceae
Cotonéaster à feuilles larges	*Cotoneaster franketii*	Rosaceae
Cognassier	*Cydonia oblonga*	Rosaceae

Cognassier du Japon	*Chaenomeles japonica*	Rosaceae
Sorbier intermédiaire	*Sorbus intermedia*	Rosaceae
Sorbus X thuringiaca	*Sorbus aria X Sorbus aucuparia*	Rosaceae
Ajonc	*Ulex europaeus*	Fabaceae (existe à l'état naturel dans les dunes et landes à sol acide)
Genêt d'Espagne	*Spartium junceum*	Fabaceae
Baguenaudier	*Colutea arborescens*	Fabaceae
Cornouiller à feuilles panachées	*Cornus alba*	Cornaceae
Cornouiller mâle	*Cornus mas*	Cornaceae
Buis	*Buxus sempervirens*	Buxaceae
Buddleya	*Buddleja davidii*	Scrophulariaceae (espèce ornementale devenant invasive)
Lilas	*Syringa vulgaris*	Oleaceae
Forsythia	*Forsythia viridissima*	Oleaceae
Symphorine	*Symphorinocarpos orbiculatus " hancok "*	Caprifoliaceae
Viorne à feuilles ridées	*Viburnum rythidophyllum*	Adoxaceae
Sureau à feuilles laciniées	*Sambucus nigra v. laciniata*	Adoxaceae
Chèvrefeuille rampant	*Lonicera nitida*	Caprifoliaceae
Weigelia	*Weigelia florida*	Caprifoliaceae
Plants of traffic areas (10)		
Pâturin annuel	*Poa annua*	Poaceae
Sagine apétale	*Sagina apetala*	Caryophyllaceae
Renouée des oiseaux	*Polygonum aviculare*	Polygonaceae
Corne de cerf commune ou Pied de corneille	*Coronopus squamatus*	Brassicaceae
Corne de cerf didyme	*Coronopus didymus*	Brassicaceae

Drave printannière	*Erophila verna = Draba verna*	Brassicaceae
Oxalis cornu	*Oxalis corniculata*	Oxalidaceae
Brunelle	*Prunella vulgaris*	Lamiaceae
Plantain à grandes feuilles	*Plantago major*	Plantaginaceae
Matricaire discoïde	*Matricaria discoidea*	Asteraceae

The lawns mowed regularly (14)

Ivraie ou Ray-grass	*Lolium perenne*	Poaceae
Paracorolle	*Narcissus pseudonarcissus*	Amaryllidaceae
Crocus printanier	*Crocus vernus*	Iridaceae (plante naturalisée
Renoncule rampante	*Ranunculus repens*	Ranunculaceae
Trèfle rampant	*Trifolium repens*	Fabaceae
Trèfle jaune	*Trifolium dubium*	Fabaceae
Brunelle	*Prunella vulgaris*	Lamiaceae
Bugle rampant	*Ajuga reptans*	Lamiaceae
Plantain à grandes feuilles	*Plantago major*	Plantaginaceae
Véronique des champs	*Veronica arvensis*	Plantaginaceae
Pâquerette	*Bellis perennis*	Asteraceae
Porcelle	*Hypochaeris radicata*	Asteraceae
Pissenlit	*Taraxacum dens-leonis*	Asteraceae
Crépis à tige capillaire	*Crepis capillaris (= virens)*	Asteraceae

The "weeds" of the flower beds (48)

Pâturin annuel	*Poa annua*	Poaceae
Pied de coq	*Echinochloa crus-galli*	Poaceae
Orge des rats	*Hordeum murinum*	Poaceae
Grand coquelicot	*Papaver rhoeas*	Papaveraceae
Fumeterre officinale	*Fumaria officinalis*	Fumariaceae

Chénopode glauque	*Chenopodium glaucum*	Amaranthaceae
Chénopode polysperme	*Chenopodium polyspermum*	Amaranthaceae
Amaranthe	*Amaranthus retroflexus*	Amaranthaceae
Mouron des oiseaux	*Stellaria media*	Caryophyllaceae
Ceraiste aggloméré	*Cerastium glomeratum*	Caryophyllaceae
Renouée faux-liseron	*Polygonum convolvulus*	Polygonaceae
Renouée persicaire	*Polygonum persicaria*	Polygonaceae
Capselle bourse à pasteur	*Capsella bursa-pastoris*	Brassicaceae
Herbe aux chantres	*Sisymbrium officinale*	Brassicaceae
Moutarde noire	*Brassica nigra*	Brassicaceae
Colza	*Brassica napus*	Brassicaceae
Passerage	*Cardaria draba = Lepidium draba*	Brassicaceae
Passerage des décombres	*Lepidium ruderale*	Brassicaceae
Radis sauvage	*Raphanus raphanistrum*	Brassicaceae
Tabouret des champs	*Thlaspi arvense*	Brassicaceae
Cardamine hérissée	*Cardamine hirsutum*	Brassicaceae
Mouron rouge	*Anagallis arvensis*	Primulaceae
Potentille des oies	*Potentilla anserina*	Rosaceae
Épilobe à tige carrée	*Epilobium tetragonum*	
Épilobe à petites fleurs	*Epilobium parviflorum*	Onagraceae
Épilobe hérissé	*Epilobium hirsutum*	Onagraceae
Euphorbe réveil matin	*Euphorbia helioscopa*	Euphorbiaceae
Euphorbe des jardins	*Euphorbia peplus*	Euphorbiaceae
Mercuriale annuelle	*Mercurialis annua*	Euphorbiacées
Oxalis cornu	*Oxalis corniculata*	Oxalidaceae
Géranium mollet	*Geranium molle*	Geraniaceae

Géranium découpé	*Geranium dissectum*	Geraniaceae
Morelle noire	*Solanum nigrum*	Solanaceae
Bourrache	*Borago officinalis*	Boraginaceae
Lamier pourpre	*Lamium purpureum*	Lamiaceae
Véronique de Perse	*Veronica persica*	Plantaginaceae
Véronique des champs	*Veronica arvensis*	Plantaginaceae
Véronique à feuilles de lierre	*Veronica hederifolia*	Plantaginaceae
Mâche (= Doucette)	*Valerianella locusta*	Caprifoliaceae
Galinsoga	*Galinsoga ciliata*	Asteraceae
Laiteron des champs	*Sonchus arvensis*	Asteraceae
Laiteron épineux	*Sonchus asper*	Asteraceae
Laiteron maraîcher	*Sonchus oleraceus*	Asteraceae
Matricaire camomille	*Matricaria chamomilla*	Asteraceae
Matricaire inodore	*Matricaria inodora*	Asteraceae
Séneçon visqueux	*Senecio viscosus*	Asteraceae
Séneçon vulgaire	*Senecio vulgaris*	Asteraceae
Érigéron du Canada	*Erigeron canadensis*	Asteraceae
Laitue	*Lactuca scariola*	Asteraceae
Waste land plants (96)		
Prêle	*Equisetum pratense*	Equisetaceae
Brome mou	*Bromus mollis*	Poaceae
Brome stérile	*Bromus sterilis*	Poaceae
Calamagrostis commun	*Calamagrostis epigejos*	Poaceae
Crételle	*Cynosurus cristatus*	Poaceae
Dactyle vulgaire	*Dactylis glomerata*	Poaceae
Fromental ou avoine élevée	*Arrenatherum elatius*	Poaceae

Pied de coq	*Echinochloa crus-galli*	Poaceae
Houlque laineuse	*Holcus lanatus*	Poaceae
Fétuque des prés	*Festuca pratensis*	Poaceae
Fétuque roseau	*Festuca arundinacea*	Poaceae
Fétuque rouge	*Festuca rubra*	Poaceae
Pâturin commun	*Poa trivialis*	Poaceae
Jacinthe des bois	*Endymion non-scriptus*	Asparagaceae (plante printanière des sous-bois)
Paracorolle	*Narcissus pseudonarcissus*	Amaryllidaceae
Épipactis à feuilles larges	*Epipactis helleborine*	Orchidaceae
Chélidoine	*Chelidonium majus*	Papaveraceae
Grande ortie	*Urtica dioica*	Urticaceae
Chénopode Bon Henri	*Chenopodium bonushenricus*	Amaranthaceae
Chénopode glauque	*Chenopodium glaucum*	Amaranthaceae
Compagnon blanc	*Silene latifolia*	Caryophyllaceae
Compagnon rouge	*Silene dioica*	Caryophyllaceae
Céraiste des sables	*Cerastium semidecandrum*	Caryophyllaceae
Silène enflé	*Silene vulgaris (=Silene inflata)*	Caryophyllaceae
Rumex (= Patience) crépu	*Rumex crispus*	Polygonaceae
Rumex à feuilles obtuses	*Rumex obtusifolius*	Polygonaceae
Millepertuis	*Hypericum perforatum*	Hypéricaceae
Mauve des bois	*Malva sylvestris*	Malvaceae
Violette odorante	*Viola odorata*	Violaceae
Violette de Rivin	*Viola riviniana*	Violaceae (
Alliaire	*Alliaria petiolata*	Brassicaceae
Drave printannière	*Erophila verna = Draba verna*	Brassicaceae

Cardamine hérissée	*Cardamine hirsuta*	Brassicaceae
Fraisier	*Fragaria vesca*	Rosaceae
Potentille des oies	*Potentilla anserina*	Rosaceae
Mélilot blanc	*Melilotus alba*	Fabaceae
Trèfle des prés	*Trifolium pratense*	Fabaceae
Trèfle jaune	*Trifolium dubium*	Fabaceae
Luzerne lupuline	*Medicago lupulina*	Fabaceae
Vesce cultivée	*Vicia sativa*	Fabaceae
Gesse des bois	*Lathyrus sylvestris*	Fabaceae
Épilobe à petites fleurs	*Epilobium parviflorum*	Onagraceae
Épilobe à tige carrée	*Epilobium tetragonum*	Onagraceae
Épilobe en épi	*Epilobium angustifolium*	Onagraceae
Épilobe hérissé	*Epilobium hirsutum*	Onagraceae
Onagre bisannuelle	*Oenothera biennis*	Onagraceae
Géranium herbe à Robert	*Geranium robertianum*	Géraniaceae
Cerfeuil sauvage	*Anthriscus sylvestris*	Apiaceae
Carotte sauvage	*Daucus carota*	Apiaceae
Grande berce	*Heracleum sphondylium*	Apiaceae
Panais	*Pastinaca sativa*	Apiaceae
Petite centaurée	*Centaurium erythraea*	Gentianaceae
Morelle douce amère	*Solanum dulcamara*	Solanaceae
Liseron des haies	*Calystegia sepium*	Convolvulaceae
Myosotis des bois	*Myosotis sylvatica*	Boraginaceae
Bugle rampant	*Ajuga reptans*	Lamiaceae
Lierre terrestre	*Glechoma hederacea*	Lamiaceae
Lamier jaune	*Lamium galeobdolon*	Lamiaceae

Plantain lancéolé	*Plantago lanceolata*	Plantaginacaea
Bouillon blanc	*Verbascum thapsus*	Scrophulariaceae
Gaillet gratteron	*Galium aparine*	Rubiaceae
Achillée millefeuille	*Achillea millefolium*	Asteraceae
Armoise commune	*Artemisia vulgaris*	Asteraceae
Bardane des bois	*Arctium nemorosum*	Asteraceae
Bleuet des montagnes	*Centaurea montana*	Asteraceae
Cirse (chardon) commun	*Cirsium vulgare*	Asteraceae
Cirse des champs	*Cirsium arvense*	Asteraceae
Crépis capillaire	*Crepis capillaris (= virens)*	Asteraceae
Eupatoire chanvrine	*Eupatorium cannabinum*	Asteraceae
Grande bardane	*Arctium lappa*	Asteraceae
Porcelle = Hypochéris	*Hypochaeris radicata*	Asteraceae
Lampsane	*Lapsana communis*	Asteraceae
Matricaire discoïde	*Matricaria discoidea*	Asteraceae
Picris fausse épervière	*Picris hieracioides*	Asteraceae
Séneçon jacobée	*Senecio jacobaea*	Asteraceae
Tanaisie	*Tanacetum vulgare*	Asteraceae
Tussilage pas-d'âne	*Tussilago farfara*	Asteraceae
Ficaire	*Ranunculus ficaria*	Ranunculaceae
bandes et autour des serres		
Dryoptéris de Borrer	*Dryopteris affinis ssp borreri*	Dryopteridaceae
Dryoptéris dilaté	*Dryopteris dilatata*	Dryopteridaceae
Fougère mâle	*Dryopteris filix-mas*	Dryopteridaceae
Polystic à aiguillons	*Polystichum aculeatum*	Dryopteridaceae
Perce-neige	*Galanthus nivalis*	Amaryllidaceae

Céraiste tomenteux	*Cerastium tomentosum*	Caryophyllaceae
Betterave maritime	*Beta maritima*	Amaranthaceae
Potiron	*Cucurbita maxima*	Cucurbitaceae
Colza	*Brassica napus*	Brassicaceae
Arabette de Thalius	*Arabidopsis thaliana*	Brassicaceae
Primevère acaule	*Primula acaulis*	Primulaceae
Bergénia	*Bergenia cordifolia*	Saxifragaceae
Vigne	*Vitis vinifera*	Vitaceae
Lin	*Linum usitatissimum*	Linaceae
Lavande	*Lavandula X burnati*	Lamiaceae
Sauge officinale	*Salvia officinalis*	Lamiaceae
Chicorée	*Cichorium intybus*	Asteraceae
Ail des ours	*Allium ursinum*	Alliaceae
In the basin (5)		
Iris jaune	*Iris pseudacorus*	Iridaceae
Scirpe des bois	*Scirpus sylvaticus*	Cyperaceae
Laîche (=carex) pendante	*Carex pendula*	Cyperaceae
Glycérie aquatique	*Glyceria maxima*	Poaceae
Lentille d'eau	*Lemna minor*	Araceae
Mosses and lichens (2)		
Bryophytes		
Lichens		