FACULTY OF SCIENCES

URBAN ECOSYSTEM MAPPING IN FLANDERS:

EXPLORING LITERATURE, MAPS AND THE FIELD

Emiel Dhondt
Student number: 01808266

Supervisors: Prof. Sander Jacobs & Toon Spanhove

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GHENT UNIVERSITY

Abstract

Research on urban ecology has grown significantly as the global urban population continues to increase. Urban environments involve complex processes of land-use decision-making, policy implementation and project authorization. Despite the availability of typology-based urban maps, Urban Ecosystem Mapping (UEM) still faces knowledge gaps and lacks standardized workflows. This research conducted a literature review on the topic of UEM, revealing its significance in terms of rapid urbanization, climate change and stakeholder engagement while highlighting necessary future advancements in the field to cope with methodological limitations. Following this review, a set of criteria was postulated to critically analyze the Biological Valuation Map (BVM) of Flanders and a set of other ecosystem mapping initiatives. To tie these theoretical explorations in with reality, the final part of this research includes a case study in Ghent's *Wondelgemse Meersen*, demonstrating how accurately urban nature is mapped in the BVM and how certain ecological components such as biodiversity, ecosystem services and relief are fully or partly neglected in the map. The classification systems from the same set of other ecosystem mapping initiatives were used to map the study area, highlighting the many different aspects to be taken into account in the practice of UEM. This is followed by a discussion on how the BVM of Flanders could be improved to more fully represent both ecologic and socio-economic patterns and processes that rule urban ecosystems. While UEM proves itself to play a vital role in promoting greener cities and achieving a more sustainable society, the practice still shows many opportunities to be improved.

Keywords

Urban ecology, Ecosystem mapping, Biological Valuation Map, Ghent Metropolitan Area

1 INTRODUCTION AND OBJECTIVES

1.1 The importance of studying urban ecosystems

When looking at the entirety of human evolution, urbanization is a relatively recent phenomenon. However, this has not stopped it from having one of the highest influences on the natural environment and global land transformation (Pickett et al., 2011). The rapid growth of cities and the expansion of urban areas have profound effects on the functioning of ecosystems and the well-being of both humans and the natural world we live in (Zoran, 2009). Urban ecosystems set themselves apart from any other type of ecosystem through them being almost fully controlled and influenced by humans. The built infrastructures and human activities define urban areas, which lead to unique ecological dynamics, characteristics, and challenges. For example, forests within urban boundaries are ecologically complex in their function and composition due to the high heterogeneity of the landscape together with them being under tight anthropogenic influence (Gu et al., 2015). Urbanization not only affects local boundaries, with studies highlighting the synergistic effects of climate change and urbanization on local, regional, and global scales. Mahmood et al. (2013) conducted a study on the effects of land cover changes on the climate and concluded that local impacts of urbanization on energy fluxes induce the Urban Heat Island (UHI) effect and changes in precipitation. Similarly, research by Argüeso et al. (2014) from Sydney showed how future urban expansion affects local climate change by altering the minimal surface temperature of the city landscape. The prediction that urban and natural forests will face greater herbivory in the future due to increasing temperature in cities leading to an increase of scale insects, is an example of how climate change and urbanization affect ecosystems on a regional and even on a global scale (Dale & Frank, 2014). Findings like these highlight the intricate relationship between urbanization and climate change, accentuating the need for a complete understanding of urban ecosystems.

Another pressing topic within urban ecology is the effect of urbanization on biodiversity. Even though the processes that underlie the patterns of urban biodiversity are still not fully understood (Faeth et al., 2011), replacing natural habitats for built environments, landscape fragmentation and the introduction of non-native species all pose threats to biodiversity in urban areas (Savard et al., 2000). Thus, highlighting the pressing need for interconnecting, safeguarding and creating urban green infrastructures (Aouissi et al., 2021). Furthermore, by losing essential ecological habitats and processes in cities, the functioning of ecosystems and the provision of ecosystem services (ESs) that ensure human well-being get endangered. Xie et al. (2018) showed that urban expansion leads to a decline in key ESs such as food production, carbon storage and air quality regulation. Addressing the ecological implications of urbanization and the importance of integrating ecology into urban planning and management, is thus of great urgency.

1.2 Introducing Urban Ecosystem Mapping

Due to the far-reaching effects of urbanization on the natural environment and human well-being, research on the science of urban ecology has significantly increased in abundance in recent decades (Picket et al., 2011; Guo et al., 2022). Unlike the wave of research that came before this, which focused mainly on the ecological aspects of urban environments, this new wave is interested in the interconnectivity of these ecological aspects with socio-economical ones. The coexistence of humans with their surrounding natural environment is being brought to the forefront with their reciprocal influences on each other being thoroughly assessed (Mace, 2014; Mak et al., 2021). Researchers, environmentalists and policymakers are determined to uncover future development and conservation possibilities of urban areas. The interconnectivity of the urban landscapes with their natural environment provides insight into sustainable spatial planning and conservation strategies, which is why research on this is of great interest. Unfortunately, information on the composition, changes and structure of most urban areas is not available (Chapa et al., 2019). To achieve this information, the practice of Urban Ecosystem Mapping (UEM) has emerged as a process to identify, map, and assess the relationships between the urban natural environment and the anthropogenic influence it has to face in urban areas. Numerous methodologies for UEM have been established in different cities, regions and nations, which have countless applications in land-use planning, nature conservation, and sustainable urban development.

However, despite the progress made in the practice of UEM, there are still many gaps and challenges that need to be addressed to improve the policy relevancy of these maps. Challenges include the integration of various social and environmental aspects into precise definitions, which has been proven to lead to imprecise urban classifications (Gopal et al., 2016). Vanderhaegen & Canters (2017) point out that due to the shortcomings of traditional landscape ecological metrics for mapping urban form, there is a need for alternative approaches for analyzing urban landscapes, which explicitly describe the morphological characteristics of the urban fabric. Another knowledge gap yet to be filled is the lack of a quantitative method to assess climate resilience in urban areas based on the present green and grey infrastructure and their characteristics (Papa et al., 2019). All these findings emphasize the underrepresentation of the interdisciplinary and heterogeneous character of cities in urban ecosystem maps. Innovative approaches and efficient methods are necessary for the improvement of their accuracy, scale, relevance and usability. This research aims to uncover new insights, innovations, and methodologies in the field of UEM, particularly for the region of Flanders. That way, our understanding of urban ecosystems can be enhanced, while informing sustainable urban development practices.

The first chapter of this research aims to give an overview of the current state of UEM, including where the field could improve and which new innovations could facilitate its implementation in across-border, national and local policies. To come to this, the literature was reviewed following the RepOrting standards for Systematic Evidence Syntheses (ROSES) protocol. ROSES comprises a flow diagram and descriptive summary, designed for systematic maps and reviews, specifically for the fields of conservation and environmental management (Haddaway et al., 2018). The review gave insights into the current status of UEM while pointing out the gaps still affecting the science. The listed potential improvements to the practice of UEM are internationally applicable, meaning that mapping projects in Flanders would benefit from the adoption of these improvements.

1.3 Analyzing an existing land-cover map of Flanders: The Biological Valuation Map

The Biological Valuation Map (BVM) of the Flemish Region in Belgium is at the heart of the second and third chapters of this research. The map consists of an extensive and detailed database of land and vegetation cover in the form of maps (Saeger et al., 2018). It acts as a base document for anyone involved in many practices including nature conservation, spatial planning and environmental impact assessments. It is used in the implementation of juridical practices such as granting permits for vegetation cover changes and providing funding for the purchase of nature reserves. Due to it being one of the most detailed and complete land-cover maps of Flanders, the goal of this research is to evaluate the map and discuss how certain additions could improve its policy relevance, with a particular interest in urban ecosystems. To get to that point, a critical analysis of the BVM was carried out. As a follow-up, a set of existing UEM initiatives with their corresponding classification systems in the form of typologies, was analyzed. Based on topics like availability, usability and thematic content, each unique initiative was critically discussed with an eye on how they compare to the BVM to uncover any potential insight they could provide to enhance the BVM. To frame the theoretical first two chapters of this research, a case study was carried out in the city of Ghent, Belgium. The area of interest is the *Wondelgemse Meersen*, a case where UEM crosses paths with socio-economical aspects. Further information on the relevancy of choosing this area for this research can be found in Box 1. Starting from how the area is mapped in the BVM, a field trip gave insights into what aspects of the natural environment were under or not at all represented on the map. Next to this, the typologies discussed in the previous chapter were used to describe how the *Wondelgemse Meersen* would be mapped according to their inferred classifications. This was set up to find out whether those typologies could uncover any future improvements to the currently installed BVM.

Overall, this research shows the broad range of the practice of UEM. Improvements to maps such as the BVM could lead to more informed decision-making and sustainable urban development. That is why research like this creates the opportunity for those improvements to be noticed and eventually implemented, promoting the integration of ecological aspects in urban management and planning. Ultimately leading to the development of sustainable and climate-resilient cities that prioritize the conservation and enrichment of urban ecosystems as a whole.

Box 1: Why choose the *Wondelgemse Meersen*?

The *Wondelgemse Meersen* (*Figure 1*), also locally dubbed as *Wissenhage*, comprises a natural patch of 148.349 m^2 located at the outer border of the city of Gent, Belgium, squashed in between residential and industrial area and a railway. The reason this area was picked for the case study becomes clear when looking into its history. Over the past two decades, a big public transportation company, *De Lijn* (*Figure 2*), has been trying to obtain a permit to build a depot for their vehicles on the terrain. Due to protests by environmental organizations and local inhabitants, the company has not been able to get the grant to start their project, even though there have been taken multiple steps in preparation of the building process (e.g., archaeological preliminary research). The most recent updates on the situation are the Flemish minister of Environment denying the grant of the permit in September of 2022 and *De Lijn* submitting a new request with an altered version of the original plan only a month later, in the hope to obtain the permit. This area and its history integrate social, economic, and ecological agendas, which make it the perfect case study and a good candidate to research how the practice of UEM could capture the present environment and how it could influence the future of the area.

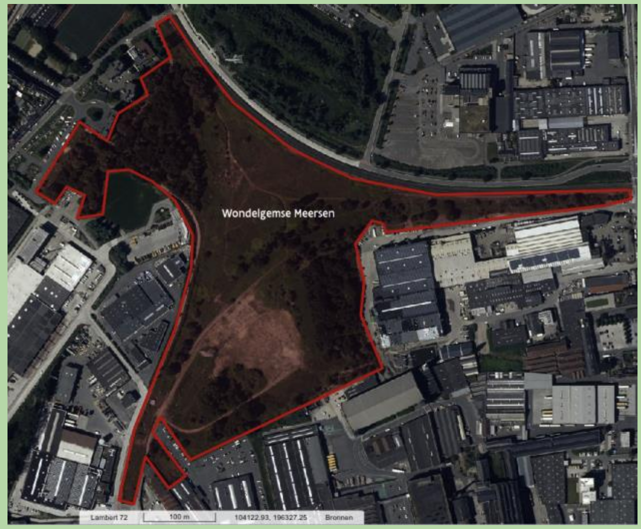

Figure 1: The *Wondelgemse Meersen*. The site of the conducted case study. www.geopunt.be

Figure 2: Logo of *De Lijn*.

2 MATERIALS AND METHODS

2.1 Reviewing literature on the subject of Urban Ecosystem Mapping

The first objective of this research is the literature review on the subject of Urban Ecosystem Mapping. The review was made using the, in environmental sciences commonly used ROSES protocol as a guideline to ensure a complete thematic coverage and a concise workflow. The protocol consists of a list of objectives and passages that should be included in a literature review to obtain a desirable overview of the discussed topic. It is also helpful in the stages of data collection, hence it provides a flow chart on how to collect and process the gathered literature (Haddaway et al., 2018). Via the use of *Web of Science*, 420 articles were obtained with the terms *urban ecology* and *ecosystem mapping* as its initial search terms. These papers were then screened based on their title, abstract and full text for their relevance and contribution to the topic of this literature review. The screening process in the form of a flowchart provided by Haddaway et al (2017) can be seen in Figure 2, showing that next to three articles from other screened sources, 65 of the initially obtained 420 papers contributed to the content of the review.

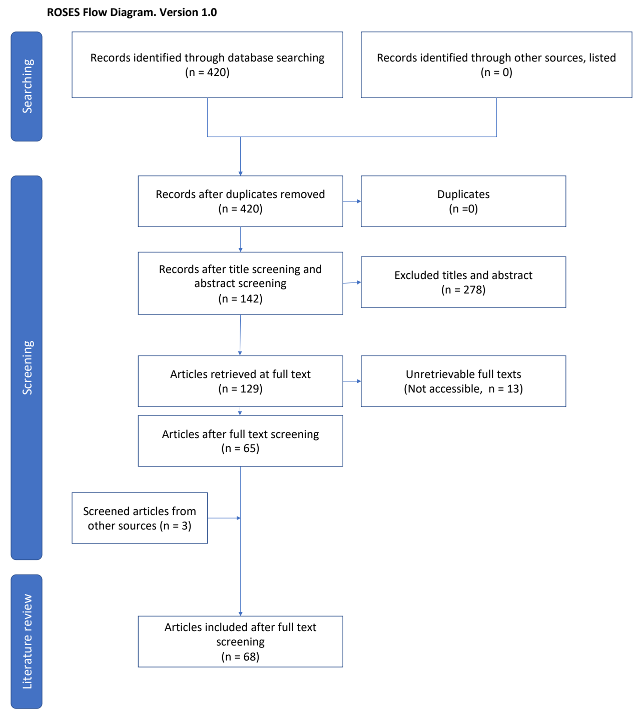

Figure 3: ROSES flow diagram for systematic maps. Obtained via Haddaway et al., 2017.

2.2 Investigating the BVM and a set of existing Urban Ecosystem Mapping initiatives

Based on the output from the literature review on the topic of UEM, it was possible to formulate relevant scoring criteria on which the Biological Valuation Map of Flanders and a set of other existing UEM initiatives could be scored. The criteria were subdivided in seven different categories, being *content*, *thematics*, *feasibility*, *(reported) usability*, *scale*, *availability* and *accuracy*, which made it possible to make an assessment of the applicability, tackled urban ecological themes and policy relevance of the different initiatives. Since the BVM is the focal point of this research, it was analyzed in more detail, together with making comparisons to the other UEM initiatives to further analyze its strengths and possible weaknesses. Due to not all of the obtained UEM mapping initiatives being translated into ecosystem maps, a subset of these categories was left blank hence the information on those specific categories does not, or not yet, exist. The initiatives were found throughs scoping the internet and literature using the snowballing method where one initiative led to the other. Several persons with knowledge on the subject of UEM in Flanders (Joachim Maes, Andreas Demey, Geert Heyneman, Sander Jacobs and Toon Spanhove) were contacted to provide plausible information and examples of UEM initiatives for this chapter of this research. Since the scope of this research is mainly focused on Flanders, typologies that covered Belgian territories were preferred, however, other typologies were also included due to the fact that those could uncover interesting viewpoints and methods that are currently not included in the BVM. From this analysis, interesting viewpoints consisting of promising future additions to the BVM or to the practice of UEM in Flanders were brought to light.

2.3 Case study in Ghent: the *Wondelgemse Meersen*

For the case study, a critical analysis was conducted on how the ecological characteristics of the *Wondelgemse Meersen*, located in the city center of Ghent, were mapped in the latest version of the BVM for the researched area. Concerning the city of Ghent, there is a detailed version of the map that provides the user with information on land use and vegetation in the city, with an indication of biological values and protection statuses, namely the BVM (Spanhove et al., 2021). It is this map that lies at the foundation of this case study.

A field visit was carried out to visually verify the correctness and the level of detail at which the area was mapped in the BVM. During this visit, observations were made on the topic of what ecological and socio-economic relevant elements of the area were not or incompletely included in the map that could improve its relevancy as a tool in practices such as nature conservation, policy creation and license issuing. After this, a thought experiment was conducted in which the area was mapped according to the UEM initiatives that were reviewed in the previous chapter of this research. Some typologies of certain of those could directly be translated from the BVM, while others were to be manually allocated to the different sub-parcels of the *Wondelgemse Meersen*. Doing this, more insights were revealed that shed light on how these initiatives could provide extra information on the ecologic and socio-economic characteristics of the area and how those initiatives differ in which aspects of the urban ecosystem they can capture compared to the BVM.

3 RESULTS

3.1 Urban Ecosystem Mapping: exploring literature

3.1.1 Introduction

3.1.1.1 Brief overview of urban ecosystem mapping

The process of urban ecosystem mapping (UEM) is most commonly described as the process of identifying and analyzing the different components of urban ecosystems. This includes both natural and built environments, economic and social systems and the relationships these have with each other (Pietta & Tononi, 2021). Next to this, aspects of urban ecology such as urban design have proven themselves to be a multidisciplinary science that should not only rely on environmental consultants, which was the strategy applied in the past (Felson et al., 2013). By collecting and analyzing multifaceted data on the urban environment, its ecological, social and economic characteristics can be examined to be better understood. UEM also has the ability to identify potential roadblocks and opportunities for sustainable urban development.

Typically, UEM involves the use of geographic information systems (GIS), which are advanced software tools that integrate, analyze, and visualize spatial data that are used to create maps that illustrate the different components of urban ecosystems (Selim & Demir, 2019). Due to the highly intertwining socio-economic and ecological characteristics in cities (Gopal et al., 2016; Galychyn et al., 2020), it is important that both get incorporated into the maps obtained via UEM. A consequence of this is that these maps vary significantly in the urban components they contain, where the distribution of vegetation, riparian areas and wildlife habitats are examples of natural urban features and roads, buildings and other human-built infrastructures are examples of socio-economic ones. Other important examples of socio-economic data include employment rates, population density and income levels, which can be added to these maps to ensure an understanding of all components of the urban ecosystem.

Another important argument in favor of the practice of UEM is its ability to analyze and understand ecosystem services (ESs) that are delivered by urban ecosystems. It has been evidenced that the provision of different bundles of specific ESs depends on urban green space (UGS) composition and configuration (Derkzen et al., 2015). Urban ecosystem maps could therefore help increase the efficiency of urban ecosystems to deliver those ESs by them being implemented in future urban design developments. Even though the spatial and temporal heterogeneity of UGS greatly complicates their improvement in favor of ES provision (Gaston et al., 2013), strategic placement and management of novel green spaces could greatly increase the supply of urban ESs, which in their turn can induce more natural, climate-resilient urban environments. City planners, policymakers and other stakeholders can use the information obtained from UEM to make decisions about resource management, environmental protection and land use. Ultimately, the maps and knowledge that are generated during the process of UEM can promote urban resilience, sustainable development and the overall quality of life in urban areas.

3.1.1.2. The relevance of urban ecosystem mapping in current times

Urban landscapes are currently ruled by an intricate interplay between human activities and the natural environment. This necessitates a comprehensive understanding of urban ecosystems. As urbanization doesn't show any sign of decelerating in the future, it becomes increasingly important to assess and map these systems to address challenges of sustainable development and environmental preservation. This section delves into the significance of UEM in current times, exploring its relevance in resource management, urban planning and policy formulation.

◊ The **increasing pressure on urban environments and rapid urbanization** call for the practice of mapping urban ecosystems to promote sustainable urban development (Griffiths et al., 2010). It helps identify and protect green spaces, natural habitats and ecological corridors within cities, which are essential for maintaining biodiversity, mitigating climate change impacts and enhancing the overall quality of life for urban residents. It has been postulated that integrating both the social and bioecological nature of urban heterogeneity supports more effective measurements for the integration of sustainability while providing the foundation for improving tools to support urban ecosystem design (Zhou et al., 2017).

◊ Understanding the **susceptibility of cities to climate change** is significantly influenced by the practice of UEM. By mapping and analyzing UGS, vegetation cover and water bodies, cities can assess their capacity to mitigate heat island effects, manage stormwater, sequester carbon and enhance overall urban resilience. This information supports the development of climate change adaptation strategies and the implementation of nature-based solutions. A common consequence of climate change is the prevalence of invasive species. A study by Paź-Dyderska et al. (2020) pointed out that management of an urban invasive tree species could be fostered by revealing its spread via a set of tools including land-use maps and predicting its natural regeneration occurrence, ultimately leading to reduced costs of monitoring. Maps that map UGS are used to assess whether these spaces contribute to the provision of certain ESs or bundles of such which are vital in sustaining the functionality of both the natural environment and the all-around human well-being (Derkzen et al., 2015). Many technologies and strategies have already been established to enlarge the capacity of urban built environments to improve their socioecological contributions by generating and providing ESs, leading to climate-resilient urban environments (Zari & Hecht, 2020).

◊ UEM provides **valuable information for urban planners and policymakers**. It aids in land-use planning, infrastructure development and policy formulation by considering the ecological and environmental aspects of urban areas. For example, the development of tree classification tools based on satellite data can offer in-depth vegetation analyses and area-wide monitoring, which is of necessity for measuring urban ESs such as carbon storage, cooling and air filtering (Tigges et al., 2013). By integrating ecosystem mapping data into decision-making processes, cities can prioritize nature-based solutions, sustainable land management practices and the preservation of valuable natural areas.

- ◊ The identification of areas with limited access to green spaces and high levels of pollution, which are determinants of **public health and human well-being**, can be promoted by the means of UEM. By mapping and analyzing these factors, cities can target interventions to improve air quality, increase access to parks and green spaces and promote physical activity, leading to improved public health outcomes and better quality of life for urban residents. An example of this can be mapping urban allergy risks in cities along a gradient of urbanization and plant invasion, providing information that can favor public health (Bernard-Verdier et al., 2022). UEM also has the power to point out inequities concerning the access of different socioeconomic groups to urban nature and its derived benefits, which is commonly known as environmental injustice (Davis et al., 2012).

- ◊ UEM can promote **stakeholder engagement and community participation in urban planning and management** (Plieninger et al., 2019). Involving local communities, researchers and various stakeholders in the mapping process fosters a sense of ownership, empowers communities and encourages collective decision-making. This participatory approach ensures that diverse perspectives and local knowledge are considered, leading to more inclusive and socially just urban development.

3.1.1.3. The objectives of this literature exploration

This literature exploration of UEM has multiple objectives. Firstly, its goal is to provide an overview of the current status of the field by examining the currently implemented methodologies, technologies, knowledge and approaches. Secondly, it aims to provide the reader with information on the relevance and on the impacts the practice has on a multitude of societal challenges such as urban planning, nature conservation and the development of sustainable urban policies. The third important objective of this synthesis of existing literature on UEM is to highlight the gaps and limitations that have been proven to pose difficulties in the field. By doing this, the last part of the exploration seeks to contribute to the advancement of the practice by providing insights and recommendations for future research. Since Flanders is at the center of this research, the findings of this literature exploration can then be applied to this specific region.

3.1.2 Historical overview

3.1.2.1 The history of urban ecosystem mapping and the key developments in the field

The practice of UEM has evolved over time, driven by a growing recognition of the importance of urban ecosystems, advancements in technology and the need for sustainable urban development. This section analyzes the key developments in the field, spanning from its origin to the most recent advancements. By investigating the historical progression, not only the innovative techniques utilized over the years are illuminated. It also highlights the transformative impact this knowledge has had on contemporary resource management, urban planning and sustainable development practices. This exploration seeks to clarify the critical role that the historical context of the domain plays in shaping the present and future directions of UEM.

In the mid-20th century, **urban planning focused primarily on physical infrastructure**, with limited consideration for ecological aspects. Mechanical and technological elements were brought to the forefront, where natural aspects were ignored and mostly seen as having an aesthetical function in the industrial city (Pietta et al., 2021). However, pioneering work by researchers such as Ian McHarg in the 1960s emphasized the need to integrate ecological information into urban planning and design. McHarg's book "Design with Nature" popularized the concept of overlay mapping, which incorporated ecological data to guide land-use decisions.

The advent of **remote sensing technologies**, such as aerial photography and satellite imagery, revolutionized urban ecosystem mapping in the latter half of the 20th century. The ability to collect high-resolution spatial data and analyze it enabled researchers to map and analyze urban land cover, vegetation patterns and other ecological features at various scales. The paper from Iverson et al. (1989) confirmed this revolution by already pointing out the huge progress remote sensing had made by that time in terms of better classification algorithms, more discriminating sensors, and the use of Geographic Information Systems (GIS) to provide additional spatially referenced data.

More recently, researchers began developing **conceptual frameworks** to guide UEM and analysis. One influential framework was the *Urban Ecosystem Analysis* (*UEA*) approach proposed by Pickett and Cadenasso (2011). It emphasizes understanding the spatial heterogeneity, ecological processes and social dynamics of urban systems. These frameworks thus follow the shift that has occurred over the past decades where practices such as urban planning paid more and more attention to the socio-ecological interactions that rule the dynamics of urban ecosystems (Pietta & Tononi, 2021). An example of another framework that views urban ecosystems as complex socio-ecological systems is dubbed with the term *urban ecology* and describes the concept of the *urban metabolism*, which is defined as the inflow and outflow of resources in urban areas (Newell & Cousins, 2015).

As the field progressed further, there was a growing recognition of the need for standardized **indicators and metrics** to assess and monitor urban ecosystems. Researchers developed metrics to quantify vegetation cover, biodiversity, habitat fragmentation, air quality, water quality and other key ecological parameters. These indicators provided a basis for comparative analysis across cities and facilitated evidence-based decision-making. Lakes & Kim (2012) found that the use of environmental indicators, such as the *Biotope Area Ratio* (*BAR*), is able to support existing field mappings and can more adequately represent urban environments in the context of decision-making processes. Another study used multiple broad-scale indicators such as biodiversity, habitat quality and ecosystem service indices to assess possible synergies and trade-offs between those indicators in UGS, where they found that stacked benefits between the indicators were the rule and trade-offs the exception (Belaire et al., 2022).

In recent years, there has been an increasing emphasis on **engaging communities and citizens** in UEM. Participatory mapping approaches involve local residents in data collection, monitoring and decision-making processes, fostering a sense of ownership and promoting social equity. Cheng et al. (2022) conducted face-to-face surveys, participatory mapping, questionnaires and interviews to identify the interactions of different cultural ESs in an urban park, where the obtained information could serve as an input for park managers and designers to guide landscape practices. Citizen science initiatives have emerged, empowering individuals to contribute data and observations, expanding the spatial and temporal coverage of urban ecosystem mapping. An example of this comes from the study by Kaymaz et al. (2021) which surveyed university students to assess their perception of cultural ESs in an urban public space. The majority marked an UGS as their favorite place, meaning that these values together with their localizations can be used in landscape management.

The development of **integrated urban monitoring platforms** has allowed for the comprehensive assessment of urban ecosystems (Babí Almenar et al., 2023). These platforms combine data from multiple sources, including satellite imagery, ground-based sensors and citizen science contributions. They provide real-time or near-real-time information on various ecological parameters, facilitating dynamic and adaptive urban planning and management. Another recent trend concerns the growing tendency towards **data sharing and open mapping initiatives** (Nitoslawski et al., 2019). Online, open-source tools are being developed to uncover the predicted ecological and financial costs and benefits of the installment of additional urban green spaces, taking into account site-specific abiotic, biotic and management attributes (Babí Almenar et al., 2023). Governments, research institutions and non-profit organizations have made efforts to make UEM data publicly accessible. This promotes collaboration, knowledge exchange and the development of innovative solutions for urban sustainability.

3.1.2.2 The various techniques and methods used for urban ecosystem mapping

Depending on the goals of different mapping projects in urban environments, there are a plethora of common techniques used for the practice of UEM. This section presents an exploration of the various approaches employed in UEM. By critically examining the strengths, limitations and synergistic potentials of these methodologies, this research seeks to foster an understanding of the urban landscape's ecological intricacies. As these mapping techniques are indispensable for informing evidence-based decision-making, sustainable urban planning, and effective conservation strategies, this investigation aims to shed light on the significance of employing a multifaceted approach to UEM in contemporary scientific and policy contexts.

- ◊ Techniques using **remote sensing**, such as satellite imagery, aerial photography and LiDAR (Light Detection and Ranging), can be used to uncover the physical characteristics of the urban environment (He et al., 2020). Chapa et al. (2019) present a detailed but simple methodology to produce accurate high-resolution land use maps using open-source software and satellite imagery, showing that this kind of data can give insights into the structural and temporal dynamics of urbanization. Remote sensing is most commonly used to collect data on land use (e.g., Chapa et al., 2019), impervious surfaces (e.g., Liang et al. 2022) and vegetation cover (e.g., Kopecká et al., 2017). Another example of how satellite data is used in the context of UEM is its function in the creation of classifications used in mapping processes. Tigges et al. (2013) used different intra-annual time series of satellite data of Berlin, Germany to develop a high-precision tree genera classification system.

- ◊ The technology of **Geographic Information Systems (GIS**) consists of computer-based systems that enable the capture, storage, analysis and visualization of geospatial data (Selim & Demir, 2019). This data can then be used to create maps and other visual representations of urban ecosystems. GIS is also used in studies that aim to uncover the effects of future climate or land use changes. GIS has also been used to map urban stewardship networks to be able to better understand sustainability relationships, opportunities and gaps between a broad range of actors (Maharramli & Romolini, 2023). Depellegrin et al. (2016) used a GIS-based method entailing 31 land-cover classes for an ES-potential assessment for the country of Lithuania. Such assessments can be used to support decision-making concerning strategy-development of resource management at different scales, while also being able to identify trade-offs and synergies between ES types.

- ◊ **Ground-truthing** is the process of collecting information in the field that is used to validate and supplement the remote sensed data. Examples of how ground-truthing is conducted are field surveys, citizen science initiatives or ground-based sensors (Nitoslawski et al., 2019).

- ◊ **Socio-economic data collection** involves data collection on socio-economic indicators. Examples of these indicators can be income levels, employment rates and population densities. These can provide a complete understanding of the urban ecosystem and the interconnectivity between anthropogenic and natural systems. Due to the many diverse stakeholders in urban environments, multiple studies that investigated and mapped stewardship networks amongst them were able to identify actions to improve those networks, eventually leading to improvements in urban nature conservation and management (Belaire et al., 2011; Maharramli & Romolini, 2023). Other forms of socio-economic indicators in the light of urban ecology can include proximity and access to urban green infrastructure and its benefits for human health and well-being, mainly to investigate possible environmental injustices (Davis et al., 2012).

- ◊ A currently highly anticipated method in UEM is the one of **ecosystem service (ES) mapping**. It involves the quantification of the benefits that natural systems in urban environments provide to society. Examples of the mapping of ESs include mapping the temporal and spatial patterns of the above (Davies et al., 2011) and belowground (Cerón et al., 2016) carbon storage across urban areas, which can both be seen as fundamental services influencing climate change mitigation policies. Liu et al. (2013) showed that by modelling and mapping ESs such as carbon storage, timber production and water-quality improvement, they could propose a definition of priority areas for the conservation of the ESs they provide to nature and society. They highlighted the power of identifying those spatially explicit areas for making decisions on land use and natural resources more efficient. Mapping ESs in urban areas has been shown to reshape the value assigned to them and to provide the data necessary for the instalment of robust and realistic goals for managing those services sustainably (Davies et al., 2011).

- ◊ The use of **typologies** in UEM holds immense significance as it facilitates the systematic categorization and classification of diverse urban environments, enabling a more comprehensive understanding of their ecological characteristics and functions. Typologies provide a structured framework for organizing complex urban landscapes based on shared attributes, allowing researchers and policymakers to identify patterns, trends and variations across different urban areas. By employing typologies, UEM becomes a more efficient process, aiding in the development of targeted strategies for sustainable urban planning and management. Typologies in urban ecosystem mapping can be based on a range of factors, such as land use patterns, vegetation density, built density, socio-economic indicators and ecological functions. For instance, a land-use-based typology may classify urban areas into different land-use classes based on the function each mapped unit has, providing insights into the varying impacts of different land uses on ecological processes (Lagrosa et al., 2018). Another example is the green space typology, which can distinguish UGS such as parks, green corridors and urban forests, facilitating an understanding of their contributions to biodiversity conservation and ESs provision (Kopecká et al., 2017). Additionally, socio-economic typologies can be utilized to analyze how demographic characteristics and urbanization patterns influence ecological dynamics and environmental challenges in specific neighborhoods or districts. These discussed forms of typologies can also be merged into a single typology where for example Farinha-Marques et al. (2017) presented an urban habitat classification procedure with classification categories covering both natural and manmade habitats. Such typologies are proven to be invaluable in tailoring context-specific urban planning strategies and fostering sustainable development in rapidly expanding urban regions.

3.1.3 Importance of Urban ecosystem mapping

3.1.3.1 The significance and potential benefits of urban ecosystem mapping

The significance and potential benefits of UEM are key in addressing the multifaceted challenges posed by rapid urbanization and its impact on the natural environment. This section delves into the profound implications of UEM, emphasizing its crucial role in promoting sustainable urban development and effective environmental management. By systematically characterizing and understanding the ecological complexities of urban landscapes, this research seeks to highlight the potential benefits that arise from informed decision-making, evidence-based policies and targeted resource allocation. Moreover, UEM offers the opportunity to identify and protect critical ecological assets, foster biodiversity conservation and enhance ESs within urban areas. Through this investigation, this literature exploration aims to underscore the transformative power of UEM in shaping cities that thrive in harmony with nature, ultimately contributing to the well-being of urban inhabitants and the resilience of urban ecosystems.

◊ UEM plays a pivotal role in **sustainable urban development** by helping to identify and assess the natural assets and ecological processes within cities (Bateman et al., 2015). This essential information is crucial for integrating nature-based solutions into urban planning, promoting sustainable land use practices and enhancing the overall resilience and livability of cities. Furthermore, UEM supports the development of green infrastructure, such as parks, green spaces and urban forests, which provide numerous environmental, social and economic benefits. For instance, a high-resolution map of the land cover of the city-state of Singapore demonstrated implications for future biodiversity studies and ES and natural resource assessments, holding the significant potential to inform sustainable urban policies (Gaw et al., 2019). In addition to its contributions to sustainable urban planning, UEM assists cities in identifying and prioritizing areas for sustainable development (Selim & Demir, 2019; Mohammad Imam Hasan et al., 2018). In conclusion, UEM's comprehensive understanding of urban ecosystems empowers cities to develop and implement sustainable policies and practices that harmonize the coexistence of nature and urban development.

◊ The practice of UEM holds the power to provide data and spatial analysis to guide **land-use planning and decision-making processes** regarding the conservation of green spaces and biodiversity (Farinha-Marques et al., 2017). It helps identify ecologically sensitive areas, habitats and corridors, enabling informed choices on where to locate infrastructure, allocate land for development, and preserve important natural areas. Simulations of future scenarios of urban expansion enable urban planners to predict future demands and patterns of ESs, enabling them to act accordingly (Eigenbrod et al., 2011). By considering ecological factors, cities can optimize resource allocation, minimize environmental impacts and achieve a balance between urban growth and conservation.

◊ In intensely urbanizing areas, artificial surfaces disrupt the flow of natural cycles and decrease the continuity of the green system by, among other things, interrupting population movement, decreasing biodiversity and a declined precipitation water infiltration capacity (Aksu & Kırca, 2023). UEM plays a crucial role in combating these disruptions by identifying areas of high ecological value within urban environments. This is especially relevant considering the role that urban areas play in biodiversity conservation (Kowarik et al., 2016). For example, a study by Planchuelo et al., (2020) pointed out that both urban natural remnants and novel urban habitats can sustain a plethora of endangered plant populations. Biodiversity and migration dynamics of individual species are highly influenced by the spatial distribution of suitable habitats, leading to the conclusion that the incorporation of this spatial aspect in conservation practices is important (Ryan et al., 2014). Next to this, investigating and mapping species distributions together with their preferred habitat types in urban areas can uncover altered resource usage or behaviors in certain urban dwelling species (Singh & Downs, 2016). This critical information is instrumental in prioritizing **conservation efforts, protecting vital habitats, and effectively managing urban biodiversity**. By comprehensively assessing the relationships among biodiversity, habitat quality and proxies of ESs in UGS, Belaire et al. (2022) demonstrated that positive correlations exist between these ecological aspects, showcasing the potential for simultaneous support and enhancement of all three aspects through strategic urban design and management. Through the meticulous mapping and conservation of these areas, cities can ensure the preservation of native species, facilitate ecological connectivity and bolster overall urban biodiversity. Moreover, improving urban habitat mapping can lead to a better understanding of the relationship between urban biodiversity filtering and ecological processes, consequently shedding light on the underlying services provided by urban ecosystems (Pinho et al., 2021). By integrating UEM into urban planning and management strategies, cities can foster sustainable coexistence between urban development and thriving biodiversity, ultimately contributing to more ecologically balanced and resilient urban environments. Furthermore, enhanced biodiversity in urban ecosystems can lead to the preservation of biodiversity in other natural ecosystems via biodiversity having a positive influence on the quality of life and education of urban dwellers, leading to a positive feedback loop to improved care and understanding of non-urban ecosystems (Savard et al., 2000).

◊ **Environmental impact assessments** can be carried out based on baseline data on ecological features and processes that are obtained via UEM. It helps evaluate the potential environmental impacts of development projects, infrastructure expansions or policy interventions (Babí Almenar et al., 2023). By considering the ecological implications, decision-makers can identify and implement measures to minimize adverse effects, ensure compliance with environmental regulations and enhance environmental sustainability. UEM can give insights into patterns and processes that rule in urban environments. It has been able to identify threats to urban ecosystems such as the loss of riparian zones and vegetation cover (Chapa et al., 2019).

◊ UEM mapping enhances **stakeholder engagement and public awareness** by providing visual representations and accessible information about urban ecosystems. It facilitates communication, education and participation of various stakeholders, including community groups, NGOs and policymakers. Involving stakeholders in the mapping process fosters a sense of ownership, promotes collaboration and encourages informed decision-making.

◊ ESs are the benefits that humans derive from ecosystems, such as air and water purification, climate regulation and recreational opportunities. UEM helps **identify and protect key ES providers** within cities, such as parks, urban forests, wetlands and green corridors where UGS has been proven to moderate urban challenges such as air quality and excessive heat (Derkzen et al., 2015). Via analysis of land-use-land cover and ES dynamics over certain periods in certain areas, important ES provisioning habitat types can be uncovered and targeted for conservation and restoration (Navara & Vedamuthu, 2022). Similarly, analyzing landscape structure changes and ES supply along an urban-rural gradient can provide a tool for ES management and social-ecological land planning by uncovering trade-offs between different ESs with changing landscape structure (Herrero-Jáuregui et al., 2019). By safeguarding and restoring these areas, cities can enhance the provision of ecosystem services, improve air and water quality, mitigate climate change impacts and enhance urban resilience.

◊ UEM contributes to **human well-being** by enhancing access to nature and green spaces. Studies have shown that exposure to green environments improves mental health, reduces stress levels and promotes physical activity (Nutsford et al., 2013). By mapping and ensuring the availability of parks, greenways and recreational areas, cities can enhance the quality of life for their residents and promote community well-being. Teixeira et al. (2015) published a paper that used a vegetation cover and land use map to investigate the relationship between a residing conflict-causing primate species and the inhabitants of a Brazilian city, showing the vast possibilities of UEM being an information tool to create an overall enhanced human well-being. Notably, an intriguing study by Tsaligopoulos & Matsinos (2022) highlighted how UEM could identify green areas as quiet spaces based on acoustic characteristics. Given the vital role of quietness in enhancing the well-being of urban residents, this discovery presents a unique opportunity to create ecologically sustainable urban environments that prioritize both human well-being and environmental considerations.

◊ The practice of UEM, together with its by-products and the information it provides can support **climate change adaptation and mitigation efforts**. By mapping and protecting natural areas, cities can increase their resilience to climate change impacts such as extreme heat events, flooding and sea-level rise (Guo et al., 2022). By producing a map of priority areas that depict areas disrupting the flow of natural cycles, Aksu & Kırca (2023) were able to interpret the causes of those disruptions, enabling sustainable stormwater management and landscape planning. Mapping also helps identify opportunities for nature-based solutions, such as urban greening, green roofs and urban agriculture, which can provide benefits to people and nature while simultaneously mitigating the effects of climate change (Hutt-Taylor et al., 2022).

3.1.4 Challenges and limitations

3.1.4.1 Challenges and limitations of urban ecosystem mapping

The effective application of UEM in urban planning and environmental management is dependent upon recognizing and addressing the inherent challenges and limitations of the process. This section delves into an examination of the various obstacles faced in UEM, encompassing aspects such as data availability, accuracy, and reliability. This research aims to critically analyze these challenges and limitations, shedding light on potential biases and uncertainties that may arise during the mapping process. By understanding and mitigating these limitations, UEM can be further refined, enhancing its effectiveness as a tool for evidence-based decision-making and sustainable urban development.

◊ One of the main challenges is the **availability of relevant and up-to-date data** for mapping urban ecosystems. Obtaining comprehensive and high-quality data on land cover, vegetation, biodiversity, and ecological processes within cities can be challenging. Spatial data obtained via remote sensing from satellites impacted broad-scale ecology in numerous positive ways, however, fine-scale patterns that operate at sub-meter resolution remain understudied (D'Urban Jackson et al., 2020). However, studies cope with this limitation by the use of new technologies and methods to uncover the ecological processes at small scales. Gu et al. (2015) partly coped with the fact that satellite imagery of moderate resolution is unable to provide the basis for individual-species detection by using imaging spectroscopy to estimate the distribution of specific tree taxa based on assemblages associated with foliar traits.

◊ Data collection efforts may be limited by **resource constraints, lack of standardized protocols and fragmented data sources**. It even goes as far as there being no consensus measures of urbanization in the scientific community with an extra challenge being the integration of socio-cultural characteristics into the definitions of different urbanization levels (Short Gianotti et al., 2016; Inostroza et al., 2019). Additionally, accessing historical data for long-term analysis can be difficult, particularly in rapidly changing urban environments. The consequence of only partially covering urban areas along with taxonomic biases consequently leads to urban biodiversity being understudied as a whole (Casanelles-Abella et al., 2021).

◊ Urban ecosystems operate at various **spatial and temporal scales**, ranging from local neighborhoods to entire cities. Mapping at appropriate scales is essential to capture the heterogeneity and complexity of urban environments. However, finding the right balance between fine-grained detail and broader coverage can be challenging. On top of that, there are few existing procedures concerning habitat and biodiversity recording that can describe urban environments on a fine scale (Farinha-Marques et al., 2017). Different research questions and applications may require different scales of mapping and it can be challenging to integrate and compare data from diverse spatial and temporal scales.

◊ The techniques used for UEM have **methodological limitations** that can affect data accuracy and reliability. Remote sensing techniques, such as satellite imagery and aerial photography, may have limitations in resolving small-scale features or distinguishing certain land cover types (D'Urban Jackson et al., 2020). Ground-based surveys and field data collection can be labor-intensive and time-consuming, limiting their scalability and coverage (Kopecká et al., 2017). Additionally, challenges may arise in standardizing methodologies across different studies and regions, leading to variations in data quality and comparability.

- ◊ **Urban ecosystems are highly dynamic**, experiencing continuous changes due to urbanization, infrastructure development and natural processes (Griffiths et al., 2010). Mapping these changes accurately requires frequent updates and monitoring, which can be resource-intensive and challenging to sustain. Rapid land-use change poses challenges in capturing and tracking these dynamic processes accurately. The dynamic nature of urban areas also poses difficulties in the assessments and management of UGS concerning the ESs they deliver due to the temporal and spatial heterogeneity of those spaces (Gaston et al., 2013).

- ◊ UEM requires **collaboration across disciplines**, including ecology, geography, urban planning and data science. Bridging the gap between these disciplines and integrating diverse expertise can be challenging. Transdisciplinary planning approaches, such as mapping and valuating ESs, strategic and integrated thinking, governance and participatory planning are said to be promoted by investigating the interface between the disciplines of urban ecology, urban planning and environmental management (Cilliers et al., 2014). Coordinating efforts, harmonizing methodologies and ensuring interdisciplinary collaboration are crucial for producing comprehensive and reliable mapping results. An illustrative instance of the prevailing deficiency in coordinating efforts within UEM pertains to the abundance of methodologies and frameworks aimed at enhancing the ecological performance of urban built environments based on ecological concepts, while their practical implementation and integration in urban planning remain largely insufficient (Zari & Hecht, 2020).

- ◊ The **engagement of diverse stakeholders** such as policymakers, researchers and local communities is important to book successes in the practice of UEM. Incorporating local knowledge, values, and perceptions can enhance the accuracy and relevance of mapping efforts. Proxies of stakeholder engagement such as collaboration can be seen as a steppingstone to nature conservation and resource management (Belaire et al., 2011). It has also been highlighted by Gaston et al. (2013) that an incomplete integration and understanding of the networks that the many land managers in urban contexts form with each other poses great difficulties in effectively managing ES provision. However, effectively engaging stakeholders and integrating their data and perspectives into mapping processes can be challenging, requiring effective communication, data-sharing mechanisms and participatory approaches. The absence of planning methods concerning the transformation of peri-urban areas has been shown to have negative impacts on those ecosystems (Navara & Vedamuthu, 2022). Luckily so-called ecosystem networks are being created which aim to ease cooperation and knowledge distribution among stakeholders within the city by organizing meetings, seminars and preparing new methodologies (Feiferytė-Skirienė et al., 2022). Understanding the goals and needs of diverse stakeholders and how they are connected is required for sustainable and resilient cities. To combat this, socio-ecological frameworks such as the one from Romolini et al. (2016) can be used to examine urban stewardship networks to ultimately help guide the integration of social and ecological phenomena in urban management. Another aspect as to why it is important to take into account all relevant stakeholders in UEM and its consequences concerns the finding that both ecosystem degradation and restoration alike can impact the well-being of urban marginalized groups (Derkzen et al., 2017). This provides evidence that installing or expanding urban green infrastructure should be preceded by thorough investigations into the consequences of those projects.

3.1.4.2 Various factors influencing urban ecosystem mapping initiatives

The process of UEM is influenced by a plethora of diverse factors that shape the collection, analysis and interpretation of data in urban environments. This section explores the various factors that impact UEM initiatives, encompassing both biophysical and socio-economic dimensions. From the availability and quality of spatial data to the selection of appropriate mapping techniques and methodologies, these factors play a crucial role in determining the accuracy, reliability and applicability of the mapping process. By understanding these influential factors, this research aims to foster a deeper appreciation of the complexities involved in UEM and provide valuable insights for effective and appropriate mapping strategies.

◊ The **scale of the study** refers to the geographic extent to which the mapping is conducted. UEM can be conducted at different scales, ranging from local neighborhoods and specific sites (e.g., Farinha-Marques et al., 2017) to entire cities (e.g., Griffiths et al., 2010) or even larger regions (Vriens et al., 2011). The scale of the study determines the level of detail and the extent of the area covered. Mapping at a finer scale provides more detailed information about specific locations, while mapping at a broader scale offers a broader understanding of the overall urban ecosystem patterns and processes.

◊ **Spatial resolution** refers to the level of detail at which spatial features and land cover classes are represented in the mapping. Higher spatial resolution allows for the identification of smaller features and a more detailed representation of the urban landscape. Remote sensing techniques, such as satellite imagery or aerial photography, play a crucial role in capturing spatial information (D'Urban Jackson et al., 2020). However, the choice of spatial resolution depends on the specific research objectives, data availability and the size and heterogeneity of the study area.

◊ **Temporal resolution** refers to the frequency and time intervals at which data are collected and analyzed. Temporal resolution influences the ability to capture land-use changes and track trends over time. Long-term monitoring provides valuable insights into the stability and dynamics of urban ecosystems. Zoran et al. (2009) analyzed the structure of urban cover dynamics based on satellite imagery over 17 years for the city of Bucharest. Understanding those dynamics provides important input necessary for urban management such as urban forest planning and runoff control. However, the availability and cost of data collection may limit the temporal resolution of mapping efforts.

◊ **Indicators** are specific variables or parameters used to characterize and measure different aspects of urban ecosystems (Selim & Demir, 2019). The choice of indicators depends on the research objectives, the characteristics of the urban area and the ESs or processes of interest. Common indicators include land cover types, vegetation indices, biodiversity metrics, air quality parameters and socio-economic variables. An example of a socio-economic variable is the *land functional value* developed by Peng et al. (2019) which is allocated to urban habitats and anthropogenic infrastructure. The value is allocated based on the integration of land, ecosystem and landscape functions, where this variable can be used to formulate land use planning. Selecting appropriate indicators ensures that mapping efforts capture the relevant ecological and environmental factors and provide meaningful information for decision-making.

3.1.5 Future directions for the field of urban ecosystem mapping

1 Remote sensing plays a crucial role in UEM, providing valuable data on land cover, vegetation and other ecological parameters. Future research can focus on exploring **advanced remote sensing techniques**, such as high-resolution satellite imagery to improve the accuracy and detail of mapping efforts. An example of how progress in the practice of remote sensing could improve our complete understanding of the dynamics in urban environments comes from a paper by D'Urban Jackson et al. (2020). They presented two high-resolution remote sensing tools that could be implemented for fast and accurate 3D mapping of ecosystems, adding a new layer of complexity to ecosystem maps and leading to those becoming more realistic. New technologies are being developed at fast rates to shift data extraction from time-consuming, labor-intensive methods to automatic and efficient ones (Kopecká et al., 2017). Liang et al. (2022) developed a way to automatically extract urban impervious surface distribution using remotely sensed data, replacing the previous classification methods that relied on intensive training and human experience. These technologies can provide more comprehensive, dynamic and fine-grained information about urban ecosystems, including vertical vegetation structure, urban heat island effects and three-dimensional mapping.

2 Integrating **data from multiple sources** can enhance the richness and accuracy of UEM. Future research can explore approaches to integrate data from remote sensing, field surveys, citizen science initiatives and existing databases. An example comes from the paper by Richards et al. (2018) where they were able to automate a method to link the content of social media photographs to their geospatial location which could provide the basis to spatially delineate urban areas with high levels of cultural ES provisioning. This integration can improve spatial and temporal resolution, provide a more comprehensive understanding of urban ecosystems and enable the assessment of long-term trends and changes. Especially in recent years, researchers are finding more and more ways to extract data from many different sources. Liu et al., (2020) developed a tool that maps and assesses landscape soundscape characteristics that can also be integrated in urban planning, highlighting the multitude of aspects urban management has to take into account.

3 **Spatial modelling and simulation techniques** can enhance the predictive capabilities of UEM. Xie et al. (2018) modelled future projections of trends in the provisioning of ESs under a scenario of future urban expansion with the use of ES mapping models and found an aggravated loss of major ESs compared to past losses, highlighting the conversion of forest land into urban land as the major driver of this aggravation. Another study simulated land-use changes in an urban area where the used model can be manipulated and used by urban planners to predict future patterns of land-use changes under different ecological, economic and sociological conditions (Lagrosa et al., 2018). By integrating spatially explicit models with mapping data, researchers can simulate the impacts of urban development scenarios, climate change and policy interventions on urban ecosystems. This can help assess future ecosystem dynamics, prioritize conservation efforts and support evidence-based decision-making in urban planning and management.

4 **Citizen science initiatives** have already proven themselves to be important in data collection, monitoring and mapping of urban ecosystems (Teixeira et al., 2015). Future research can explore the use of citizen science approaches for UEM, leveraging the collective knowledge and contributions of community members. This can involve participatory mapping exercises, mobile applications for data collection and collaborative platforms for data sharing and analysis (Nitoslawski et al., 2019). Engaging citizens in mapping efforts can enhance data availability and foster a sense of ownership and stewardship of urban ecosystems.

5 UEM mapping can benefit from **incorporating social and cultural dimensions** alongside ecological assessments since cities are characterized by complex relationships between natural and socio-economic systems (Galychyn et al., 2020). Next to assessments on ES supply based on traditional biophysical modelling and ecological inventories, including maps of socially perceived ES supply obtained from the local public and diverse stakeholders can lead to the allocation of ES supply hotspot areas relevant for nature and landscape planning, management and governance (De Vreese et al., 2016). Future research can explore the integration of socio-economic data, cultural values and human perceptions of urban ecosystems into mapping efforts. An example could be the integration of economic cost and benefit predictions into the mapping process of future urban greening projects (Babí Almenar et al., 2023). Mapping and documenting how a common, open-access urban natural space becomes redefined into private urban infrastructure can help understand trends in the management of these common spaces and help govern them as vulnerable resources (Unnikrishnan et al., 2016). This interdisciplinary approach can help capture the multifaceted nature of urban environments, promote equity and social justice and support the development of inclusive and culturally relevant urban planning and management strategies.

6 **Standardization of methodologies, data formats and interoperability of mapping efforts** can enhance the comparability and compatibility of urban ecosystem data across different regions and studies (Inostroza et al., 2019). Future research can focus on developing standardized protocols, data formats and quality control measures for UEM. This would enable data sharing, meta-analysis and the development of databases and tools for urban ecosystem assessment and monitoring.

3.1.6 Conclusion

In conclusion, the literature exploration on UEM has illuminated several crucial insights into the intricate relationship between urban environments and the ecosystems they house. The key findings of this review highlight the significance of accurate and up-to-date mapping methodologies in understanding the complex dynamics of urban ecosystems. The integration of advanced technologies like remote sensing, Geographic Information Systems (GIS) and citizen science have expanded the capabilities of UEM, enhancing our ability to assess biodiversity, ESs and their interactions. The implications of these findings for urban planning and management are substantial. UEM not only aids in identifying green spaces, biodiversity hotspots and potential areas for nature-based solutions but also facilitates informed decision-making in urban development projects. The application of ecosystem mapping in urban planning fosters the creation of more sustainable, resilient and livable cities. Furthermore, this knowledge proves instrumental in identifying spaces vulnerable to ecological pressures, invasive species and habitat degradation, thereby directing conservation efforts and shaping effective management strategies. It is imperative to underscore the importance of continued research and innovations in the field of UEM. Urban environments are dynamic and constantly evolving, which calls for the need for adaptive and responsive mapping techniques. Additionally, while the existing literature provides a solid foundation, it also reveals certain gaps and challenges that require further investigation. These include the need for standardized methodologies, increased data accuracy and the incorporation of socio-economic and cultural dimensions within mapping frameworks. Continued research endeavors and interdisciplinary collaborations hold the potential to refine existing techniques and develop novel approaches that can address these challenges. To sum up, as urbanization accelerates and the significance of green spaces and biodiversity becomes ever more apparent, the importance of advancing UEM cannot be overstated. This research underscores the importance of embracing innovation, collaboration and ongoing investigation in this field, ultimately paving the way for cities that harmonize with and support the ecosystems they encompass. All these findings now have the potential to be applied to the case of Flanders, hence they are universally applicable.

3.2 Review of a set of existing urban ecosystem mapping initiatives

The obtained typologies from multiple sources were reviewed according to a set of drawn-up criteria, subdivided into 7 different categories, namely *content*, *thematic*, *feasibility*, accuracy, *(reported) usability*, *scale* and *availability*. These categories were chosen to represent the, in the literature review highlighted important themes and challenges the UEM initiatives have to conquer in urban environments. The list of criteria together with an explanation of what they refer to can be found in *Table 1*. Starting with the Biological Valuation Map (BVM) of Flanders and the Brussels Capitol Region, each initiative was scored on every criterion using available online sources. A table containing the scoring of every typology can be found in *Appendix 1*. A critical analysis of each typology was conducted deriving from how they scored on the criteria, with the BVM being discussed in a more complete sense compared to the others, due to it being at the heart of this research. From the analysis, aspects on which the BVM could score better were uncovered, while the analysis of the other initiatives shed light on possible future additions to it.

Table 1: Formulated criteria used to score the obtained UEM initiatives.

Category	Criteria	Explanation	Category	Criteria	Explanation
Content	Map	*Is the typology directly translated into a map?*	**(Reported) usability**	Policy creation	*Can and/or is the classification system being used in the process of policy creation?.*
	Valuation system	*Does the map infer a valuation system? Specification of the type.*			

	Inclusion of biodiversity	*Does the map hold information on the present biodiversity, whether it being plant or animal diversity?*		Developers	*Which organization/body developed the typology?*
	Inclusion of ecosystem services	*Does the classification system include the valuation of ecosystem services?*		Extrapolation potential	*Can the classification system be extrapolated to other areas?*
	Inclusion of non-natural areas	*Does the typology include anthropogenic categories and habitat types?*		Specific applications	*Does the typology and its related instruments have specific implications in decision-making and/or land use management practices?*
Thematic	Thematic resolution	*What is the thematic resolution of the classification system (cf. the number of classes, habitat types, etc.)?*	**Scale**	Method of delineation	*Does the classification system use rasters or polygons as mapping units?*
	Urban classification	*Does the typology include a classification system specifically for urban areas?*		Scale and pixel size	*At what scale is the typology being implemented?* *If the delineation process infers a raster, what is the pixel size?*
	Tackled ecological pressures	*Does the use of the typology aim to tackle ecological pressures? If yes, which ones?*			

	Socio-economic impact	*Does the typology also include socio-economical aspects? If yes, which ones?*		Minimal mappable unit	*What is the smallest possible mapped entity?*
Feasibility	Data collection	*How is the data collected? Indication of the labor-intensiveness of collecting this data.*		Range/extent	*What is the current range at which the typology is being implemented?*
	Classification feasibility	*Are the mapping units consistent and easy to determine in practice?*			
	Specific training	*Does asserting the area to specific mapping units ask for specific training?*			
Accuracy	Reflection of reality	*How accurate is the typology? Does it reflect reality?*	**Availability**	Metadata availability	*Is there metadata available?*
	Accuracy testing	*Is the accuracy of the typology being tested?*		Open source	*Is the typology and its related instruments openly available to the general public?*

3.2.1 Biological Valuation Map (BVM) of Flanders and the Brussels Capitol Region

This first UEM initiative represents the focal point of this research. The BVM consists of a database for land and vegetation cover of the Flemish territory and the Brussels Capital region. The following critical analysis of its content and the implementations of the map was conducted to discover new insights that could lead to its improvement and increased relevance in urban ecology. *Table 2* shows how the BVM scored on the postulated criteria from *Table 1*.

Table 2: Scoring of the Biological Valuation Map of Flanders based on the formulated criteria

		Biological Valuation Map of Flanders
	Criteria	
Content	Map	*Yes.*
	Valuation system	*Ecological Valuation: rarity, key species, biodiversity, vulnerability and replaceability.*
	Inclusion of biodiversity	*Inclusion of faunistic important areas. Use biodiversity as an indicator of the value of delineated habitats.*
	Ecosystem services	*No.*
	Inclusion of non-natural areas	*Yes.*
Thematic	Thematic resolution	*List of mapping units based on land use and vegetation type, alliance and association. In the form of codes.*
	Urban classification	*In development.*
	Tackled ecological pressures	*Nature conservation and environmental issues: agricultural nitrogen and sulphur emissions, delineating nature reserves and Natura2000 network conservation.*
	Socio-economic impact	*Heavy focus on ecology.*
Feasibility	Data collection	*Intensive field surveys, aerial photographs and existing GIS layers.*
	Classification feasibility	*Hard, specific training is needed.*
	Specific training	*Permanent and well-trained team of professional field surveyors. Workshops to ensure standardization.*
Accuracy	Reflection of reality	*Areas visited once every decade, during the flowering season of dominant vegetation. Level of land use, vegetation type or vegetation associations.*
	Accuracy testing	*A posteriori quality assessments.*
Reported Usability	Policy creation	*Nature conservation and environmental protection.*
	Developers	*The Flemish government in collaboration with the Research institute for Nature and Forest (INBO).*
	Extrapolation potential	*Full coverage reached.*
	Specific applications	*Indicates land-use (built, forest or grassland).*
Scale	Method of delineation	*Polygons.*
	Scale and pixel size	*1/10.000.*
	Minimal mappable unit	*Small relicts (rows of trees, sunken roads, etc.).*
	Range/extent	*Flanders and Brussels Capital Region.*
Availability	Metadata availability	*Publicly available via Flemish government site.*
	Open source	*Maps are openly available for consultation and download.*

3.2.1.1 Content

The BVM of Flanders is a comprehensive GIS-based map that depicts the distribution and ecological value of diverse ecosystems and habitats within the region. Developed through a collaboration between the Flemish Government and research institutes like the *Instituut voor natuur- en bosonderzoek* (INBO) (Vriens et al., 2011), the map offers detailed information on the spatial arrangement of ecosystems such as forests, grasslands, heathlands, wetlands, as well as specific habitat types like quarries, dunes, and industrial sites. It employs a classification system based on land use and vegetation cover, assigning a level of biological value to each mapped parcel. This value is determined by assessing the rarity of the habitat, presence of key species, overall biodiversity, the vulnerability of the habitat patch and its replaceability in the case the habitat is lost. Additionally, the map incorporates data on the distribution of fauna species within different habitats, highlighting areas of faunistic significance. However, it is important to note that the BVM does not include an assessment of ESs or factors such as relief, soil types and vegetation height. By providing valuable insights into habitat connectivity and condition, the BVM enables informed decision-making for species movement and the overall functioning of ecosystems. As a result, the map serves as a crucial tool for conservation, land-use planning and the protection and sustainable management of urban habitats in Flanders.

3.2.1.2 Thematic

The thematic resolution of the BVM is structured as a coding system, where delineated habitats are assigned mapping units in the form of codes. The number of letters in the code indicates whether the habitat is mapped to the level of vegetation or land cover, vegetation alliance, or vegetation association. While the BVM covers non-natural habitats, there is a scarcity of mapping units that represent urban natural and non-natural habitat patches. However, there is ongoing work to develop a new urban classification specifically tailored for cities. The usage of the BVM effectively addresses various ecological pressures. By assigning ecological value to different habitat types based on criteria such as biodiversity and vulnerability, the map facilitates the protection and conservation of these habitats, mitigating the negative effects of habitat loss and fragmentation. Moreover, the BVM contributes to biodiversity conservation, landscape connectivity and the maintenance of local ecological processes. Land-use planners and developers can consult the map to prevent the conversion of valuable natural areas into built-up areas, promoting sustainable land use.

Although the BVM primarily focuses on ecological aspects and does not directly map socio-economic characteristics such as cultural or recreational values that are significant in urban systems, it has the potential to influence sociologic and economic aspects. For instance, the map raises awareness about the ecological value of different areas, fostering a greater understanding of the importance of conservation practices among the general public. Additionally, ecologically valuable areas identified by the BVM can serve as attractions for ecotourism and nature-based recreational activities, potentially generating economic benefits. Furthermore, these areas can also have an impact on property values.

3.2.1.3 Feasibility

Data in the BVM is collected via a combination of intensive field surveys, aerial photographs, expert assessments and existing data sources (e.g., Flemish Forest Inventory). The classification of the delineated patches in the map to the specific mapping is done by individuals who went through specific training, highlighting the difficulty of that process. Still, acknowledging the interpersonal differences in the classification process is important to highlight the possibility that a specific situation in the field is vulnerable to multiple interpretations (Vriens et al., 2011). Luckily, Vriens et al. (2011) also mention that the field surveyors follow frequent workshops to ensure minimal interpersonal differences. The biological valuation assignment process poses difficulties concerning polygons that consist of mixtures of multiple mapping units, since those different mapping units can have a different biological value. The same reasoning can be applied to the surface estimations of the different biotopes in those mixtures. The creation of a flawless, complete land covering BVM for the entire Flemish region asks for lots of resources in the form of funding, staff, and time, which all have proven to be hard to obtain.

3.2.1.7 Accuracy

The BVM is able to obtain relatively high accuracies due to the scientific methods and the extensive data collection in its development. Mapping the delineated polygons to the level of land use or vegetation cover, alliance or association provides an accurate reflection of reality. The classification process is carried out in the flowering season of the most dominant present vegetation type, which also helps to map the habitats more realistically. The areas are visited every decade to update the map were needed and post-mapping quality assessments are carried out to test and evaluate the accuracy of the BVM. Due to the highly heterogeneous characteristics of urban areas, it comes to no surprise that these areas are mapped in lesser detail compared to more natural ones. Next to this, the highly dynamic nature of urban environments most likely requires more frequent revisits to capture their most up-to-date state of being.

3.2.1.4 Reported Usability

The BVM has significant implications for nature conservation and environmental protection, serving as a valuable tool in land use decision-making and project authorization processes. It holds a crucial position as a reference point for a range of legal and policy instruments, including the European guidelines for nature protection. However, it is important to note that the BVM, as acknowledged by Vriens et al. (2011), does not fully capture landscape ecological relations, thus missing explicit inclusion of these relationships. This presents an opportunity to enhance the map's relevance in environmental analyses by incorporating vertical elements such as vegetation height and horizontal aspects such as landscape connectivity. By incorporating these landscape relations, the BVM can provide a more comprehensive understanding of the ecological dynamics within the mapped areas.

Considering that the BVM has achieved full coverage of the Flemish region, its extrapolation potential is limited. However, a collaboration with Wallonia could pave the way for a nationwide detailed land-cover inventory which would be the first of its kind for Belgium. Such collaboration would enhance the comprehensive understanding of the country's ecosystems and support more integrated and coordinated conservation and land management efforts on a larger scale.

3.2.1.5 Scale

The BVM employs a scale of 1/10,000 to represent the mapped area. The map utilizes polygons as the primary method for delineating the covered regions. However, it should be noted that smaller features such as rows of trees and sunken roads are mapped at smaller scales, representing the minimal mappable units within the map. While the chosen scale allows for a detailed representation of the area, it is often necessary to supplement the BVM with additional maps when studying or utilizing it at the level of individual parcels.

3.2.1.6 Availability

The BVM is readily accessible to the public, facilitating user-friendliness and ease of consultation and download. In terms of transparency, the BVM excels by openly sharing comprehensive metadata related to the mapping process, including the utilized data frameworks and background information. This transparency ensures that users have access to the necessary information to understand and interpret the map accurately.

3.2.2 Other urban ecosystem mapping initiatives

3.2.2.1 European Union Nature Information System (EUNIS)

The European Union Nature Information System (EUNIS) habitat classification system is an extensive framework developed by the European Environment Agency (EEA) to categorize and describe habitats across Europe. Its main goals include the facilitation of cross-border communication, conservation efforts and policymaking. The classification consists of a structured hierarchy of habitat types, each assigned to a unique code, scientific name and description, making it a consistent and standardized framework for the classification and interpretation of habitats. It covers a wide array of habitats, ranging from terrestrial ecosystems like forests, grasslands and wetlands to freshwater and marine environments, including coastal zones, aquatic ecosystems and cave systems. By offering a high thematic resolution together with detailed descriptions of each habitat type's ecological attributes, species assemblages and environmental conditions, nuanced understanding and accurate categorization of diverse habitats is assured.

The system is designed to be applicable across different scales, making it feasible for various geographic levels, ranging from local ecosystems to broader regional and continental contexts. Its structured approach ensures user-friendliness for both experts and non-experts, including researchers, policymakers and conservationists. EUNIS has been widely adopted as a standard reference for habitat classification, assessment and management in Europe. However, since the EUNIS habitat classification does not include mapping units that consider habitat types of anthropogenic origin, its usage in an urban context is detrimentally impaired. The accuracy of application of the classification system highly depends on the data used in each specific habitat classification project. By being openly available through the EEA's resources, including their website and environmental databases, the usage of EUNIS is encouraged for research or land management purposes.

When comparing the EUNIS habitat classification system to the BVM, the main difference between the two concerns the geographic scope and scale at which the two are implemented. While both serve a purpose in contributing to habitat assessments and conservation, the BVM specifically focuses on the Flanders region of Belgium, where EUNIS categorizes and describes habitats across various countries and regions within the European Union, typically at a regional level.

3.2.2.2 Coordination of Information on the Environment (CORINE) Land Cover

The Coordination of Information on the Environment (CORINE) Land Cover (CLC) system is a comprehensive land cover and land use classification scheme designed to provide consistent and comparable data across Europe. It serves as a valuable tool for environmental monitoring, policy making and spatial planning (Büttner et al. 2021). It provides a categorization of land into various classes based on its physical and human-made characteristics. It covers a wide range of thematic categories, including natural areas, agricultural land, urban areas and more. The system provides a standardized framework to describe the complex interactions between human activities and natural environments. The CLC system operates at a thematic resolution of five levels, ranging from general land cover categories (e.g., forests) to more specific subclasses (e.g., deciduous forests). This hierarchy allows for a detailed analysis of land cover characteristics while maintaining a manageable level of complexity for large scale mapping.

The main uses of the system consist of environmental assessments, habitat monitoring, land use planning and policy formulation. Similar to the EUNIS classification system described in *3.2.2.1*, the CLC system facilitates cross-border comparisons and supports the evaluation of land changes over time. Another shared trait with EUNIS is that the accuracy of the CLC data varies depending on the sources of information used for mapping. Generally, it is considered suitable for large-scale applications and regional assessments, but the accuracy may decrease at finer spatial scales or in complex landscapes such as urban areas. Due to its standardized classification, the CLC system enables harmonized reporting and cross-national comparisons, making it a valuable resource for decision-makers and researchers, albeit on a more regional scale. CLC data is made available through the EEA and national environmental agencies and can be accessed through geospatial databases and web services.

While both the CLC system and the BVM contribute to environmental management and decision-making, the CLC system differs in similar ways to the BVM as the EUNIS classification system. Like EUNIS, the CLC system covers a much broader geographical scope, leading it to being used for regional and European-scale assessments, providing a broad overview of land cover changes and trends. It is thus valuable for cross-border comparisons and monitoring large-scale environmental changes, while the BVM offers detailed insights into the ecological significance of different habitats and supports targeted, local conservation efforts and land use planning. There is however another aspect in which the CLC system differs from the BVM. Namely, it includes anthropogenic features like roads and buildings in its classification, while both the BVM and EUNIS predominantly focus on natural habitats and ecosystems. In conclusion, the CLC system focuses on comprehensive land use mapping across Europe, while the BVM of Flanders is specific to assessing the biological value of habitats within the Flanders region.

3.2.2.3 Green Surge and the Green Surge urban green space typology

The European project called Green Surge aims to address pressing urban issues by integrating green spaces, biodiversity, people, and the green economy. It aims to promote innovation and to connect environmental, social, and economic services with local communities, while offering solutions for the planning and implementation of green infrastructure (Stahl Olafsson & Pauleit, 2018). Its program consists of a multi-level approach to develop Urban Green Infrastructure (UGI) as a planning concept, while ensuring effective governance arrangements and investigating the valuation and market integration of biodiversity and ES. The ultimate goal of this project is thus to promote multifunctional green spaces. Their work packages include the identification, description, and quantification of the full range of UGSs. To come to this, they developed a typology of in urban settings that includes UGSs varying from larger public parks and urban woodlands to gardens, green roofs, and domestic greenery. They obtained this typology by studying literature and data on UGS descriptions, together with analyzing different European cities, conducting field work, remotely sensed data and relevant case studies.

The typology is an innovative framework designed to categorize and understand the diversity of UGS within cities. It was specifically designed for application across various urban contexts, enabling urban planners, researchers and policymakers to assess and categorize their local green spaces effectively. While it may not be universally available as a standardized tool, the framework's principles and concepts can be shared and adopted by cities interested in enhancing their understanding and management of UGS.

While both the Green Surge project and the Biological Valuation Map of Flanders contribute to the understanding and management of urban ecosystems, they differ in their scope and methods. The Green Surge project takes a holistic approach, encompassing various aspects of urban sustainability, integrating social and economic dimensions and emphasizing the multifunctionality of green spaces. In contrast, the BVM primarily focuses on assessing the biological value of habitats and providing information for conservation and land-use planning. These initiatives complement each other by addressing different aspects of urban ecosystems and providing valuable tools and knowledge for sustainable urban development.

3.2.2.4 Mapping and Assessment of Ecosystems and their Services (MAES)

The Mapping and Assessment of Ecosystems and their Services (MAES) is a framework and approach developed by the European Union to systematically evaluate and map the state of ecosystems and the services they provide. The primary goal of MAES is to provide decision-makers with valuable information to support policies related to biodiversity conservation, sustainable land use and ecosystem management. MAES covers a broad spectrum of societal aspects, including biodiversity, ecosystems and the ESs they deliver to human-wellbeing. The framework uses information input from multiple sources, including forest cover, grassland, riparian zones and Natura2000 distribution layers to produce an ecosystem type map that represents the terrestrial EUNIS habitat classes on level 2 on a 100 x 100-meter spatial resolution grid that covers 39 European countries (EE1, 2019). Thus, even though the MAES initiative is able to map at a relatively small scale considering its large geographical range, it is still unable to capture the fine scaled heterogeneity of urban ecosystems. Nevertheless, it is still practical and applicable across diverse geographic regions and policy contents, providing a common language for communication and collaboration among scientists.

The classification system used in the MAES framework comprises a versatile tool that categorizes ecosystems and services, enabling structured and informed assessments and mappings. Its coverage of diverse ecosystem types and flexibility in scale to its significance in supporting sustainable ecosystem management, policy development and decision-making. When comparing the MAES framework and its used classification system to the BVM, some similarities as well as differences can be pointed out. They both involve spatial representation of ecosystems and their characteristics and use GIS to map and visualize the distribution of different ecosystems and habitats. While both frameworks involve classification systems, the MAES classification system is more extensive by encompassing terrestrial, freshwater and marine ecosystems, compared to the BVM classification only including terrestrial ones. They also differ in the geographic scope at which they are implemented, where the MAES framework encompasses a wide range of ecosystems across different countries in contrary to the BVM that only covers the region of Flanders. This is reflected by their contributions to informed decision-making and policy development also acting at these different geographic scopes. The most interesting difference between the two systems is the strong emphasis of the MAES framework on the assessment of ecosystem services and their contributions to human well-being. It aims to quantify and map the benefits that ecosystems provide, while the BVM focusses on assessing the biological value of habitats based on ecological criteria.

3.2.2 Key findings of reviewing a set of existing urban ecosystem mapping initiatives

A set of key findings can be highlighted following the review of a set of existing typologies. Different frameworks and typologies used in the field of UEM differ substantially in their used scales, thematic coverage and approaches. While some typologies focus primarily on ecological aspects at a broader scale, others have evolved to capture fine-scaled heterogeneity in urban ecosystems and incorporate a broader range of themes, including socio-economic aspects. This reflects an increasing recognition of the interconnectedness between ecological and socio-economic factors in urban environments (Mak et al., 2021).

The review highlights that certain typologies and classification systems used in UEM practices can sometimes fall short in capturing the true heterogeneity of urban ecosystems. This limitation arises from various factors, including the scale at which these typologies operate and the complexity inherent in urban environments. Urban ecosystems are characterized by a multitude of microhabitats, each with its unique ecological and socio-economic features. These finer-scale variations, such as small green patches, rooftop gardens, or even cracks in pavement harboring plants, contribute significantly to the overall biodiversity and functionality of urban ecosystems. However, traditional typologies might lack the spatial resolution needed to identify and map these small-scale features accurately. Each typology often possesses its unique set of categories, criteria and methodologies, tailored to the specific context of the study area. While this context-specific approach ensures accuracy within the original study area, it can hinder the seamless transferability of results to other locations. When attempting to apply findings from one UEM project to another site, discrepancies between typologies can arise. Differences in terminology, categorization, and assessment criteria can complicate the comparison and integration of data between projects.

In conclusion, while certain typologies and classification systems have been valuable tools in UEM, they can fall short in capturing the heterogeneity of urban environments. The evolving urban landscape, coupled with the intricate interplay of ecological and anthropogenic factors, necessitates more sophisticated typologies that can accommodate finer spatial resolutions and multifaceted perspectives. Such advancements are vital to inform effective urban planning, increase extrapolation possibilities, cross-border collaboration, management, and policies that foster the sustainability and well-being of urban communities and their surrounding ecosystems.

3.3 Case study – the *Wondelgemse Meersen*

3.3.1 Exploration of the *Wondelgemse Meersen* and how it is currently mapped in the BVM

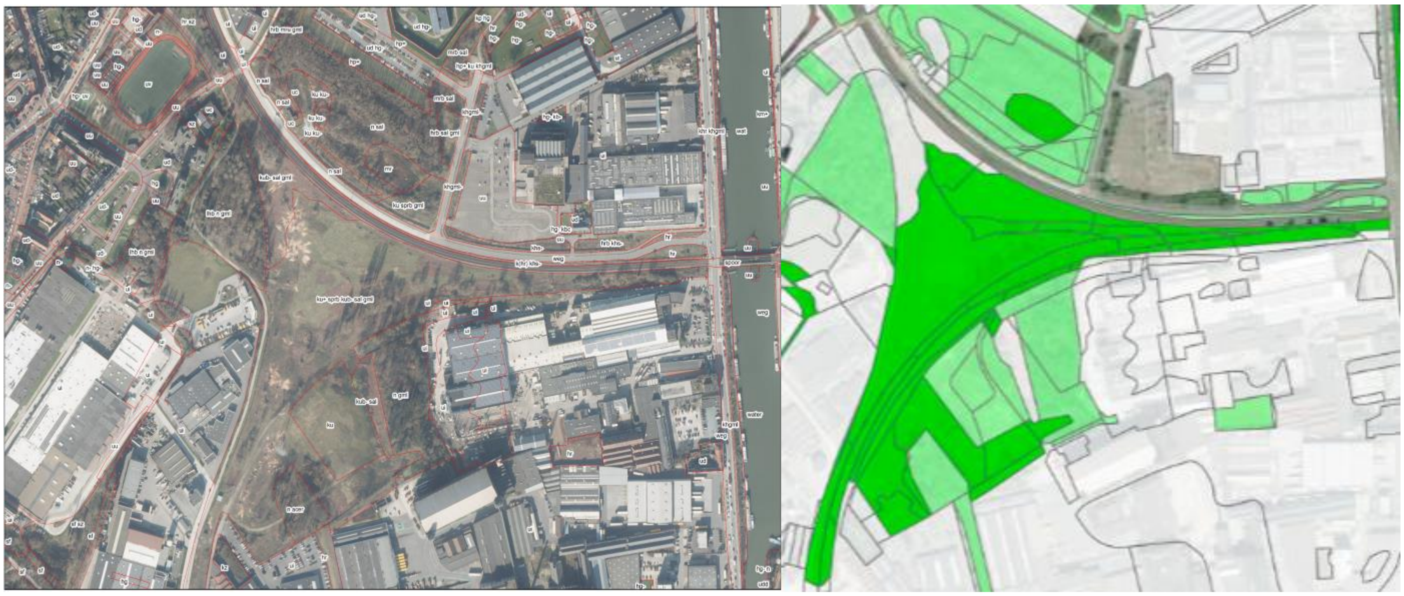

Figure 4 & 5: (left) The *Wondelgemse Meersen*, mapped according to the mapping strategy used in the BVM (v2020). Obtained via Toon Spanhove. (right) Visualization of the biological valuation that is assigned to the different areas of the *Wondelgemse Meersen*. The dark green color translates to those areas being *biologically very valuable*, the light green translates to those areas being biologically valuable, and the white areas get assigned under being *biologically less valuable*. Obtained via www.stad.gent.be

Table 3: Clarification on the mapping units used in research area (*Wondelgemse Meersen*) in the BVM. Obtained via Vriens et al., 2011.

Polygon, with corresponding BVM mapping units	**Definitions of each separate mapping units contained in the polygon**	**Appointed biological valuation to the polygon**
1. *kub- sal gml*	◊ *kub-* : brushwood with banal, common species and with tree cover (on elevated terrain, ...). ◊ *sal* : presence of willow trees. ◊ *gml* : mixed cover of deciduous tree species.	*Biologically less valuable*
2. *lhb n gml*	◊ *lhb* : poplar plantation on moist soils with alder and/or willow tree undergrowth. ◊ *n* : deciduous plantations ◊ *gml*: mixed tree cover of deciduous species.	*Biologically valuable*

3. ku+ sprb kub-sal gml	◊ *ku+* : various pioneer vegetation and species-rich brushwood (on elevated terrain, …) ◊ *sprb*: thorn and burr vegetations ◊ *kub* - : brushwood with banal, common species and with tree cover (on elevated terrain, ...). ◊ sal: presence of willow trees ◊ glm: mixed tree cover of deciduous tree species	*Biologically very valuable*
4. n gml	◊ *n* : deciduous plantations ◊ glm: mixed tree cover of deciduous tree species	*Biologically valuable*
5. kub- sal	◊ *kub-* : brushwood with banal, common species and with tree cover (on elevated terrain, ...). ◊ sal : presence of willow trees	*Biologically less valuable*
6. ku	◊ ku : brushwood (on elevated terrain, former farmland, …)	*Biologically valuable*
7. n acer	◊ *n* : deciduous plantations ◊ *acer* : presence of maple trees	*Biologically valuable*

An exploratory field trip (*Figure 6*) was conducted to verify the validity of the assigned mapping units that were allocated to the various polygons within the research area of the *Wondelgemse Meersen* (*Figure 4*). The same was done with the biological values that are assigned to the area in the BVM (*Figure 5*). *Table 3* provides the mapping units of the different polygons and their corresponding definitions (Vriens et al., 2011). During the field trip, several observations and remarks were made in the process of verifying the validity of the BVM and its capability to represent all aspect of the present environment.

Figure 6: Picture taken in the *Wondelgemse Meersen*, during the conducted exploratory field trip. Taken by Emiel Dhondt.

Overall, the mapping units generally reflected the reality of the area, but there were some discrepancies observed. For instance, in polygon 4 (as indicated in *Figure 4*), a watershed was located that strongly resembled a developing marsh habitat (*Figure 7*). Additionally, at the edge of a tree-covered patch in the same polygon, both sweet cherry (*Prunus avium*) and field rose (*Rosa arvensis*) were present, which was not reflected in the BVM. The presence of these species is significant as they serve as indicators for a good status of different specific habitat types. Sweet cherry is an indicator of three different Natura2000 habitat types, while field roses indicate a good status of thorn woodlands (*www.ecopedia.be*). If these species and their assemblages are present in substantial abundance or if they were to further develop in the future, they could be assigned a different mapping unit, which could potentially lead to stricter protection of the area. Even though the information provided by the map is ecologically relevant, there are a lot of ecological characteristics that are being ignored in it. So is it that the different mapping units per polygon are ordered in descending order of the area they cover, but lack the information on the exact frequency they occupy in those polygons. By not including this, a whole aspect of reality is being ignored. Another example that can serve as measures for the structural heterogeneity in the area that are not included is vegetation height. An important factor of urban ecology these days is the inclusion of biodiversity, which the BVM lacks almost entirely. Without this kind of data, weighted decisions concerning conservation and management strategies are harder to make. Another aspect which the map lacks is the inclusion of soil types, including the indication of the levels of disturbance and pollution of the present soils. Undisturbed, more natural soils have a higher chance of acquiring protective measures in favor of their perseverance. Lacking both information on soil types and biodiversity, researchers studying the *Wondelgemse Meersen* can have a hard time predicting the future trajectories of the present habitat types.

When it came to the verification of the assigned biological values of the area, it became clear that this mirrored reality relatively well. The majority of the area, especially the polygons containing the mapping unit *ku*, was given the status of being *biologically very valuable*. However, one discrepancy was acknowledged. Polygon one that resides in the North-West corner of the researched area, was assigned the status of being *biologically less valuable* even though it contained similar natural elements as other polygons in the area that were assigned under either *biologically very valuable* or *biologically valuable*. This shows that valuable habitats can go unnoticed in the BVM, which can have detrimental consequences to their continued existence. The field visit also uncovered that there was a remarkably high prevalence of the highly invasive Japanese knotweed (*Reynoutria japonica*). This is partly included in the mapping units of the BVM, namely the unit *kub-*, where the minus-sign indicates the presence of the less desired species. Urban environments like these can function as sources of super populations of invasive species due to higher disturbance levels and the high levels of anthropogenic traffic of seeds, making the inclusion of invasive species in urban ecosystem maps an important asset (Gaertner et al., 2016). After the field trip, it became clear that a lot of the structural heterogeneity in the area goes unnoticed on the map. This made it clear that more detailed mapping units could better reflect the complex structure and layering of the present natural elements. This finding went hand in hand with the remark that dividing the area in more, smaller polygons, could also lead to uncover the currently unmapped structural heterogeneity.

Figure 7: Present developing march habitat in polygon 4 of the *Wondelgemse Meersen*. Taken by Emiel Dhondt

A last aspect that was highlighted during the field visit was the lack of including mappings and information on the ESs the *Wondelgemse Meersen* provide to the natural environment and to society in general. Incorporating this currently hot-topic in the practice of UEM into the BVM-Gent could help understand the value of its residing habitats and species. Calculating how the *Wondelgemse Meersen* provides these services would be a valuable tool in assessing the in- and extrinsic value the area has and how it contributes to the well-being of not only the nearby inhabitants but also to the well-being and natural health of the city of Ghent as a whole. The area provides zero to few provisioning services since nothing is cultivated or extracted from the area. It does, however, provide important regulating services that regulate environmental conditions and processes. The downside to this is that services such as air and water quality regulation, climate regulation, pollination, and pest control are hard to assess. The quantification of these services requires a significant amount of valuable time and a high input of difficult-to-obtain data. The same goes for supporting services that support the production of all other types of ecosystem services. Data on soil formation, nutrient cycling, and primary production is not impossible to obtain but requires lots of resources. The cultural services provided by the area are amongst the services that are the easiest to delineate and value. Recreation, aesthetic and spiritual inspiration, and cultural heritage are easily quantifiable via surveys of inhabitants in proximity to the *Wondelgemse Meersen*. Data obtained from those services could influence decision-making on spatial planning and the equipment of infrastructure that supports the provision of these services in the area. Furthermore, due to the input of diverse stakeholders of the area not being included in the BVM, assessing the values of the provided ESs of the area becomes even harder. Ultimately, by incorporating the link to ecosystem services together with a valuation of those, informed decisions can be made about conservation and land use planning in the area.

3.3.2 Mapping the area using classification systems from a set of urban ecosystem mapping initiatives

To assess whether the use of different classification systems could lead to new insights on how the mapping process of an urban natural area such as the *Wondelgemse Meersen* could be improved, different earlier discussed typologies (see 3.2) were used to map the area of the case study according to their corresponding typologies. Two of the typologies that are going to be used in this chapter, namely the EUNIS habitat classification and the CORINE land cover systems, are cited in the book by Vriens et al. 2011, on the Biological Valuation Map of Flanders and the Brussels Capitol Region. There, the correspondence between the mapping units from the BVM and those systems is discussed and listed. For the other typologies, no correspondence was available online.

3.3.2.1 European Nature Information System (EUNIS)

As discussed in 3.2.2.1, the EUNIS habitat classification is an information system established the European Environment Agency (EEA). It consists of 10 mainland-type categories (A – J), wherein each of those, three hierarchical levels of habitat classifications are contained. Vriens et al. (2011) listed the relevant EUNIS habitat types for Flanders with the corresponding mapping units from the BVM. Following the same numbering of the polygons as they are listed in *Table 3*, correspondence between the mapping units of the BVM and the EUNIS habitat classification could be found and are given in table *Table 4*. Since the EUNIS classification system assigns only one mapping unit per delineated polygon, the different polygons could only be assigned with the mapping unit that corresponds with the mapping unit from the BVM that occupies the largest surface area in that specific polygon. The results show that even though there is a correspondence between the mapping units of the BVM and the ones from EUNIS, this does not necessarily consist of a one-on-one relationship. Most of the mapping units from the BVM correspond with multiple EUNIS mapping units, with some even being spread over multiple EUNIS mainland-type categories. This means that a direct translation of the BVM using the EUNIS habitat classification system requires further information input. Ultimately, there are two main aspects where the assignment process of the mapping units to the delineated polygons from the BVM have the upper hand compared to the EUNIS classification system. The first aspect concerns the fact that in most of the polygons, namely polygon 1, 2, 3, 4, 6 and 7, either the dominant tree species (e.g., *acer*, *sal*) is mentioned, or it is mentioned that the present trees consist of a mixed set of deciduous species (*gml*). Secondly, some of the mapping units (e.g. *ku+*, *kub-*) come with an indication of the biological value of the specific mapping unit, which is great information for urban planners and management practitioners.

Table 4: Correspondence between the assigned mapping units of the delineated polygons from the *Wondelgmese Meersen* according to the BVM and the EUNIS mapping units.

Polygon, with corresponding BVM mapping units	Most abundant mapping unit of the polygon with according definitions from the BVM	Corresponding EUNIS mapping unit(s)
1. kub- sal gml	***kub-*** : brushwood with banal, common species and with tree cover (on elevated terrain, ...)	◊ E5.1 Anthropogenic herb stands ◊ I1.5 Bare tilled, fallow or recently abandoned arable land ◊ E2.8 Trampled mesophilic grasslands with annuals ◊ E5.41 Screens or veils of perennial tall herbs lining watercourses
2. lhb n gml	***lhb*** : poplar plantation on moist soils with alder and/or willow tree undergrowth	◊ G1.C1 Poplar plantations
3. ku+ sprb kub- sal gml	***ku+*** : various pioneer vegetation and species-rich brushwood (on elevated terrain, …)	◊ E5.1 Anthropogenic herb stands ◊ I1.5 Bare tilled, fallow or recently abandoned arable land ◊ E2.8 Trampled mesophilic grasslands with annuals ◊ E5.41 Screens or veils of perennial tall herbs lining watercourses
4. n gml	***n*** : deciduous plantations	◊ G1.C Highly artificial broadleaved deciduous forestry plantations ◊ G5.2 Small broadleaved deciduous anthropogenic woodlands
5. kub- sal	***kub-*** : brushwood with banal, common species and with tree cover (on elevated terrain, ...)	◊ E5.1 Anthropogenic herb stands ◊ I1.5 Bare tilled, fallow or recently abandoned arable land ◊ E2.8: Trampled mesophilic grasslands with annuals ◊ E5.41 Screens or veils of perennial tall herbs lining watercourses
6. ku	**ku** : brushwood (on elevated terrain, former farmland, …)	◊ E5.1 Anthropogenic herb stands ◊ I1.5 Bare tilled, fallow or recently abandoned arable land ◊ E2.8 Trampled mesophilic grasslands with annuals ◊ E5.41 Screens or veils of perennial tall herbs lining watercourses
7. n acer	***n*** : deciduous plantations	◊ G1.C Highly artificial broadleaved deciduous forestry plantations ◊ G5.2 Small broadleaved deciduous anthropogenic woodlands

Since the MAES initiative uses the EUNIS classification system to produce its land cover maps (see 3.2.2.4), the same results and conclusions can be found when using it to map the *Wondelgemse Meersen*.

3.3.2.2 Coordination Information Environment (CORINE) Land Cover

The European coordination information environment (CORINE) land cover (CLC) initiative applies a habitat classification system consisting of 44 mapping units categorised into three hierarchical levels, where 32 of which are present in Belgium. The corresponding mapping units of the BVM with the CLC classification units are listed in Vriens et al. 2011, where the correspondence between the BVM mapping units from the different delineated polygons from the *Wondelgemse Meersen* with the mapping units from the CLC classification system is given in *table 5*. Identical to the EUNIS classification (see 3.3.2.1), the CLC classification system only assigns one mapping unit per polygon, meaning that the different polygons could only be assigned with the mapping unit that corresponds with the mapping unit from the BVM that occupies the largest surface area in that specific polygon. Again, similarly to the EUNIS classification, the correspondence between the BVM mapping units and the ones from the CLC system do not necessarily follow a one-on-one relationship. Furthermore, two of the mapping units from the BVM present in the *Wondelgemse Meersen*, namely *lhb* and *n*, are assigned the same CLC mapping unit, decreasing its thematic resolution compared to the BVM. The BVM outperforms the CLC system in the same ways as it does the EUNIS classification system (see 3.3.2.1). Thus, this is proof that even though non-natural mapping units are contained within the current CLC classification system, it is still unfit to capture the present heterogeneity of the urban site.

Table 5: Correspondence between the assigned mapping units of the delineated polygons from the *Wondelgmese Meersen* according to the BVM and the CLC mapping units.

Polygon, with corresponding BVM mapping units	Most abundant mapping unit of the polygon with according definitions from the BVM	Corresponding CLC mapping unit(s)
1. kub- sal gml	***kub-*** : brushwood with banal, common species and with tree cover (on elevated terrain, ...)	◊ 321 Natural grassland ◊ 211 Non-irrigated arable land
2. lhb n gml	***lhb*** : poplar plantation on moist soils with alder and/or willow tree undergrowth	◊ 311 Broad-leaved forests
3. ku+ sprb kub- sal gml	***ku+*** : various pioneer vegetation and species-rich brushwood (on elevated terrain, …)	◊ 321 Natural grassland ◊ 211 Non-irrigated arable land
4. n gml	***n*** : deciduous plantations	◊ 311 Broad-leaved forests
5. kub- sal	***kub-*** : brushwood with banal, common species and with tree cover (on elevated terrain, ...)	◊ 321 Natural grassland ◊ 211 Non-irrigated arable land
6. ku	**ku** : brushwood (on elevated terrain, former farmland, …)	◊ 321 Natural grassland ◊ 211 Non-irrigated arable land
7. n acer	***n*** : deciduous plantations	◊ 311 Broad-leaved forests

3.3.2.3 Green Surge

The Green Surge project is split up into three different work packages. The third package studies the functional linkages between UGS and the ESs provided by them, while also analyzing their impacts on biodiversity, human health and well-being, social cohesion and the green economy (Stahl Olafsson & Pauleit, 2018). To come to this, the goal of the work package is to identify, describe and quantify the full range of UGS. Next to this, the identification and quantification of the demand for ESs provided by these UGS will be carried out. That way, the needs and improvements of UGS can be assessed to optimize their service provision. Remarkable is thus the inclusion of the importance of ESs and the socio-economic impacts of UGS in our society, which is absent in both the EUNIS and the CLC classification systems, as well as in the BVM.

To be able to carry out the work package, the Green Surge project developed an inventory of UGS elements with a green-infrastructure perspective. The inventory is based on existing inventories, internal project meetings and discussions and a commented draft disseminated to all their partners. It consists of 44 UGS elements, compacted into 8 categories. From the exploratory fieldtrip, a certain set of the UGS elements were found to be present in the *Wondelgemse Meersen*, which can be seen in *Table 6*. The Interesting aspect of these mapping units is the fact that they take anthropogenic infrastructure into account, which is an integral part of urban ecosystems and an aspect that is mostly neglected in the BVM and other UEM initiatives (e.g., EUNIS). However, the indication of the most abundantly present tree species together with indicating the biological value of specific mapping units still give using the BVM an advantage of the Green Surge UGS typology. On the contrary, linking mapping units and their spatial pattern to ES provisioning is an advantage of using the Green Surge typology due to that information being crucial in practices such as urban land planning and policy formulation.

Table 6: Observed UGS elements from the Green Surge urban typology with their respective number and description. Obtained via Cvejic et al., 2015.

No. UGS element	Description
11. Railroad bank	Green space along railroads.
31. Forest (remnant woodland, managed forest, mixed forms)	Natural or planted areas of dense tree vegetation.
32. Shrubland	Natural or secondary shrubland, e.g., heath, macchia, etc.
33. Abandoned, ruderal and derelict area	Recently abandoned areas, construction sites, etc. With spontaneously occurring pioneer or ruderal vegetation.
37. Wetalnd, bog, fen, marsh	Areas with soil permanently or periodically saturated with water and characteristic flora and fauna.

7 DISCUSSION

7.1 Road to a highly valuable urban ecosystem map

Following the findings from the literature review, the analysis of the set of existing UEM initiatives and the case study, it is now possible to narrow down possible improvements and future steps to be taken to enhance the Biological Valuation Map (BVM) of Flanders and ultimately, the practice of UEM as whole. In this section, some of the following given potential improvements and future steps are being clarified with practical examples applied to the research area of the case study, being the *Wondelgemse Meersen*.

1. Incorporating more recent and comprehensive data may provide more realistic and up-to-date information on the distribution, biophysical structure and abundance of different species and habitats. An example of how the incorporation of more recent and comprehensive data into the BVM could lead to a more complete picture of reality is the inclusion of data on where green areas reside in Flanders, with an indication of their height. The *Groenkaart* is an openly-available map via the website *Geopunt.be* and holds this information in a raster format with a 1-metre resolution. Incorporating this data in the BVM could not only help with the mapping process but could also be a tool to uncover the structural heterogeneity of areas of interest. The area of the Groenkaart that covers the *Wondelgemsen Meersen* can be seen in *Figure 8*, where the light green refers to green space lesser in height than 3 meters and the dark green being larger in height than that set threshold.

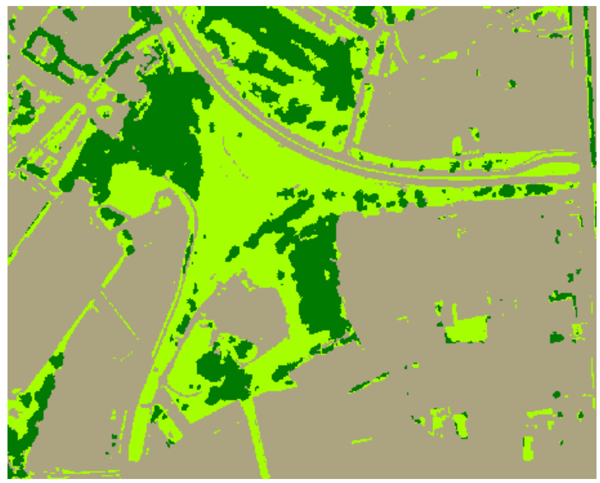

Figure 8: The *Wondelgemse Meersen* mapped according to the *Groenkaart* of Flanders. Obtained via Geopunt.be.

Concerning biodiversity, data could be acquired via multiple routes. The first option is for the developers of the map to conduct field trips and observe the biodiversity of the site manually, which is extremely resource demanding and time consuming and thus not easily applicable. A plausible possibility is for them to rely on **citizen science data**, which has proven to be a helpful strategy in acquiring more information on the ecological characteristics of urban areas (Teixeira et al., 2015). To frame this concept, the popular website *Observations.org* was used to obtain data on the observed biodiversity in the area over the last five years (*Figure 9*). Over these past five years, 531 observations representing more than 14 thousand individuals were added to the website in the area. In these observations, 236 species, 5 hybrids, 19 multispecies and 2 subspecies were registered. The fact that data like this can uncover the presence of in Flanders rare (e.g., yellow-browed warbler *(Phylloscopus inornatus)*, bristly hawkbit *(Leotodon hispidus)*) and very rare (e.g., cream scabious *(Scabiosa ochroleuca)*, Italian tree cricket *(Oecanthus pellucens)*) species, makes it an interesting source of additional data in ecosystem maps. This is especially true for urban ecosystems since it has been proven that the process of urbanization decreases the overall abundance and species richness of terrestrial animals (Faeth et al., 2011)

Figure 9: Delineation of the *Wondelgemse Meersen* with the indication of the 16 observations from the last 30 days. Obtained via *Observation.org* on the 12th of May, 2023.

Additionally, the inclusion of this kind of citizen science data could lead to the optimization of managing and monitoring invasive species. This is especially relevant in urban environments, since they are more severely threatened by invasive species via the various ruling environmental disturbances and an increased propagule pressure (Gaertner et al., 2016). Adding data like this to the BVM could induce changes in the management of the *Wondelgemse Meersen* by it giving a more complete picture of reality.

A last example of a possible source of data that could be added to the BVM of Ghent to induce changes in the management of urban areas is the inclusion of an indication of soil compositions on the map. This together with information on the present flora and fauna could make predictions on the future developments of the present ecosystems possible (Corbin & Flatland, 2022). Depending on the combined ecological and socio-economic value of those future developments, preventive measures could provide insurance for the continued existence of these developing natural communities. Essential to recognize in this section is the fact that comprehensive data like this is seemingly already heavily available. However, the point that is being made here is that the addition of that data into the BVM and other UEM initiatives, would augment the general relevance and power of their primary applications, being conservation planning, urban planning and policy formulation.

2. By **refining the classification system**, the complexity and heterogeneity of the landscape could be fully incorporated and reflected in the map. More detailed categories could be added to the classification system of the mapping units that reflect the complex structure and layeredness of the present natural elements. Furthermore, the classification systems used in UEM initiatives should include mapping units that represent the semi-natural (e.g., green roofs, private gardens, etc.) and anthropogenic elements (e.g., roads, buildings, etc.), that set urban ecosystems apart from their more natural counterparts. This is typically something that is not included in certain UEM initiatives (e.g., MAES), making them less valuable in practices such as urban planning and urban sustainable development. However, newer initiatives do have the tendency to include such classification units (e.g., GreenSurge) while other initiatives put efforts in the creation of new classification keys specifically for urban environments (e.g., BVM). The refinement of the classification systems should go hand in hand with **enhancing the spatial resolution** of the mapped polygons. This is because more detailed mapping units enable the indication of smaller scaled structures and vegetation types. An example of how current UEM initiatives fail to reflect the complex and small-scale heterogeneity of urban ecosystems comes from the previously discussed CORINE Land Cover (CLC) initiative (see 3.2.2.2 and 3.3.2.2). When looking at the latest updated version of the CLC map from 2018 (obtained via *www.land.copernicus.eu*), the area of the *Wondelgemse Meersen* is not mapped under any of the previously mentioned CLC mapping units indicated in *Table 5*. The vast majority of the area is mapped under *Road and rail networks and associated land,* while the other parts fall under the unit *Industrial or commercial units*. Both of those mapping units fall under the overarching category of *Industrial, commercial and transport units*, meaning that the CLC map fails to report any form of natural infrastructure. The reason for this is due to the fact that the surface area for the minimal mappable unit amounts to 25 hectares (Bossard et al., 2000), whereas the research area of the *Wondelgemse Meersen* only amounts to less than 15 hectares. Following these findings, it comes as to no surprise that obtaining a higher spatial resolution is the most desired enhancement idea for the CLC classification and its produced maps (Büttner et al., 2021). Diverse remotely sensed imagery could support the data collected via field visits and previous inventory assessments of the land cover in the researched area, leading to easier creation of new mapping units and their specific spatial allocations at a level of high spatial resolution.

3. Urban ecosystems are characterized as being highly dynamic and ever-changing (Griffiths et al., 2010), which is an important but challenging aspect of the practice of UEM. As cities grow, adapt, and transform, new ecological niches emerge and the distribution of habitats changes. Conventional typologies might struggle to keep pace with these changes, potentially rendering them unable to capture the current state of urban ecosystems. The BVM of Flanders has been updated a couple of times, meaning that an **assessment of the temporal dynamics** over those periods of time can be carried out. However, the updates are spread over quite some time. More attention should be directed towards carrying out accuracy tests to check whether the mapped areas are still accurate reflections of reality. The creation of more dynamic models that incorporate more short-term changes in land use, vegetation cover, biodiversity and other anthropogenic factors over time could help to better understand the temporal dynamics of the ecological characteristics of urban areas. This is, unfortunately, easier said than done due to this being a very resource demanding task in terms of time, money and manpower. However, this is exactly where the opportunity lies to explore **newly developed technologies**

and methods to ultimately lower the amount of acquired resources. An example of such a technology could be the new form of remote sensing that is able to uncover structural heterogeneity by mapping environments in three dimensions (D'Urban Jackson et al., 2020).

4. A current hot topic in the science of urban ecology, which could also be concluded from the conducted literature review and the analysis of a set of UEM initiatives is the **incorporation of ecosystem services** in ecosystem maps. This rise in interest in ESs is reflected in the development of online tools that calculate the monetary and ecological costs and benefits of future projects based on the changes in ESs those projects would cause (Babí Almenar et al., 2023). Such a tool has already been developed for Flanders, namely the *natuurwaardeverkenner (natuurwaardeverkenner.be)* tool which does exactly that. Considering the *Wondelgemse Meersen* being a candidate for a radical future infrastructure development project (see Box 1), applying this tool in that specific case could give insights in what the monetary and ecological costs and benefits of the project would be. Those insights are crucial in the process of determining whether the development project is going to take place or not and has the potential to help safeguard the natural site form destruction if the costs outweigh the benefits. This kind of scenario modeling could help policymakers anticipate potential impacts and devise strategies for sustainable urban growth. Mapping ESs in the BVM would ensure a better understanding of the value of its different habitats, leading to the map transcending mere ecological descriptions, providing a more holistic perspective that aids decision-makers, urban planners and policymakers in making informed choices that balance ecological health, human well-bein and sustainable development. ESs can be split up into different categories, namely provisioning, regulating, cultural and supporting services (Yapp et al., 2010). However, there are differences in the feasibility of calculating ecological and monetary values of the provided services amongst those categories. The input of **information coming from diverse stakeholders** could help overcome this by community groups, landowners and conservation organizations infusing local knowledge and values into the map which would lead to it reflecting the needs and priorities of the community. To frame this using the *Wondelgemse meersen* as an example, local residents could provide the intricate knowledge they possess of their surroundings. They can offer insights into land use patterns, culturally significant areas and observations of species and habitats. Scientists and researchers on the other hand can contribute with empirical data, ecological surveys and advanced mapping techniques. Environmental organizations could contribute historical data, advocacy for conservation priorities and insights into potential threats and opportunities. Collectively, these stakeholders ensure a comprehensive and well-rounded representation of the ecosystem, where their input can be used as information sources by ecosystem map developers. This can also decrease the workload of those developers and the number of resources to be spent. Thus, the acknowledgement of UEM being a transdisciplinary practice by involving experts from various fields, including ecology, urban planning, economics and sociology can lead to more actionable insights. It can help bridge the gap between ecological research and policy implementation.

5. Following from the results on mapping the area of the *Wondelgemse Meersen* according to the classification systems from the set of UEM initiatives, it became clear that even though correspondence between different classification systems exists (e.g., BVM compared to the EUNIS habitat classification system), this does not always allow for direct translations of one map, using the classification system of another map. This highlights the need for the utilization of **standardized classification systems**, which holds immense potential for enhancing the effectiveness and comparability of different urban ecosystem maps. Such typologies would provide a common framework that ensures consistency in categorizing and classifying urban habitats and features. They would enable direct comparison of data across different maps and studies, fostering a more all-round understanding of urban ecosystems on a larger scale. Next to this, standardized typologies could facilitate the sharing of information and collaboration among researchers, practitioners and policymakers, promoting a unified language for discussing urban features.

By pursuing these future directions, the Biological Valuation Map of Flanders has the potential to evolve into a an even more powerful tool for policy formulation and urban planning. It would not only accurately reflect the complexity of urban ecosystems but also offer valuable insights to support sustainable development and enhance the quality of urban life.

7.2 Shortcomings of this research and directions for future similar research

Despite the valuable contributions of this research that consists of an exploration of UEM and its derived tools with a focus on the territory of Flanders, Belgium, there are certain limitations that warrant consideration. The analysis of a set of UEM initiatives might not have captured the entire spectrum of available projects, potentially leading to an incomplete comparison. For example, except for the GreenSurge initiative, the discussed initiatives are all developed to be implemented at a broad, regional scale. It would be interesting to include more initiatives that consist of small-scale projects that are specifically designed to capture small-scale urban heterogeneity at a local scale. An example of such an initiative comes from a paper by Jones et al. (2022), which describes a feature-based typology of urban green infrastructure that combines elements of land cover, land use and both ecological and social function. The typology is constructed to, with the use of models, conduct ecosystem service assessments that can guide small-scale nature-based-solution design. The insights projects like this can give are extremely valuable in this new age of urban ecology that focuses on intertwining both the social and ecological functioning of urban ecosystems.

The case study, while informative, has limitations in representing the entire spectrum of the complexity present in urban ecosystems. It does not give a complete picture of urban ecosystems, it is merely an example of such, where only a subset of the total package of processes that rule urban systems are present. By it for example not including built infrastructures within its borders, an extremely important aspect of urban ecosystems is being overlooked. Moreover, as the research predominantly focuses on the BVM of Flanders, generalizations to other regions could be limited. Future research in the realm of UEM should aim for a more comprehensive comparative analysis of various mapping initiatives from diverse geographical locations. That is why the research conducted here could have benefited from actually producing land cover maps of the case study area with the use of the classification systems from the discussed UEM initiatives. This approach could offer a more nuanced understanding of the field's variation and potential, while further pointing out the strengths and weaknesses of each applied classification system. Additionally, future case studies should focus on capturing the complete complexity of urban environments by not only including natural habitat patches but also focusing on the semi-natural and built infrastructures. That way, the socio-economic aspects that are extremely relevant in urban environments can be better analyzed and understood. An example of such a case study could be the analysis of how urban areas with different levels of urbanization are mapped in ecosystem maps, which is a methodology that has already been applied (Sun et al., 2023). This could give insights into how those areas are represented differently and what the necessary steps are to improve this representation so that they better reflect reality. Next to this, research should focus on standardized typologies and classification systems that accommodate both ecological and socio-economic dimensions. The integration of dynamic temporal aspects, emerging technologies and broader stakeholder engagement is pivotal for advancing the accuracy, applicability and relevance of UEM in shaping sustainable urban futures.

8 CONCLUSION

As a conclusion to this exploratory research, it can be stated that this research delved into the realm of UEM, shedding light on its significance and potential for enhancing urban planning, policy formulation and sustainable management. Through an extensive literature review and a detailed analysis of various UEM initiatives, including the BVM of Flanders, key insights have been drawn up that hold valuable implications for the advancement of the BVM and the field of UEM as a whole. The examination of different typologies and classification systems underscored the need for harmonization and standardization, which would facilitate comparability across studies and enable a more holistic understanding of urban ecosystems. It became evident that the successful implementation of UEM depends not only on ecological factors but also on the integration of socio-economic ones. The incorporation of data on ESs, community engagement and economic valuations emerges as vital aspects for developing comprehensive and actionable strategies.

The analysis of the BVM of Flanders highlighted its use and potential in aiding conservation efforts, urban planning and sustainable land management. However, the map's limitations, such as the exclusion of certain aspects of the urban environment, revealed opportunities for further refinement and expansion. The field's potential to leverage advancements in remote sensing, citizen science and interdisciplinary collaboration was evident, promising enhanced accuracy, efficiency and completeness in future UEM endeavors. As we move forward, it is crucial for research and policy implementation to embrace a transdisciplinary approach. Bridging the gap between ecological sciences, urban planning and social sciences is essential for unlocking the full potential of UEM. Future research should focus on the development of standardized typologies, the incorporation of dynamic temporal aspects and the exploration of emerging technologies. These efforts will contribute to a comprehensive understanding of urban ecosystems, fostering resilient cities that prioritize both ecological integrity and human well-being.

In a rapidly urbanizing world, where the challenges of climate change, biodiversity loss and sustainable development loom large, UEM stands as a beacon of hope. By enhancing our comprehension of the intricate relationships between natural and built environments, we pave the way for informed decision-making, resilient urban designs and the creation of livable, sustainable cities for generations to come.

Summary

This master's dissertation builds upon the recent increase in research on urban ecology that follows the acknowledgment that urban ecosystems are one of the fastest changing and expanding ecosystems universally. Due to the complex intertwining ecologic and socio-economic patterns that characterize urban environments, this recent wave of studies has made it its goal to uncover and map these patterns to properly inform urban management and planning practices. That is why this dissertation consists of an exploration of literature, maps and field applications on the topic of Urban Ecosystem Mapping (UEM), with the region of Flanders and the Biological Valuation Map (BVM) of Flanders and the Brussels Capital Region being the focal points of these explorations. Firstly, an overarching literature review on the topic of UEM was conducted based on the in environmental sciences commonly used RepOrting standards for Systematic Evidence Syntheses (ROSES) protocol. With the use of *Web of Science*, a total of 420 papers were screened for their relevance and capacity to contribute to the literature review. Ultimately, 60 of the initially obtained papers contributed to the content of the review, together with the incorporation of information retrieved from 3 pre-screened papers gained via other sources. The review provides an in-depth overview of the current state of UEM, highlighting its importance in urban planning, policy formulation and sustainable management. It pointed out the challenges faced by UEM, including the standardization of typologies, integration of socio-economic factors and accurately representing the fine-scaled urban heterogeneity. The review ended with listing universally applicable directions in terms of future research and practice endeavors, including the incorporation of ecosystem services (ESs) and emerging technologies.

Secondly, based on the important themes and challenges UEM initiatives have to conquer that were highlighted by the literature review, a set of criteria was drawn up to assess the BVM and a set of other UEM initiatives obtained via internet searches and individuals with knowledge on the subject of UEM. The criteria were subdivided into 7 different categories, namely *content*, *thematic*, *feasibility*, accuracy, *(reported) usability*, *scale* and *availability*, each reflecting a different aspect of UEM. All UEM initiatives and their respective classification systems were each scored and assessed based on these criteria to determine their strengths and weaknesses in the field of urban ecology and their capability of representing the urban environment as realistically as possible. Due to the central role of the BVM of Flanders in this exploration, it was assessed in more detail and compared to each of the other UEM initiatives to further investigate its application possibilities. The assessments illuminated the variations in thematic coverage, spatial resolution and feasibility of application across different initiatives, while highlighting the absence of certain socio-economic aspects in the BVM, being the inclusion of anthropogenic infrastructure and ESs.

Lastly, a case study in the form of an exploratory field trip was carried out to add a practical dimension to the conducted research. Its goal was to assess the accuracy of the BVM of Flanders in representing the different aspects of urban ecosystems, applied to a specific site, namely the *Wondelgemse Meersen* in the city of Ghent, Belgium. While verifying the map's capabilities as an effective tool for conservation and urban planning, certain ecological aspects, such as height profiles and soil composition, and socio-economical aspects, such as ES provision were found to be fully absent from the map. As a follow-up to this, the classification systems from the UEM initiatives from the previous chapter of the research were used to map the site of the case study, revealing how the BVM of Flanders solidifies itself as a promising urban ecological tool compared to the other initiatives, while also indicating that there is room for improvement in terms of its capabilities to represent important socio-economic aspects such as ES provisioning and mapping anthropogenic infrastructures. The findings from these explorations provided a basis for identifying opportunities for refinement and enhancement of the BVM of Flanders in terms of accuracy, scale, and inclusion of socio-economic dimensions, which are discussed in the discussion of this dissertation. These opportunities include the incorporation of more recent and comprehensive data, refining the classification system and incorporating ESs into the map. The discussion ends with highlighting the need for further research in the field to potentially further confirm and implement the findings from this exploratory research. As a conclusion, this exploration of the field of UEM shed light on its significance and potential for enhancing urban planning, policy formulation and sustainable management. Key insights were listed that hold valuable implications for the advancement of the BVM of Flanders and the field of UEM as a whole. By enhancing our comprehension of the intricate relationships between natural and built environments, research like this paves the way for informed decision-making, resilient urban designs and the creation of livable, sustainable cities for generations to come.

Samenvatting

Deze masterproef bouwt voort op de recente toename van onderzoek naar stedelijke ecologie, dat volgt op de erkenning dat stedelijke ecosystemen wereldwijd tot de snelst veranderende en uitbreidende ecosystemen behoren. Vanwege de complexe verweving van ecologische en sociaaleconomische patronen die kenmerkend zijn voor stedelijke omgevingen, heeft deze recente golf van studies zich ten doel gesteld om deze patronen bloot te leggen en in kaart te brengen om stedelijk beheer en planningspraktijken zo correct mogelijk te informeren. Daarom bestaat deze masterproef uit een verkenning van literatuur, kaarten en veldtoepassingen omtrent het onderwerp Urban Ecosystem Mapping (UEM), met de regio Vlaanderen en de Biologische Waarderingskaart (BWK) van Vlaanderen en het Brussels Hoofdstedelijk Gewest als middelpunt van deze verkenningen. Ten eerste werd een overkoepelend literatuuronderzoek uitgevoerd naar het onderwerp UEM op basis van het in milieukunde veelgebruikte RepOrting standards for Systematic Evidence Syntheses (ROSES) protocol. Met behulp van *Web of Science* werden in totaal 420 artikelen gescreend op hen relevantie en mogelijke bijdrage aan het literatuuroverzicht. Uiteindelijk droegen 60 van de aanvankelijk verkregen artikelen bij aan de inhoud van de review, samen met informatie uit 3 vooraf gescreende artikelen die via andere bronnen werden verkregen. Het overzicht biedt een diepgaand inzicht in de huidige stand van UEM, waarbij de nadruk wordt gelegd op het belang ervan in stedelijke planning, beleidsvorming en duurzaam beheer. Het wees op de uitdagingen waarmee UEM wordt geconfronteerd, waaronder de standaardisatie van typologieën, integratie van sociaaleconomische factoren en het nauwkeurig weergeven van de fijnschalige stedelijke heterogeniteit. Het overzicht eindigde met het vermelden van universeel toepasbare richtingen voor toekomstig onderzoek en praktijkinspanningen, waaronder de integratie van ecosysteemdiensten en opkomende technologieën.

Ten tweede werd een set criteria opgesteld, gebaseerd op de belangrijke thema's en uitdagingen die UEM-initiatieven moeten overwinnen die in het literatuuronderzoek werden belicht. Aan de hand van die criteria werd de BWK en een reeks andere UEM-initiatieven die werden verkregen via internetzoekopdrachten en individuen met kennis omtrent UEM, beoordeeld. De criteria werden onderverdeeld in 7 verschillende categorieën, namelijk *inhoud*, *thematisch*, *haalbaarheid*, *nauwkeurigheid*, (*gerapporteerde*) *bruikbaarheid*, *schaal* en *beschikbaarheid*, die elk een ander aspect van UEM weerspiegelen. Alle UEM-initiatieven en hun respectievelijke classificatiesystemen werden vervolgens beoordeeld op basis van deze criteria om hun sterke en zwakke punten op het gebied van stedelijke ecologie en hun vermogen om de stedelijke omgeving zo realistisch mogelijk weer te geven, te bepalen. Vanwege de centrale rol van de BWK van Vlaanderen in deze verkenning, werd deze uitgebreider beoordeeld en vergeleken met elk van de andere UEM-initiatieven om de toepassingsmogelijkheden ervan verder te onderzoeken. De beoordelingen belichtten de variaties in thematische dekking, ruimtelijke resolutie en haalbaarheid van toepassing bij de verschillende initiatieven en benadrukten het ontbreken van bepaalde sociaal-economische aspecten in de BWK, zoals het opnemen van antropogene infrastructuur en ecosysteemdiensten.

Ten slotte werd een casestudie uitgevoerd in de vorm van een verkennende veldtrip om een praktische dimensie aan het uitgevoerde onderzoek toe te voegen. Het doel hiervan was om de nauwkeurigheid van de BWK van Vlaanderen te beoordelen bij het vertegenwoordigen van de verschillende aspecten van stedelijke ecosystemen, toegepast op een specifieke locatie, namelijk de Wondelgemse Meersen in de stad Gent, België. Bij het verifiëren van de capaciteiten van de kaart als een effectief instrument voor natuurbescherming en stedenbouw, bleek dat bepaalde ecologische aspecten, zoals hoogteprofielen en bodemsamenstelling, en sociaal-economische aspecten, zoals het leveren van ecosysteemdiensten, volledig afwezig waren op de kaart. Als vervolg hierop werden de classificatiesystemen van de UEM-initiatieven uit het vorige hoofdstuk van het onderzoek gebruikt om de locatie van de casestudie in kaart te brengen, waarbij werd aangetoond hoe de BWK van Vlaanderen zichzelf bevestigt als een veelbelovend stedelijk ecologisch instrument in vergelijking met andere initiatieven, terwijl ook werd aangegeven dat er ruimte is voor verbetering wat betreft de mogelijkheden om belangrijke sociaal-economische aspecten zoals het leveren van ecosysteemdiensten en het in kaart brengen van antropogene infrastructuren weer te geven.

De bevindingen van deze verkenningen vormden de basis voor het identificeren van mogelijkheden voor verfijning en verbetering van de BWK van Vlaanderen op het gebied van nauwkeurigheid, schaal en opname van sociaal-economische dimensies, die worden besproken in de discussie van deze masterproef. Deze mogelijkheden omvatten onder andere het opnemen van recentere en uitgebreidere gegevens, het verfijnen van het classificatiesysteem en het opnemen van ecosysteemdiensten in de kaart. De discussie eindigt met het benadrukken van de noodzaak van verder onderzoek op het gebied om mogelijk de bevindingen van dit verkennende onderzoek verder te bevestigen en te implementeren. Als conclusie wierp deze verkenning van het vakgebied van UEM licht op de betekenis ervan en het potentieel om stedenbouw, beleidsformulering en duurzaam beheer te verbeteren. Er werden belangrijke inzichten vermeld die waardevolle implicaties hebben voor de vooruitgang van de BVM van Vlaanderen en het vakgebied van UEM als geheel. Door ons begrip van de complexe relaties tussen natuurlijke en gebouwde stedelijke omgevingen te verbeteren, legt onderzoek zoals dit de weg vrij voor geïnformeerde besluitvorming, veerkrachtige stedelijke ontwerpen en de creatie van leefbare, duurzame steden voor de komende generaties.

Word of thanks

This master's dissertation would not have been able to come into being without the whole process being guided by my promotors, Sander Jacobs and Toon Spanhove. By shedding light on how to structure this dissertation, how I could find the necessary information and guiding me in the conducted field trip, they made it possible for me to conclude this body of work. I also want to show my gratitude towards Geert Heyneman and Andreas Demey, whom I was able to interview on what forms of Urban Ecosystem Mapping operate in the city of Ghent. Thank you to Joachim Maes for providing me with valuable leads on where I could find potential UEM initiatives that I could include in my analysis. Another thank you goes out to Pieter Van Dorsselaer, who made it possible for me to extract all past observations added to the website of *Observations.org* by delineating the case study area of this research. Last but not least, I would like to thank the many friends and family members that helped in correcting and optimizing my written text, where an extra special thank you goes out to my father, who was a great help in guiding me with the lay-out and the design of my cover page.

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Appendix 1 – Scored urban ecosystem mapping initiatives

	Typology	BWK	CORINE land cover	MAES / EUNIS	GreenSurge
	Criteria				
Content	**Map**	Yes.	Yes.	Yes.	No.
	Valuation system	Ecological Valuation: rarity, key species, biodiversity, vulnerability and replaceability.	None.	Ecological valuation: condition of ecosystems and biodiversity, and their capacity to provide ecosystem services	Goal is to find out how valuation and real market integration of biodiversity and ecosystem services can facilitate choices in favour of the development of multifunctional green spaces in urban areas.
	Inclusion of biodiversity	Inclusion of Faunistic important areas. Use biodiversity as an indicator of the value of delineated habitats.	No.	No.	Integrates and promotes biodiversity.
	Ecosystem services	No	Not included.	Yes.	Integrates and promotes ecosystem services.
	Inclusion of non-natural areas	Yes.	Yes.	Yes.	Yes.
Thematic	**Thematic resolution**	List of mapping units based on land use and vegetation type, alliance and association. In the form of codes.	44 classes within five main groups: Articficial surfaces, Agriculture, Forests and Seminatural areas, Wetlands and Water.	47 land, freshwater and marine habitat types and 5 seabed types. To the level of EUNIS classes level 2.	44 urban green space elements.
	Urban classification	In development.	No, but some classes refer to urban areas (e.g. Green urban areas).	Included in urban pilot.	Yes.
	Tackled ecological pressures	Nature conservation and environmental issues: agricultural nitrogen and sulphur emissions, delineating nature reserves, Natura2000 network conservation.	Environment, agriculture, transport, spatial planning etc.	Ecosystem conditions, biodiversity and ecosystem service provision.	Tackles climate change adaptation.

	Socio-economic impact	Heavy focus on ecology.	Community policies in domains of environment, agriculture, transport, spatial planning etc.	Ecosystem services are important in provisioning economical and social benefits. Goal is to ensure that ecosystems achieve or maintain a healthy stat or good condition to secure the sustainability of human activities and human-well-being.	Tackles land-use conflicts, demographic changes, humand health and wellbeing.
	Typology	**BWK**	**CORINE land cover**	**MAES / EUNIS**	**GreenSurge**
Feasibility	**Data collection**	Intensive field surveys, aerial photographs and existing GIS layers.	High resolution satellite imagery, national in-situ data, satellite image processing, GIS integration and generalisation.	Copernicus land monitoring service portfolio, EUSeaMap, EUNIS and other recent land cover data.	Literature reviews, stakeholder and expert interviews, GIS data, field surveys…
	Classification feasibility	Hard, specific training is needed.	Relativaly easy.	Not specified.	Not specified.
	Specific training	Permanent and well-trained team of professional field surveyors. Workshops to ensure standardization.	Not specified.	Not specified.	Not specified.
Accuracy	**Reflection of reality**	Areas visited once every decade, during the flowering season of dominant vegetation. Level of land use, vegetation type or vegetation associations.	Thematic accuracy >= 85%.	The spatially explicit input data are not always sufficient to allow precise delineation of each EUNIS habitat. Input information is not fully homogeneous in its spatial and thematic accuracy.	NA
	Accuracy testing	No, but updated every decade.	Thementic accuracy tested via European validation studies.	Information on geometric and thematic reliability of the map is available online. Allow users to specify spatial and thematic accuracy, while being able to address the uncertanties in assessments.	NA
(Reported) Usability	**Policy creation**	Nature conservation and environmental protection.	Community policies in domains of environment, agriculture, transport, spatial planning etc.	This ecosystem assessment serves two main policy requests: (1) provide an evaluation of the headline biodiversity target of the EU Biodiversity Strategy to 2020 in general and of Target 2 in particular	Apply an innovative biocultural diversity perspective to develop successful governance arrangements facilitating socio-ecological integration and local engagement in planning of urban green spaces.

				and (2) provide a baseline and trend, as well as support to the definition of good ecosystem condition for the EU Biodiversity Strategy for 2030.	
	Developers	The Research institure for Nature and Forest (INBO) in collaboration with the Flemish government.	European Environment Agency	European Commission / European Environment Agency	European Commission. Project funded by the European Commission Seventh Framework Programme (FP7). Potential to be applied in cities.
	Extrapolation potential	Full coverage reached.	Easily applicable for the European countries currently not included.	To contries not belonging to the EEA-39.	NA
	Typology	**BWK**	**CORINE land cover**	**MAES / EUNIS**	**GreenSurge**
	Specific applications	Indicates land-use (built, forest or grassland).	Environment, agriculture, transport, spatial planning etc. CLC change is created by direct mapping of changes taking place between two consecutive inventories. Ecosystem mapping, modelling the impacts of climate change, landscape fragmentation by roads, abandonment of farmland and major structural changes in agriculture, urban sprawl and water management.	Development of knoledge base for the final evaluation of the EU biodiversity strategy to 2020. Part of analytical framework developed to asses ecosystem conditions. Future assessments and policy developments, with respect to the ecosystem restoration agenda for the current decade.	Provides a sound evidence base for green infrastructure planning and implementation, exploring the innovation potential, and linking environmental, social and economic services with local communities. identify, develop and test different ways of connecting green spaces, biodiversity, people and the green economy.
Scale	**Method of delineation**	Polygons.	Polygons, but derived products in raster format available.	Fixed raster.	NA
	Scale and pixel size	1/10.000.	1/100.000 (25 ha).	100 x 100 m spatial resolution grid.	NA
	Minimal mappable unit	Small relicts (rows of trees, sunken roads, etc.).	25 hectares for areal phenomena and a minimum width of 100m for linear phenomena.	The level of the raster unit.	NA
	Range/extent	Flanders and Brussels Capital Region.	39 European countries, 6 million km2.	39 Europoean countries, 12 milion km2. Covers total land area of the EU.	Project spans 11 European countries.

Availability	**Metadata availability**	Publicly available via Flemish government site.	Open source metadata catalogue service of the European Environment Agency.	Available online.	Yes.
	Open source	Maps available for consultation and download.	Maps available for consultation download.	Yes, avalailable online.	Yes.