LESSONS FROM THE FOREST TO IMPROVE URBAN WATER MANAGEMENT AND BIODIVERSITY

Nehizena Osagie
Applied Biology
2022, Almere

LESSONS FROM THE FOREST TO IMPROVE URBAN WATER MANAGEMENT AND BIODIVERSITY

Using biomimicry and biomorphic urbanism to adopt forest ecosystems' best practices for water management and biodiversity facilitation and implement these in our cities.

Nehizena Osagie
Applied Biology Student, Animal specialisation
Student number: 3027559
Email: 3027559@aeres.nl

Danny Merién
Lecturer at Aeres University of Applied Sciences
Email: d.merien@aeres.nl

7 June 2022, Almere, Flevoland

Preface

The forest echoes through fog and trees, true wisdom rooted in nature’s peace. - Angie Weiland-Crosby

This thesis has come about because of my fascination for bioinspiration (Biomimicry) in combination with my inherent need to solve problems in a somewhat unorthodox and creative way. In this thesis/dissertation I propose a different way to look at a city, namely as if it were a forest. By looking at the city this way it is easy to locate the points where the sustainable and circular ways that the forest operates can be integrated. I want to thank everyone that has read this preliminary investigation and provided me with feedback. In particular my supervisor Danny Merién and another lector Femke Jochems.

INDEX

Abstract

Anthropogenic climate change will worsen the environmental problems in European cities. With the main ones being floods, water scarcity and biodiversity decline. Furthermore, Europe's climate will shift from its current temperate climate to a sub-tropic climate. One way to combat these problems is with Nature-Based Solutions. However, there have recently been studies indicating the limitations of Nature-Based Solutions for climate adaptation. There is an up and coming field in biology named, biomimicry. This field could help to make cities better adapted to a changing climate. As it is mainly concerned with translating natural processes to solve human problems. And the proposed blueprint for cities are forest ecosystems.

To find solutions the following research question has been devised, ''*Which temperate and subtropic forest ecosystem processes can be mimicked to improve urban water management and biodiversity in European cities, for climate adaptation?''* To help answer this question four sub-questions have been explored; 1. How do temperate and subtropic forest ecosystems manage water & biodiversity? 2. What are the problems with urban water management? 3. What are the problems with urban biodiversity? 4. How can Bioinspiration help to adopt these processes? 105 articles passed the screening and have been reviewed. The main finding concerning water management is that rainfall is stored and valued as a great source of water. Both in the soil and in stems. For biodiversity, the diversity of vegetation in different layers is very important for overall biodiversity. The biggest problems with urban water management are in the infrastructure and mindset of water drainage. Rainwater has been designed for to almost entirely run off, instead of being valued and captured. Habitat loss and fragmentation are the main drivers of biodiversity decline in cities. Both hydrological and biodiversity problems are underlined by the expansion of impervious surfaces.

Biomimicry has two main themes. These are the idea that nature should be mimicked instead of copied. And multifunctionality should be a key component of human design and society moving forward. Concluding that water storage- & diversity of vegetation in different layers are processes that can be mimicked and combined. Resulting in two major recommendations. Firstly, rainwater has to be stored in the urban environment. This can be done at different levels in the vertical dimension. Secondly, the abundance and diversity of plant species within the vertical dimension has to be increased. Both these recommendations can work together with Nature-Based Solutions.

DUTCH SUMMARY

Antropogene klimaatverandering zal de milieuproblemen in Europese steden verergeren. De belangrijkste daarvan zijn overstromingen, waterschaarste en biodiversiteitsverlies. Bovendien zal het klimaat van Europa verschuiven van het huidige gematigde klimaat naar een subtropisch klimaat. Eén manier om deze problemen te bestrijden is met Nature-Based Solutions. Maar, nieuwe studies geven de beperkingen van Nature-Based Solutions voor klimaatadaptatie aan. Er is een opkomend gebied in de biologie, genaamd Biomimicry. Dit gebied zou kunnen helpen om steden beter aan te passen aan een veranderend klimaat. Het houdt zich vooral bezig met het vertalen van natuurlijke processen naar oplossingen voor menselijke problemen. En de voorgestelde blauwdruk voor steden zijn bosecosystemen.

Om oplossingen te vinden is de volgende onderzoeksvraag opgesteld: ''Welke gematigde en subtropische bosecosysteem processen kunnen worden nagebootst om waterbeheer en de biodiversiteit in Europese steden te verbeteren, voor klimaatadaptatie?'' Om deze vraag te helpen beantwoorden zijn vier deelvragen onderzocht; 1. Hoe beheren gematigde en subtropische bosecosystemen water en biodiversiteit? 2. Wat zijn de problemen met stedelijk waterbeheer? 3. Wat zijn de problemen met de biodiversiteit in de stad? 4. Hoe kan Bio-inspiratie helpen om deze processen over te nemen? 105 artikelen zijn door de screening gekomen en gelezen. De belangrijkste bevinding met betrekking tot waterbeheer, is dat regenval wordt opgeslagen en gewaardeerd als een goede bron van water. Zowel in de bodem als in de stengels. Voor biodiversiteit is de diversiteit van vegetatie in verschillende lagen van groot belang. Het grootste problemen met stedelijk waterbeheer ligt in de infrastructuur en de denkwijze van waterafvoer. De stad is zo ontworpen dat regenwater bijna volledig wegloopt, in plaats van gewaardeerd en opgevangen. Het verlies en de versnippering van leefgebied zijn de voornaamste oorzaken van biodiversiteitsverlies in steden. Zowel hydrologische als biodiversiteitsproblemen worden onderstreept door de uitbreiding van ondoordringbare oppervlakken.

Biomimicry heeft twee hoofdthema's. Dat is het idee dat de natuur moet worden nagebootst in plaats van gekopieerd. En multifunctionaliteit moet een essentieel onderdeel zijn van ontwerpen en de samenleving in de toekomst. De conclusie is dat wateropslag & diversiteit van vegetatie in verschillende lagen, processen zijn die kunnen worden nagebootst en gecombineerd. Dit leidt tot twee belangrijke aanbevelingen. Ten eerste moet regenwater worden opgeslagen in de stedelijke omgeving. Dit kan gebeuren op verschillende niveaus in de verticale dimensie. Ten tweede moet de rijkdom en diversiteit van plantensoorten in de verticale dimensie worden vergroot. Beide aanbevelingen kunnen worden gecombineerd met Nature-Based Solutions.

1 INTRODUCTION

The breath between trees is as vital as the tree itself – Angie Weiland-Crosby

Anthropogenic climate change went from being a controversial, scrutinized theory to an accepted fact in the last 50 years (IPCC, 2022; KNMI, 2021). The severity of the consequences is still being debated. However, there will certainly be consequences. Including higher volumes of rainfall, extended periods of drought, an increase in mean temperatures and the disruption of cyclical processes. All of these are likely to increase in intensity even further (Ferreira et al., 2021). These consequences will have negative effects on a lot of organisms, including humanity (*Homo sapiens),*. As natural systems will lose their ability to provide ecosystem services (United Nations, 2019). Global temperature levels are still increasing and models show this will continue at the world's current carbon emission rate. This would mean shifts in climate regions, with most of Europe going from a temperate to a subtropic climate. Paired with the fact that lasting climate impacts on the world are already happening and most are now projected to occur between an increase of 1.2-1.5 degrees. It is important to prepare for climate impacts right now (IPCC, 2022; KNMI, 2021).

Cities generate about 70% of global Greenhouse Gas emissions, but at the same time are particularly vulnerable to the effects of climate change. This means that they need to become less polluting, more sustainable and increase efforts to deal with climate change. Water, for example, is interlinked with and affects all aspects of city life: agriculture, industry, energy production and, of course, the environment (Alberti et al., 2019). Cities are already experiencing the effects of global warming (EEA, 2021). Although environmental problems have been intensified by urbanization, these effects are expected to increase in frequency and intensity as a consequence of climate change (Alberti et al., 2019; Ferreira et al., 2021). What adds to the complication of the situation, is the fact that there are no universal guidelines for cities to adopt (Axelsson et al., 2021.).

Environmental problems in urban European areas include changes in hydrological processes, which mainly are: reduced water infiltration, groundwater recharge, increased runoff, peak discharge and water quality degradation (Ferreira et al., 2016; Kalantari et al., 2017). These problems are increasing the need to manage the growing flood hazard, but also water supply concerns, since urban areas account for 60% of residential water use (Yu et al., 2019; Zhang et al., 2019). Large volumes of rainfall paired with impervious surfaces, overwhelm the sewage systems, resulting in localized flooding. This can bring about the loss of life and destruction of property, pollution of drinking water, and spread of diseases within cities (Okaka and Odhiambo, 2018). Climate change will exacerbate these problems, as most regions of the world are projected to see higher rainfall intensities (Ferreira et al., 2021).

On the other end of the hydrological spectrum are periods of drought. Droughts are also becoming an increasing concern for megacities worldwide. Around 80 megacities worldwide already suffered extensively from drought disasters in the first two decades of the 21st century (Zhang et al., 2019). This increases land fragmentation in densely populated areas. Unequal land distribution, land degradation and inefficient land use increase the probability of droughts and erratic rainfall due to climate change (Lin et al., 2021). Water is already periodically a scarce resource in many European cities, and water scarcity will increase with global warming (European Union, 2011).

The hydrological cycle plays a crucial role in all life on earth, As water is necessary to support life (Westall & Brack, 2018). Another necessity for life is the availability of food and shelter, something that has increased for humanity. However, as these factors have increased for humanity, they have decreased for other organisms (IPCC, 2022). Urbanisation and in particular petrification, fragmentation and land-use change of natural areas, have negatively impacted biodiversity globally. Many organisms lose food and shelter as a result of these anthropogenic activities. Natural systems lose their ability to perform ecosystem services, both for people and other organisms (United Nations, 2019).

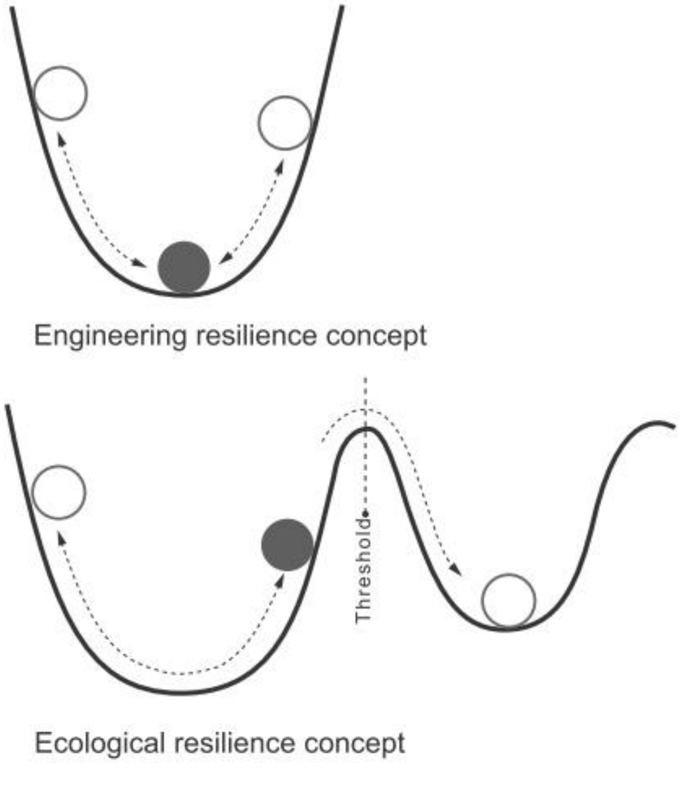
There are many definitions of a city. The word usually refers to a certain number of inhabitants in an area. Towns and cities are differentiated. With the former being smaller (between 10.000-50.000 inhabitants) and the latter larger (> 50000 inhabitants). The city can also refer more generally to perceptions of an urban way of life and specific cultural or social features, as well as functional places of economic activity and exchange. People are migrating to cities more and more (European Union, 2011). Despite population totals being used to define a city, not all cities are equal. This is due to geography and history. Meaning not every city faces the same challenges. However, despite their unique features, every city needs to take measures to prepare for climate impacts (Bruyninckx, 2021).

This process is also known as climate adaptation. Being defined as a country or city taking measures minimise the impacts of climate change (Milieu Centraal, n.d.).

Measures for cities should be designed to connect the urban environment and the biotic systems. A way to accomplish this is with Nature-Based Solutions (NBS), which have become increasingly more popular in the past few years (Bayulken, 2021). An example of this is planting more trees in cities to gain the benefits that a forest ecosystem provides. However, recent studies indicates the limits of tree planting as an NBS to become sustainable and mitigate climate change. Forest dynamics, soil dynamics, species composition and the costs of planting and managing are important variables in the success of urban forests. These factors must be taken into account for successful planning and management (Oldfield et al., 2013). In addition, recent empirical studies show that spatial and temporal scales play a big part in the limits of benefits that urban trees can provide. Some of the supposed benefits of urban forests require that trees are planted on large spatial scales beyond city boundaries, and be maintained over a long period to ensure effectiveness. Meaning that this is not an effective current measure against climate change and unsustainability (Pataki et al., 2021). Lin et al. (2021), states that a better understanding of how to create enabling environments is necessary, to integrate solutions that enable cities globally to adapt to climate change. One of the most enabling environments for life is the forest. Forests are circular (no emission), sustainable, provide benefits for all the residents and are resilient. Meaning the ecosystem will recover after great shock or stress. (Den Ouden et al., 2010; Oldfield et al., 2013).

Alberti et al. (2019), explain a resilient city as follows: ''A resilient city can maintain a continuity of services and functions throughout any shock or stress, while protecting and enhancing people's lives'' (p. 12). However, human made cities are currently not resilient. As external factors (frost, flooding and extreme heat) can make humanly engineered systems malfunction or break down entirely. If we say for example that the functionality of a system can be seen as a ball and a mountain range. When the ball is at the top of a mountain it functions well, but when a disturbance occurs the ball rolls down. Because the system as a whole is not resilient, there is no possibility for the ball to roll out of the valley. As the conditions for getting back up the mountain are impossible (too steep). This is different in natural systems. That are able to go back to the way they were functioning, to a certain degree. Because in natural systems, the overall system allows for rolling back out of the valley after a disturbance. As the complex interplay of many factors allow for the system to be able to go back to the way it used to function before the disturbance (not too steep), see figure 1.1. So, this problem could be solved by having a city fulfill the same level of functionality that an ecosystem has, as opposed to the humanly engineered systems we have today.

Figure 1.1, difference in resilience between humanly engineered systems vs ecological systems (Liao, 2012).



There is an up and coming field within biology that can help to adopt strategies from nature to solve problems that humanity faces. This field emerged in 1997 and is called biomimicry. The term for this field was coined by Janine Benyus, who also founded the Biomimicry Institute. Biomimicry is defined as stating a problem in such a way that you can look for a similar situation in nature. To then proceed and find a solution that nature has found for this same type of problem. As the motto of biomimicry is that nature is the greatest inventor, with 3.8 billion years of R&D (Benyus,1997). Biomimicry falls under the broader umbrella of bioinspiration. And while there are advancements in the field of biomimicry, its use for applying a big ecosystem is still in the developmental stage. As the only real established biomimicry form from ecosystems is that they are circular, sustainable and create conditions that promote life (French, 2021). So what if instead of trying to use nature as the solution we try to mimic what nature does to tackle a problem? Meaning we should stop trying to place a forest inside the city, and start to view the city as a forest. To transform the city to function like a forest.

Greater collaboration between biologists, designers and engineers is needed to understand how we can translate knowledge of ecological processes into systems for future urban societies (French, 2021). As stated before simply planting more trees within cities will not be a realistic solution to become actually sustainable and fully prepared for climate change. Therefore the proposed idea is that cities should not just try to create small forests inside them, but function like forests themselves. The limitations of NBS with respect to the hydrological cycle and biodiversity loss, combined with the fact that there are currently no universal guidelines for cities to deal with the effect of climate change, have led to the formulation of the following research question:

''*Which temperate and subtropic forest ecosystem processes can be mimicked to improve urban water management and biodiversity in European cities, for climate adaptation?''*

To answer this question a set of 4 sub-questions have been devised:

- How do temperate and subtropic forest ecosystems manage water & biodiversity?
- What are the problems with urban water management?
- What are the problems with urban biodiversity?
- How can Bioinspiration help to adopt these processes?

This report will not focus on the specific diversity of one species, but only on overall biodiversity. Also, because the hydrological cycle is very complex and far reaching. This report will only look at the local water cycle within forest ecosystems. Meaning from rainwater falling, to water being used by organisms. For bioinspiration, the main area of research will be to find methodologies. That describe a process of going from natural inspiration to a viable solution. It is expected that there will be a vast number of concepts and processes within temperate and subtropic forest ecosystems that could be beneficial to human-made cities. Mostly because these systems are circular, sustainable and have been developed through evolution in a process longer than human existence. These are in particular interest of national, provincial and municipal government officials, Biologists, architects and urban planners. Temperate forests are reflective of the current climate region, that most of the European cities and all of the Dutch cities are in. Subtropic forests reflect the southern belt of European cities. This could become the new climate region for the rest of Europe, as a result of climate change. In turn, the second and third sub-questions are expected to result in the discovery of barriers ,limitations and difficulties in implementing forest ecosystem concepts in European cities. This is due to a high complexity of forest ecosystems as well as the problems in urban areas. Also, certain concepts could prove to be too impractical for current city infrastructure. Meaning these adaptations would be too cost-intensive to be realised. The answers to these research questions will generate the conditions for implementing forest ecosystem processes. These are not expected to be universal for every city. This report will limit itself to two long term recommendations. These will be provided with an exemplary image and key aspects that need to be addressed.

2 Method

To provide realistic and feasible recommendations and answer the research question; "*Which temperate and subtropic forest ecosystem processes can be mimicked to improve urban water management and biodiversity in European cities, for climate adaptation?*'', along with the sub-questions, an integrative literature review has been conducted.
In paragraph 2.1, the used search engines with their web-link are presented. To find useful sources, keywords were selected for use in these databases. Paragraph 2.2 provides the general keywords per sub-question. Along with a combination of other relevant terms. The sources found through the search terms have been screened, to ensure whether they are relevant. The criteria for this screening will be described in paragraph 2.3. All the relevant sources that passed the screening were collected in a source matrix. Lastly, paragraph 2.4 presents the method of analysing the obtained data.

2.1 USED DATABASES

Sources have been acquired from several databases known for providing scientific and peer-reviewed literature, see table 2.1. The databases used for obtaining alternative literature have been indicated with an underline.

Table 2.1, Database overview.

Consulted database	Weblink
Google Scholar	https://scholar.google.com
Researchgate	https://www.researchgate.net/
Science Direct	https://www.sciencedirect.com
Springer Link	https://link-springer-com
WUR Library search	https://www.wur.nl/en/Library.htm
Wiley	https://onlinelibrary-wiley-com
Academia	https://www.academia.edu/
Frontiers in	https://www.frontiersin.org/
Scopus	https://www.scopus.com
Asknature	https://asknature.org/
Biomimicry toolbox	https://toolbox.biomimicry.org/
Google	https://google.com

2.2 SEARCH TERMS

The tables 2.2-2.5, show the general keywords used for searching relevant literature on the left column. The right column shows the terms that were added or combined with the general keywords to enable more specific data collection. In each database, the general keyword was combined with the combination terms to search for literature. Only for biomimicry and biomorphic urbanism, there was also searched for alternative literature. Since these topics cover more than just a scientific approach but also a design and human behaviour approach.

Table 2.2, Search terms for: How do forest ecosystems manage water & biodiversity?

General keywords	Combination terms
Forest ecosystem	Temperate OR Subtropic AND Functions OR Sustainability OR Services OR Water regulation OR Water storage OR Water purification OR Biodiversity management OR Biodiversity facilitation OR Climate change adaptation

Table 2.3, Search terms for: What are the problems with urban water management?

General keywords	Combination terms
City	European AND Water regulation OR Water management OR Hydrological climate change adaptation OR Climate needs OR Needs
Urban	European AND Water regulation OR Water management OR Hydrological climate change adaptation OR Climate needs OR Needs

Table 2.4, Search terms for: What are the problems with urban biodiversity?

General keywords	Combination terms
City	European AND Biodiversity management OR Climate change biodiversity adaptation OR Biodiversity needs OR Future Needs
Urban	European AND Biodiversity management OR Climate change biodiversity adaptation OR Biodiversity needs OR Future Needs

Table 2.5, Search terms for: How can Bioinspiration help to adopt these processes?

General keywords	Combination terms
Climate change	Mitigation OR adaptation OR Forest ecosystem mitigation
Biomimicry	Process OR Strategies OR Methods

2.3 Criteria sources

At first, the publications will be selected by their title appearing relevant for this review. The search results will be further narrowed down by excluding publications. These exclusion criteria are mentioned in table 2.6. The remaining publications are sorted by relevance and the first 20 publications listed in each database will be selected. Duplicates will then be removed and the remaining publications screened, by reading the title and abstract for relevance manually on the following criteria:

- Empirical work that looks at
- Natural systems OR
- Regulatory systems
- That provides examples OR
- A clear strategy/methodology

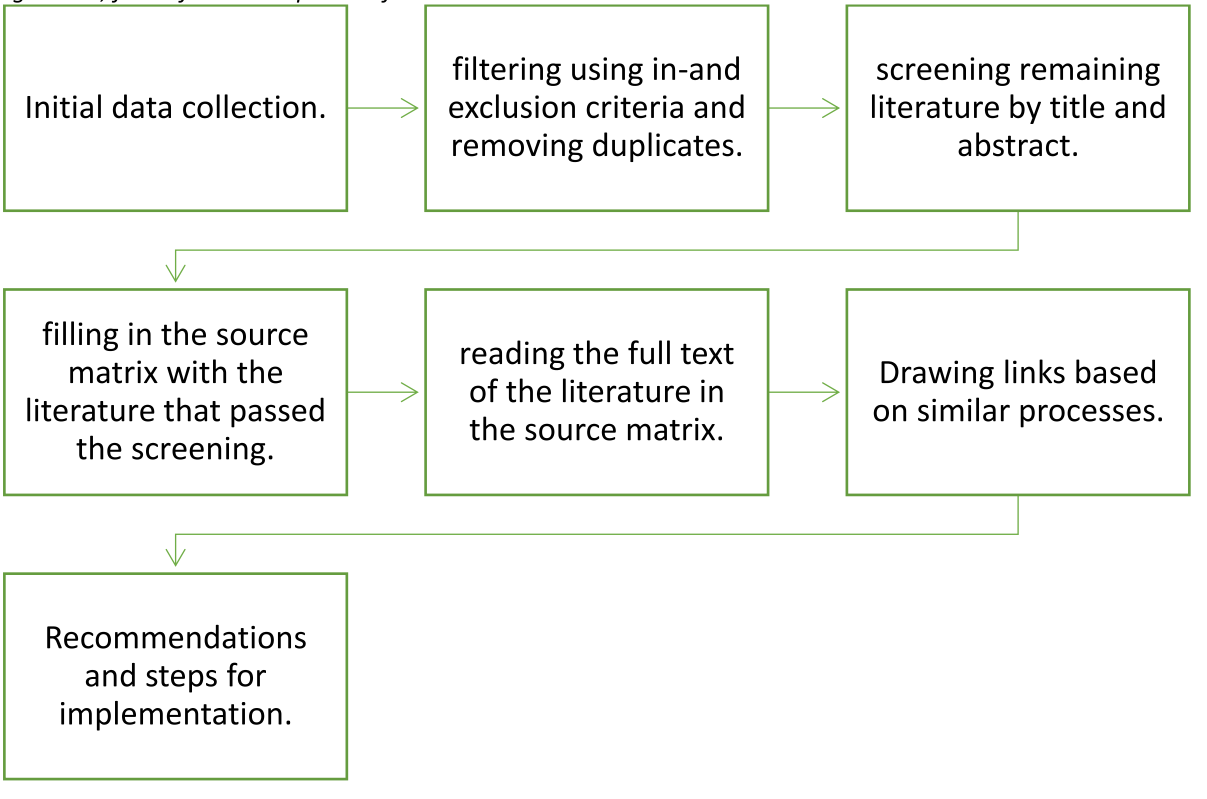
Table 2.6, In- and exclusion criteria.

Inclusion criteria	Exclusion criteria
Relevant disciplines	Unrelated disciplines e.g. medicine, theoretical physics, toxicology
English or Dutch texts	Languages other than English or Dutch
<30 years	>30 years
	Duplicates

2.4 Analysis

After the data collection phase, the selected publications will be analysed more in-depth. The publications that are stored in the source matrix will be read. During which the most relevant concepts will be noted, but no more than 3 per article. This will include duplicates/similar concepts found within multiple articles, to help determine the most prevalent concepts. Following this, links will be drawn between the natural processes and the humanly created & regulated processes. This will be done to see if there are already any similar processes. Lastly, 2 recommendations will be given and elaborated on. These recommendations will be based on the natural processes in combination with their feasibility for human processes. Biomimicry and biomorphic urbanism methodologies will be used to elaborate on these recommendations. And help to provide, in the most complete way possible, of implementing/adopting these recommendations. The whole process can be seen below in figure 2.1.

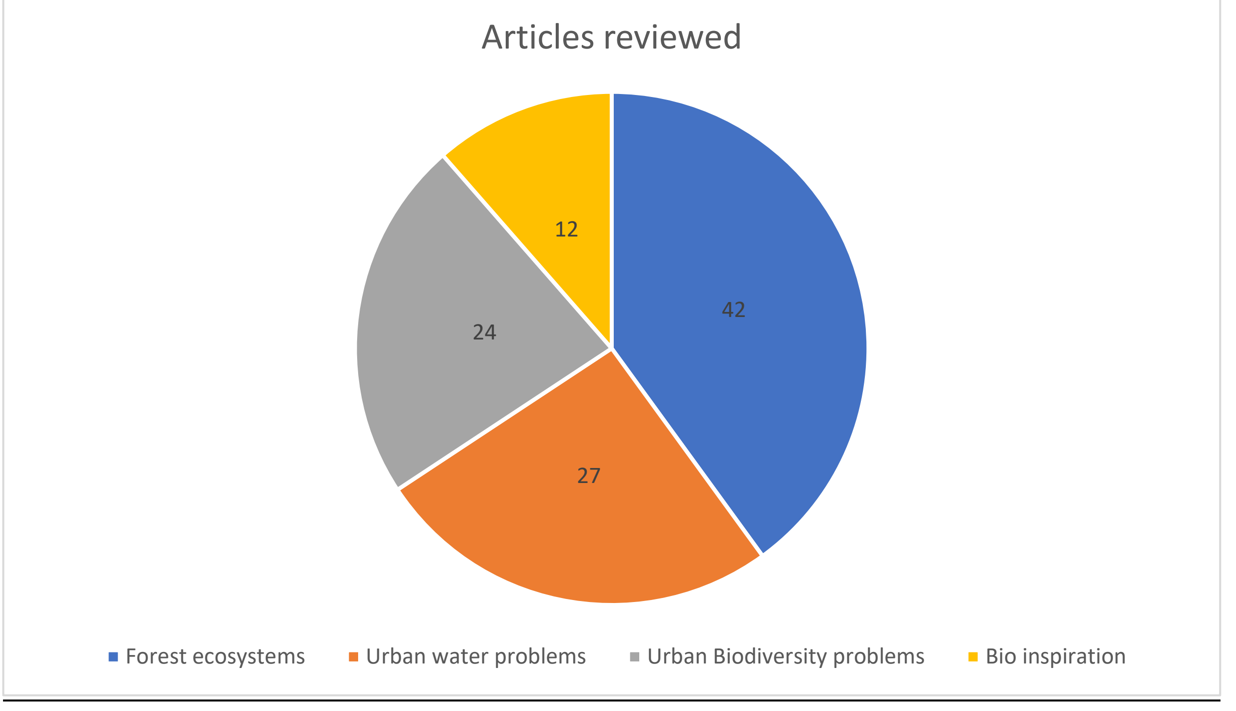
Figure 2.1, flow of selection process for relevant literature.



3 RESULTS

180 articles passed the initial filtering using the formulated in- and exclusion criteria stated in paragraph 2.3. After the titles and abstracts had been read and screened, 105 articles remained, see table 3.1. These articles were found in the databases of Google Scholar, Research gate, Science Direct, Springer Link, WUR Library search, Wiley, Academia, Frontiers in, Scopus, Ask nature, Biomimicry Toolbox and Google. Of these articles the introduction, results, discussion and conclusions have been read. To draw links between similarities and differences. All the studies that have been reviewed were authored between 2010 and 2022.

Table 3.1, an overview of the number of articles that have been reviewed divided by sub-question.



3.1 HOW DO TEMPERATE AND SUBTROPIC FOREST ECOSYSTEMS MANAGE WATER & BIODIVERSITY?

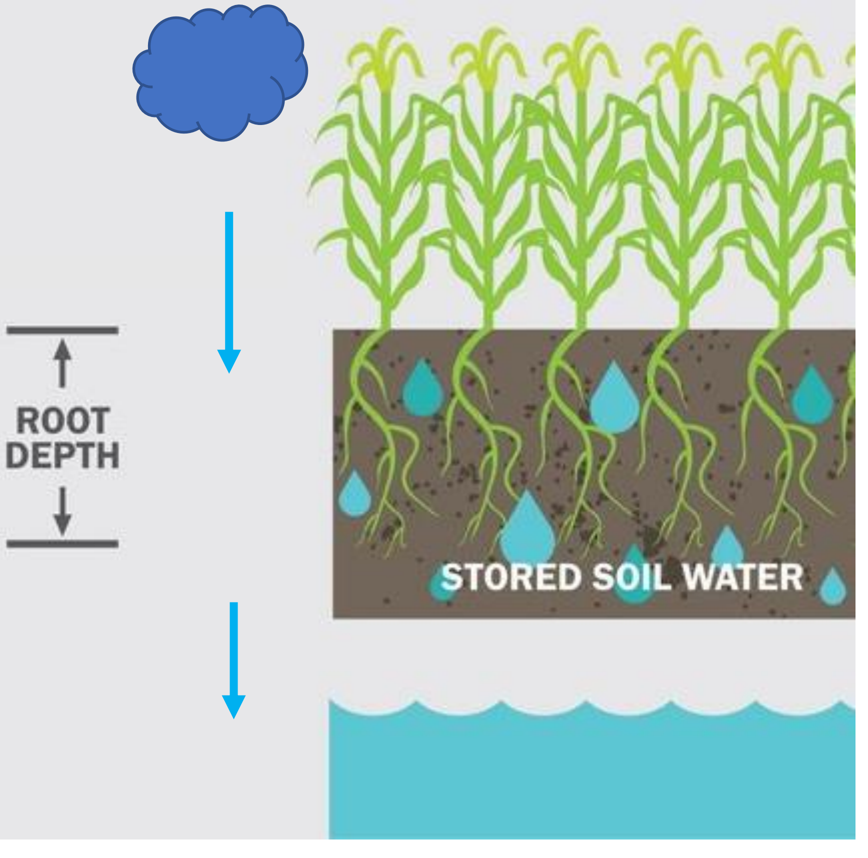
A total of 42 articles have been read for the sub-question: ''How do temperate and subtropic forest ecosystems manage water & biodiversity?'' All of which were peer-reviewed. Of these articles 22 focussed on water management and 20 on biodiversity. The most common discussed systems/concepts for water management in temperate forests were, water storage in the soil and (shallow) groundwater levels. With 18 and 16 counts respectively, see table 3.1. For subtropic forests, the most commonly discussed systems were, the water extraction from different depths/soil layers and water storage in the stems. With 18 and 12 counts respectively.

Table 3.1, found concepts for forest water management and their occurrence.

System/concept	Forest ecosystem type	Occurrence
Soil water storage	Temperate	18
Water extraction from different depths	Sub-tropic	18
Groundwater levels	Temperate	16
Stem water storage	Sub-tropic	12
Soil composition and porosity	Temperate	10
Evapotranspiration	Temperate	10
Transpiration rate	Sub-tropic	8
Stomatal size and activity	Temperate	6

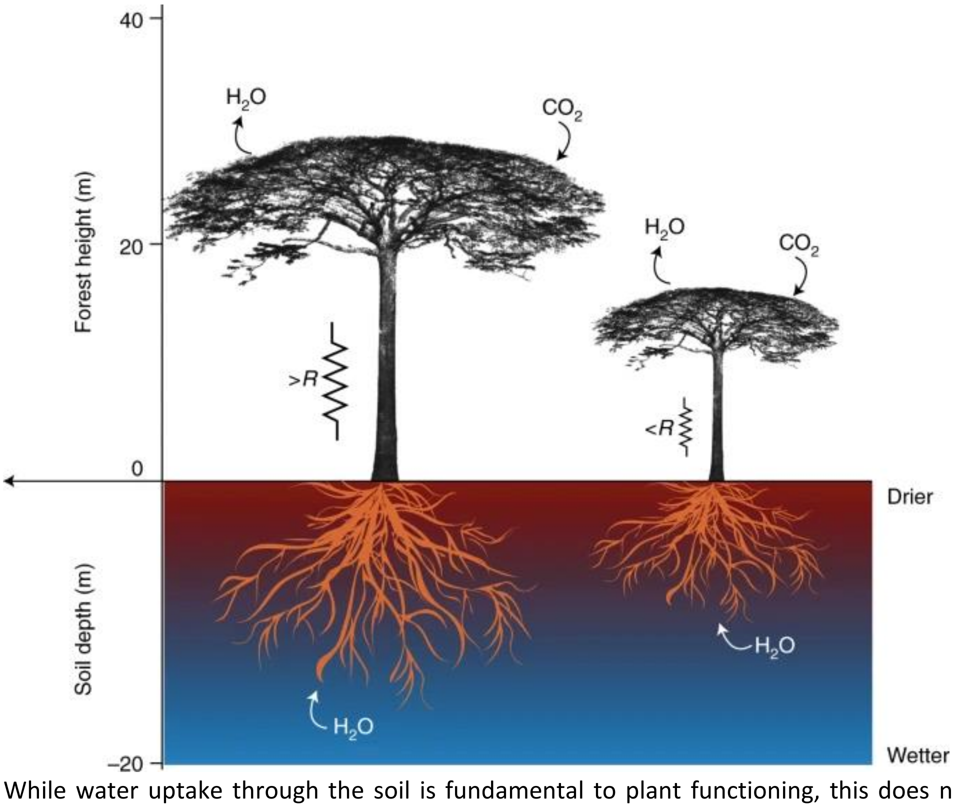
Water storage in the soil is understood as the infiltration of water into the soil that stays stored. This water is then available for vegetation and organisms. Excess water drains down to recharge the groundwater level, see figure 3.1. Most of this water comes from precipitation (Xie et al., 2014). In saturated soil, the water availability is consistent across the vertical dimension. However, this is not a condition that is always present. There are many factors influencing soil water concentration. With the main ones being evaporation and extraction by organisms (Nakahata, 2022). Groundwater levels are strongly connected with the concept of water storage in the soil. This concept is mainly about water being readily available at levels just below the soil layer (Ciruzzi & Loheide, 2021). Different types of soil vary in their permeability and water retention. But a consistent phenomenon is that when there has been a period of drought, the availability of water in the soil is low. When this occurs groundwater will be pulled up into the soil. After the groundwater table has been reduced, it takes more time for this to be restored. Water that infiltrates after the next rainfall period will pass through the soil first. Where most of this water will get stored. After saturation of the soil, the groundwater table will be recharged (Ciruzzi & Loheide, 2021; McGregor et al., 2021). It has even been observed that more drought-resistant species of tree can extract their water from deeper soil layers, when water availability in the topsoil is becoming scarce (Brinkmann et al., 2019). But relatively shorter tree species can vary broadly in the depth of water uptake. While larger trees also invest in shallow roots that are beneficial for taking up water from rainstorms (McGregor et al., 2021).

Figure 3.1, The storage of rainwater in the soil, adapted from Brown (2016).



It has been observed that to survive, different plant species or even different individuals within species, can extract their water from different depths in the soil, see figure 3.2. (Freschet et al., 2021; Rog et al., 2021). Observations showed that older, and coincidentally higher trees had a deeper root depth. Giving them easier access to soil water in times of drought *(*Brando*, 2018).* Soil water niche partitioning is a mechanism that decreases interspecific competition (Hildebrandt, 2020). Tree species show divergent water-use strategies, which coincides with the difference in water uptake depth. The greater the diversity in tree species, the greater the decrease in competition over soil water. As the season changes from wet to dry a clear benefit becomes apparent. Deeply rooted species in the first half of the dry season, have access to more soil water. This is because when there is precipitation in a subtropical forest, it is often a large quantity of rainfall. Meaning that the soil will get saturated and hold water at different depths. However, due to the high temperature, water close to the soil will evaporate quicker than water deeper in the soil (Ouyang et al., 2019; Rog et al., 2021). In these water-limited times, root water access has a great effect on water use (Zhao et al., 2020). In particular how long plant water use can continue into the summer period (Rog et al., 2021). Nonetheless, this did not result in tree species simply deepening their root depth. As stated before, some species kept their root depth shallow but very spread out. To capture water in the event of precipitation *(*Brando*, 2018;* McGregor et al., 2021*)*. And there have even been results showing that some tree species can vary their water use, depending on the water table (Zhao et al., 2020).

Figure 3.2, diagram showing the different depths at which tree roots extract water (Brando, 2018).



While water uptake through the soil is fundamental to plant functioning, this does not mean that water is necessarily extracted at the moment of use. Woody plant species can store water in their stems. And in subtropical forests, multiple species of trees store large amounts of water in their upper trunk region. This is in contrast with other plant species, like lianas for example (Chen et al., 2017). Trees tend to have a higher canopy transpiration rate than lianas. However, they tend to have a slow increase in sap flow relative to increasing transpiration. Whereas lianas have a quick sap flow in response to increasing transpiration rates. This difference is attributed to water being withdrawn from stem water storage in response to transpiration. (Chen et al., 2016; Ganthaler et al., 2019). Water lost by transpiration at the canopy is generally replaced by water stored in the top portion of the tree's trunk. While trees differ in the size of stem water storage, all species show a substantial difference to lianas. Lianas rely primarily on soil water. As their potential for internal water storage is not big enough to replace this deficit (Chen et al., 2017).

For biodiversity, the most commonly discussed systems for biodiversity management in temperate forests were forest floor cover and soil microbial diversity. Both with a count of 7 times, see table 3.2. For subtropic forests, the most common concept was strata diversity. With 10 counts.

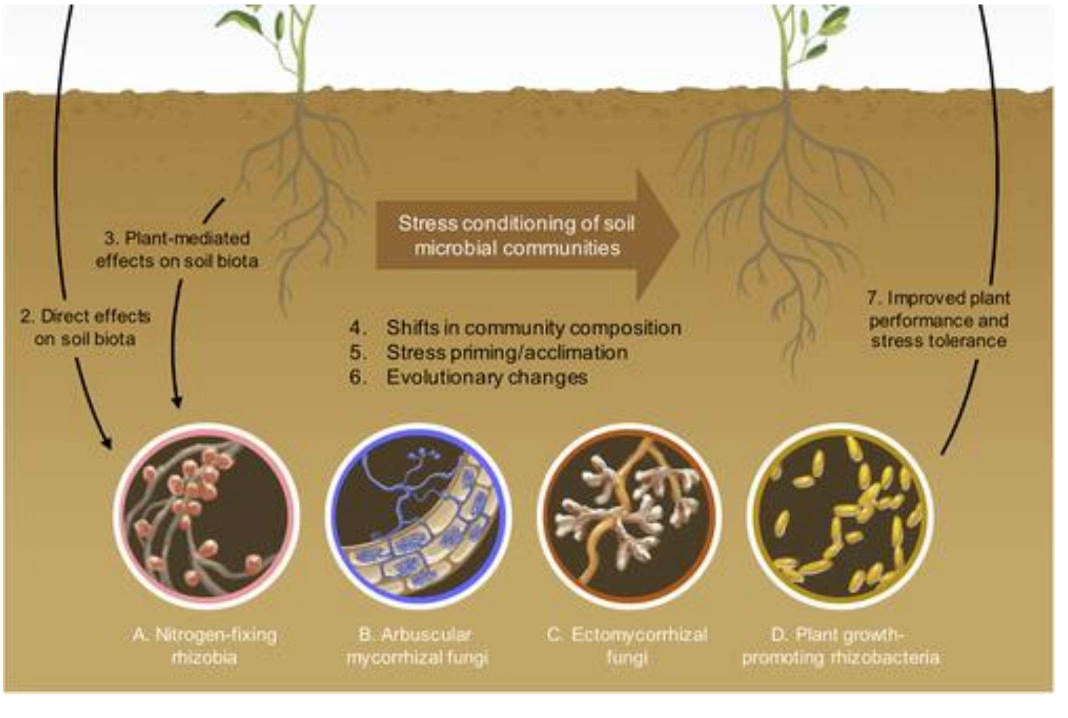
Table 3.2, found concepts for forest biodiversity and their occurrence.

System/concept	Forest ecosystem type	Occurrence
Strata diversity	Sub-tropic	10
Forest floor cover	Temperate	7
Soil microbial diversity	Temperate	7
Tree species diversity	Sub-tropic & temperate	6
Water availability	Sub-tropic & temperate	5
Soil nutritional availability	Sub-tropic & temperate	5
Erosion control	Temperate	3

The forest floor cover concerns the vegetational diversity in the layer just above the soil. In temperate forest, the diversity of plant species here is usually around 80% of the total plant diversity in this forest type (Yuan et al., 2020). And together with the bordering shrub layer consisting of around 90% of the plant diversity. The forest floor is predominantly covered by herbs (Spicer, Mellor & Carson, 2020). The forest floor cover affects other organisms in multiple ways. The most notable are food, shelter and microclimate generation. These microclimates cover a wide array of variations to the general climate. Mainly consisting of variations in humidity, air temperature, light, and wind speed (Kovács et al., 2017). Shrubs have also been found to facilitate microclimates, and usually work in tandem with the floor cover. Shrub layer density is closely linked to forest floor cover. As a richer floor vegetational diversity typically coincides with a denser shrub layer. Moreover, a diverse forest floor vegetation has a positive effect on herbivore diversity. Which in turn provides more potential food for carnivores (Jouveau et al., 2020; Tinya et al., 2021). Multiple studies indicated that not only living plants are important on the forest floor, but also dead plant material and deadwood. Deadwood consists of logs and branches. Their presence has been found to mainly improve wood-inhabiting fungi diversity, as well as beetle diversity (Tinya et al., 2021). The dead plant material consists of stems, roots and leaves. This material can come from all the different layers and accumulates on the forest floor. This material is in turn decomposed by microbes.

The soil microbial diversity is the total diversity of microbial species in the soil. These species usually have mutualistic interactions with plant species through their root systems, see figure 3.3. They also serve an important role in the cycle of nutrients and the decomposition of organic matter (Yuan et al., 2021). The soil microbes contribute to the early recovery of soil carbon and different nitrogen processes. Which include nitrogen fixation, the degradation of organic carbon and ammonium oxidation (Pajares & Bohannan, 2016). Yuan et al. (2021), also propose that there is a positive feedback loop between nitrogen fixating, ammonium oxidating microbes and vegetation. As an increase in vegetation heightens the demand for nitrogen. So too increases the possibility for mutualistic relationships and thus the number of soil microbes that can perform these functions.

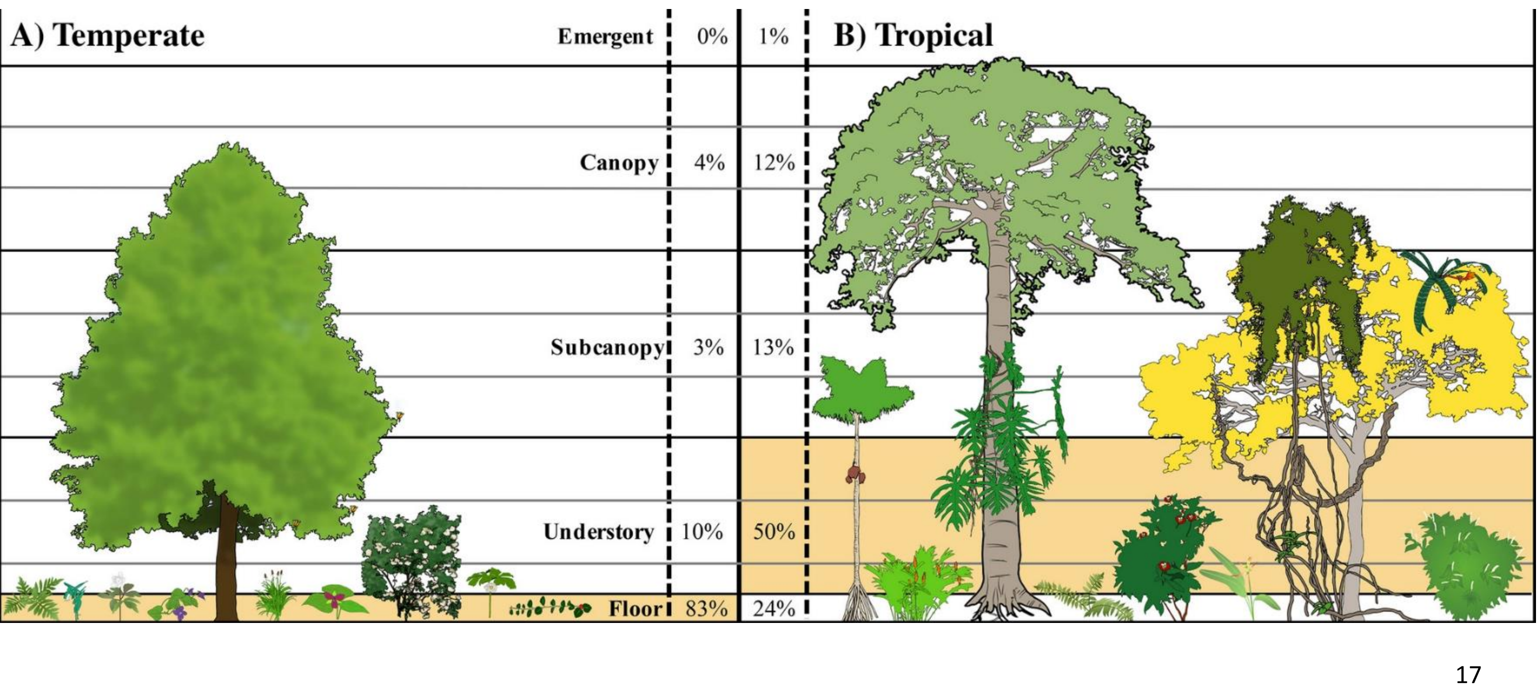
Figure 3.3, Positive effects of a diverse soil microbe composition (Valliere et al., 2020).



In the concept of strata diversity, the results show that vegetational diversity in both the over and understorey improves total biodiversity. Within subtropical forests, the understory is the most diverse vegetational layer. However, the proportions of the overall vegetational diversity are more spread out, when compared to temperate forests (Spicer et al., 2020), see figure 3.4. There is a positive relationship between individual tree size variation and species diversity in the overstory strata. Ali & Yan (2017), attribute this to the niche complementarity effect. This effect proposes that different species through selection fulfil a different niche. This will lead to different resources at a site becoming fully utilised. Which reduces interspecies competition. This utilisation progressively increases as the diversity of species increases (Ali & Yan, 2017; Zhang et al., 2017). Different tree species and tree species with high size variations have their own set of habitat requirements. This mainly pertains to water availability and soil nutrients (Ali et al., 2016). The reach of the niche complementarity effect is proposed by Ali & Yan (2017), to go even further than just the overstorey. As they exclaim that the plant diversity in the overstorey positively relates to other layers. More specifically tall trees, short trees, liana, shrubs and herbs improve the overall biodiversity. As the threes that have grown and reached the overstorey, improve the habitat conditions through a mechanism known as facilitation (Zhang et al., 2017). In facilitation, some species may alter the environment in such a way that it favours the fitness of other species. Most notably by creating microstructures, microclimates, protection from light intensity, wind, and regulation of temperature and soil composition. This facilitates coexistence through increasing the amount of possible niche space (Hilmers et al., 2018). Overstorey trees mainly affect understorey vegetation by altering below- and above-ground resource availability such as water, light and space, especially for the shrub and herbaceous layers (Mason et al., 2011; Zhang et al., 2017). A multilayered forest structure allows for more efficient utilization of available resources, due to niche differentiation (Ali et al., 2016). Plant diversity in turn, positively affects the diversity of other organisms. The combination of diverse vegetation in these different layers positively affects different species of organisms. As the full utilisation of all the resources in turn reduces competition on multiple levels (Ali & Yan, 2017). It has been observed that an increase in first-order consumers, is frequently followed by an increase in the abundance of herbivorous organisms. This increase in prey will in turn increase the abundance of predators. For example beetles, spiders and birds. Thus the overall biodiversity increases (Hilmers et al., 2018).

Additionally, tree species in overstorey strata with high aboveground biomass and great tree size may consume a large part of the resources. Which reduces resource availability to understorey species (Mason et al., 2011). The strong response of overstorey species diversity and weak response of understorey species diversity to soil nutrients collectively suggest a dominant filtering role of the overstorey trees in shaping understorey structure and function (Zhang et al., 2017).

Figure 3.4, Difference in vegetational diversity in the strata of temperate and sub-tropical forests. With the orange line indicating the layer with the greatest vegetational diversity (Spicer et al., 2020).



3.2 WHAT ARE THE PROBLEMS WITH URBAN WATER MANAGEMENT?

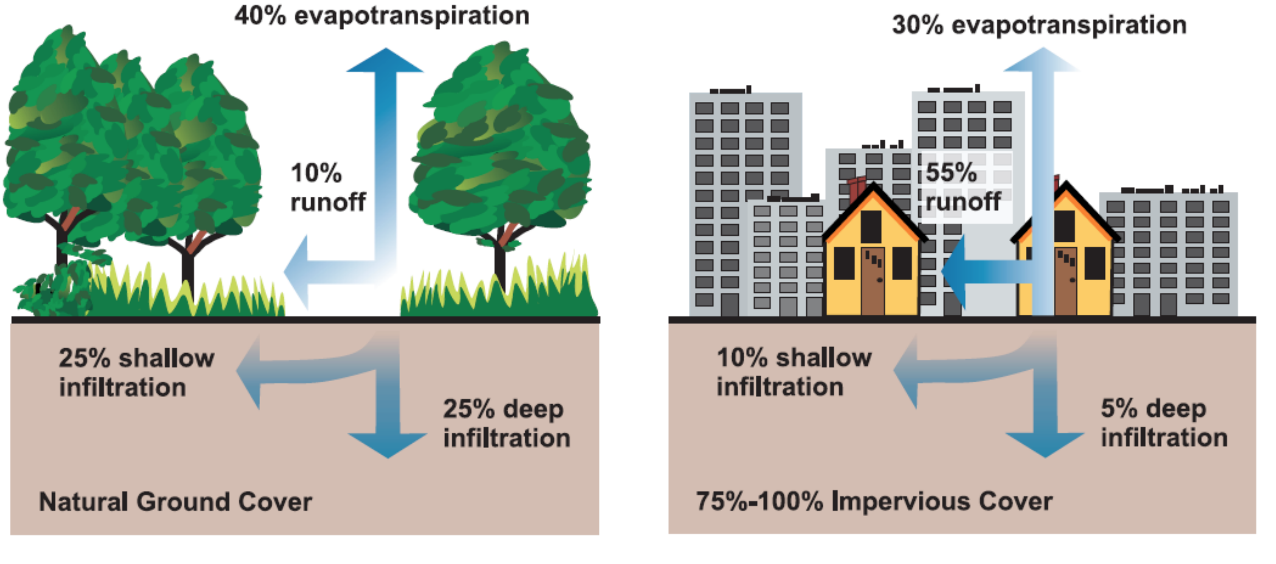
A total of 27 articles have been read for the sub-question: 'What are the problems with urban water management?'' 9 of which were peer-reviewed. The non-peer-reviewed articles were reports from either the European Union or EU collaborative research departments. There were three most prevalent problems mentioned in the literature, namely: Non-permeable/impervious surfaces, infrastructure designed to make rainfall run off and the combination of sewer and storm drain infrastructure. With 24, 22 and 22 counts respectively, see table 3.3.

Table 3.3, found concepts for urban water management and their occurrence.

System/concept	Occurrence
Non-permeable/impervious surfaces	24
infrastructure designed to make rainfall run off	22
combination of sewer and storm drain infrastructure	22
Focus on extreme phenomena and peak discharge	12

Most articles agree that the process of flooding is an inevitable periodic occurrence. It happens in natural systems from time to time. However, the impacts and consequences of flooding in cities are made worse by human influences (Gawlik et al., 2017; Pot, 2019). This is mainly apparent in the water management strategies of cities. Which has negatively contributed to increased flood risk. Most notably are the excessive rate and reach of urbanisation and construction (Dziedzic & Twardoch, 2021). As we have restricted the natural process of water infiltration by covering the ground with non-permeable surfaces (streets, roads, buildings, etc.). The materials used for infrastructure hardly allow for any water to infiltrate into the soil. As the most commonly used materials are concrete and asphalt. Both of which are fully impervious (Dziedzic & Twardoch, 2021; Gawlik et al., 2017), see figure 3.5. Another important aspect is the effect of urbanisation on vegetation. removal and/or change in vegetation caused by urbanisation. This vegetation has the potential to also store water from floods and rainfall. But, because of the increase in impervious surfaces, there is not enough space for vegetation to grow. And the vegetation that grows is either managed by humans or hindered in its potential. As urbanisation results in the hardening of the biologically active surface. Even flood defences made from impervious material can have a negative impact. Generally speaking, they do not store water, but rather push the flood elsewhere (Oral et al., 2020). So as urbanisation progresses in a way where natural land cover is replaced by impervious surfaces. The effect of impervious surfaces will lead to increased surface runoff of rainwater (Dziedzic & Twardoch, 2021; Niemeläinen et al., 2015).

Figure 3.5, the difference in hydrological distribution after precipitation between a natural ground cover and the average urban ground cover (U.S. Environmental Protection Agency, 2003).



So, while impervious surfaces play a big part in surface rainwater runoff, there is another important managerial aspect that became apparent in the articles. In most European cities the hydrological infrastructure is built to make all the rain- and stormwater drain away (Niemeläinen et al., 2015), see figure 3.6. The infrastructure for precipitation mainly consists of storm drains and sewers. This channelling away of water, instead of allowing the water to infiltrate locally, also adds to flood risk (Gawlik et al., 2017). When precipitation is usually drained into the sewage system, this is the same system that also receives the drainage of domestic water use. This concept is also known as the combined sewage system (Langeveld, 2019). Currently, ageing water infrastructure, especially sewage systems, poses a challenge for European cities. As their maintenance is a huge investment challenge for local and national governments (Özerol et al., 2020). Pot (2019), even states that increased rainfall intensity will further increase the pressure on existing water infrastructure. This is problematic as ageing infrastructure is already a cause of concern worldwide.

Dziedzic & Twardoch (2021), describe conventional water management in cities as mechanistic. This is because historically city officials and planners have focused on a specific goal or problem within the hydrological system. Usually without taking into account the interactions between infrastructure and environment. They pose that the main issue lies within the mindset or goal of solutions. As the often ‘wrong’ approach to water management in cities enhances the flood problem. Generally, all the effort is put into diverting water as quickly as possible, from the place where it falls. And this approach hurts the circularity of the hydrological cycle. As well as cause other problems. Oral et al. (2020), support this statement. As they say that in fast developing cities, the loss of circularity goes hand in hand with the altered hydrological cycle. Because governments and city planners do not see rainwater as the natural, valuable resource, that it is. But rather, as a threat to the urban environment. So, in turn, there emerges a positive feedback loop. Where impervious surfaces lead to surface runoff of rainfall. Due to the infrastructure not being designed to absorb this water, it becomes the main cause of flooding. This leads to humans seeing rainwater as a threat to the urban environment.

The increased runoff and inability of water to infiltrate into the soil, also lowers groundwater levels. Ultimately leading to soil degradation. Which in turn leads to the disappearance of biotic components of the natural environment. This affects the urban capacity to store water and microclimate, causing problems such as the urban heat island effect (Alfieri et al., 2015; Dziedzic & Twardoch, 2021). Climate change will lead to more extreme rainfall patterns, with an increase in precipitation totals per event. This will cause frequent overloading of the drainage systems. As a result of this floods will occur, especially in central city districts with a high level of impervious surfaces. Such events, referred to as pluvial flash floods, are followed by long dry spells (Alfieri et al., 2015; Oral et al., 2020). Further increasing the need for water to be able to infiltrate and be stored.

Figure 3.6, diagram showing the different routes of water runoff, including stormwater and their convergence in the current hydrological system (Sultan Washington, n.d.).

3.3 What are the problems with urban biodiversity?

A total of 24 articles have been read for the sub-question: 'What are the problems with urban biodiversity?'' 18 of which were peer-reviewed. Among the non-peer-reviewed articles were governmental documents from the European Union, or EU collaborative departments. There were two most prevalent problems mentioned in the literature, namely: The loss of natural habitats and habitat fragmentation. With counts of 24 and 22 respectively, see table 3.4.

Table 3.4, found concepts for urban biodiversity and their occurrence.

System/concept	Occurrence
Loss of natural habitats and	24
Habitat fragmentation	22
Human disturbances	9
Petrification	7

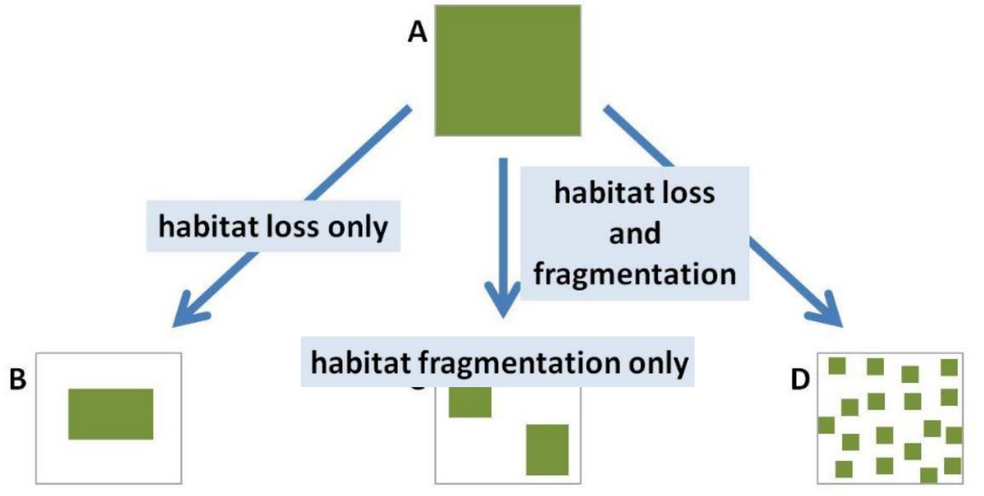
The urban environment has been sub divided into different areas: Urban, industrial, commercial, transport, mines, dumping, construction, and urban green areas. All these areas show a decrease in biodiversity (Maes et al., 2013). The main drivers of this biodiversity loss are habitat loss and habitat fragmentation. These two phenomena are the result of land-use change by anthropogenic forces (Cortina-Segarra et al., 2021). Habitat loss generally refers to the decrease in size availability. Urbanisation causes natural habitats to be converted into impervious surfaces, leading to habitat loss (Kareiva et al., 2018; Liu et al., 2016). Two indicators that have been used in multiple articles were, pollination potential and habitat quality. Both of these indicators show a downward trend. Deforestation combined with the loss of grassland, are the main causes of this drop. In the case of grassland, there is special importance in grassland next to other habitats. These two habitats mainly affect the food availability, flower availability, and nesting suitability and availability (Maes et al., 2013). These problems are worsened by the fact that there is almost no replacement for these habitats, as the soil in urban areas is covered by impervious materials. These mainly consist of asphalt and concrete. This in turn affects the ecological functions that habitats fulfil, and thus the previously mentioned resources become unavailable in urban areas (Cortina-Segarra et al., 2021).

Simultaneously to habitat loss, the development of railways, roads and other impervious infrastructure results in habitat fragmentation. Habitat fragmentation is understood as the breaking apart of habitats, without taking habitat loss into the equation (Kareiva et al., 2018). Multiple articles state the negative effects of impervious surfaces on biodiversity, as these fragment habitats. The creation of roads and railroads often cut straight through natural habitats. Thus, fragmenting them. Additionally, within urban areas fragmentation occurs as well. Natural habitats are turned into patches that vary in size and isolation (Liu et al., 2016). One of the main consequences of these smaller habitat patches is that they usually support less diverse insect communities (Fattorini et al., 2018). This often goes hand in hand with reduced immigration. Because more habitats get fragmented, the distances between them increase. And as the distance increases to other urban habitat patches, more species will become unable to successfully travel between them (Fenoglio et al., 2021). Paired with this is the fact that infrastructure often restricts the movement of many organisms. As they can get killed or scared off to cross.

While both habitat loss and habitat fragmentation decrease urban biodiversity. These processes usually occur concurrently and are interrelated, see figure 3.7. Some articles even state that habitat loss and fragmentation happen at the same time. As the combination of these processes strengthens the negative effects of each other. Making their co-existence further worsens urban biodiversity decline (Cortina-Segarra et al., 2021; Liu et al., 2016).

While the effects of urbanisation on biodiversity loss are undeniable. Beninde et al. (2015), argue that is also a positive side to urbanisation. Albeit only for a small number of species groups. As urbanisation creates conditions that only very well adapted species can thrive in. Meaning that there are species that currently benefit from urbanisation. Having said that, they do acknowledge that there is still an overall decline in biodiversity. Which should be tackled. But just in a way that looks at the potential for urban habitats.

Figure 3.7, The visual difference between habitat loss, fragmentation and the combination of the two (Kareiva et al., 2018, p15).



3.4 How can Bioinspiration help to adopt these processes?

12 articles have been read for the research question: ''How can Bioinspiration help to adopt these processes?'', 2 of the articles read were peer-reviewed. And 2 books passed the screening. Of these books, specific chapters have been read.

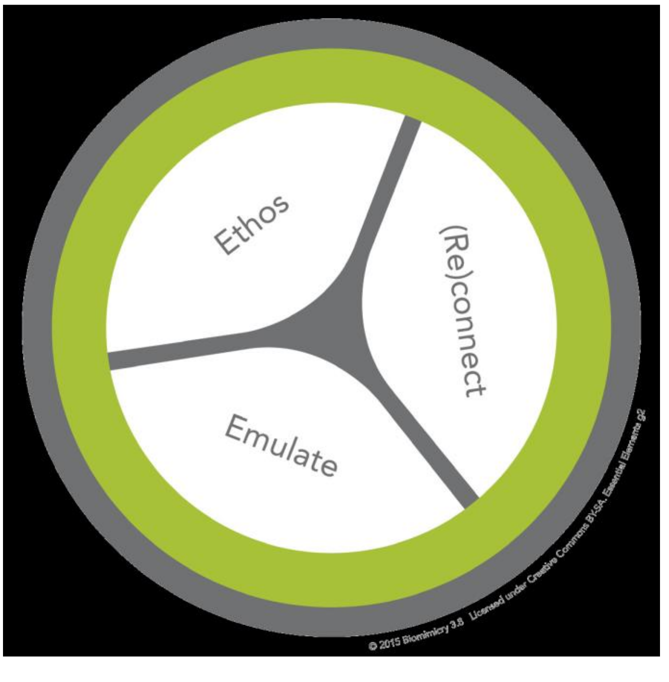
Coelho & Versos (2011), state that there are around six different bio-inspired design methods. However, all these methods have a few commonalities. First, there is always the identification of a problem or need. In this part of the process details and specifications of the problem(s) need to be found and formulated. After this step then comes the search for biological inspiration. As usually the specified problems lead to abstraction. That is then used to find solutions to the problem, through searching for similar functions in nature. When the most suitable examples have been identified the next steps are the design and developmental steps. In these steps, some methods referred to the natural inspiration as analogies, interpretations, or the extraction of principles. Kennedy et al. (2015), state that biomimicry is about abstracting natural strategies into design principles. To solve human challenges.

Bio-inspired design can be done in any sector. However, Baumeister et al. (2011, pp. 139-158), indicate that bio-inspired design is merely about drawing inspiration from nature. Three essential elements differentiate between bio-inspired design and biomimicry. These three elements are Ethos, Reconnect, and Emulate, see figure 3.8. Because bio-inspiration per se does not have to result in a sustainable and circular solution. But biomimicry is concerned with creating a more sustainable and circular human world. So, when the three essential elements are applied to bio-inspired design, you will get biomimicry. Ethos refers to our ethics, intentions, and philosophy. Ethos represents our respect for and responsibility to nature. Reconnect concerns itself with reinforcing the fact that human beings are nature. And thus, should be part of natural systems/processes. Emulation is the essential step between natural principles, patterns, strategies, and functions into design.

Across all the different sources, two central themes were present. These themes were: Natural inspiration should not simply be copied. The function performed is what should be looked at and the process/system that does this has to be emulated. And the second theme was that, for bioinspiration to be successful it is important to realise that almost nothing in nature simply has one function. Multifunctionality is key to both sustainability and resiliency (Zari, 2018, pp. 16-43).

This mindset is reinforced by Kennedy et al. (2015), who states that the aim of biomimicry is not to create a replica of nature. Instead, the goal is to derive design principles from nature. Mimicking nature is different from using organisms to accomplish a desired function. The difference lies in intention. Does one simply want to use an organism to do what it does? Or is the design principle performed by the organism emulated (Baumeister et al., 2011, pp. 139-158; Zari, 2018, pp. 16-43). One example mentioned is using fireflies to produce light, instead of understanding and applying the complex system of bioluminescence.

Figure 3.8, the three essential elements of biomimicry (Biomimicry institute, 2015).



4 DISCUSSION

This study represents a qualitative review of current English and Dutch written articles. The performed literature review served to gain insight into the four sub-questions. All to find and devise systemic improvements for urban water management and biodiversity. In which forest ecosystems could serve as inspiration for improvements, that are necessary for European cities.

4.1 RESEARCH

The data collection and filtering went according to plan. There were only difficulties with the search term sub-tropic. The use of sub-tropic was sometimes seen by databases as tropic and sometimes resulted in very limited returns. The articles that covered tropical forests were excluded because this climate region is not the same as the sub-tropical one. While the combination of peer-reviewed, non-peer-reviewed scientific articles and so-called grey literature are combined to get broader inspiration for the posed problem, there still are limitations to the study.

Deciding to look only at literature published in English (and Dutch) excludes research conducted in other languages, which in turn can limit the findings. The decision to use certain in- and exclusion criteria may have similarly affected the findings. Most notably the exclusion criteria of <30 years. Because there could very well have been scientific studies covering the topics, that now fall outside of this study. It was also the case that because a broad array of databases was used, the literature search resulted in quite some duplicates. This is because some databases are integrative. Meaning that they show results that are linked to other sites. Meanwhile, other databases only show results that are findable in their records. This leads to the fact that, if only the integrative databases were used, fewer duplicates would have been found. Resulting in more unique articles that can be reviewed.

Another possible limitation is the fact that per database the cut off number for potential literature was 20. This can limit potential findings a lot. However, there was filtered for relevance. Meaning that all the found literature was recent. This is apparent in the fact that none of the reviewed literature was published before 2010. This in turn makes the found results not only relevant but also up to date with current world issues and progressions. What also benefits this case is that scientific research builds on the body of work that already exists. All the recent literature most likely uses sources that predate the search criteria, while also updating any previous knowledge gaps and or errors. This highly improves the success rate and correctness of the found concepts.

4.2 HOW DO TEMPERATE AND SUBTROPIC FOREST ECOSYSTEMS MANAGE WATER & BIODIVERSITY?

For the first sub-question, the information can be seen as the most scientific. As all the reviewed articles were scientific, peer-reviewed articles. Therefore, there is a high likelihood that the presented systems are factual. While the natural systems are very complex and dynamic, the proposed strategies have a higher chance of being successful. Soil water storage was mentioned in almost all the literature on temperate forest water systems, indicating its importance in the hydrological cycles of this ecosystem type. The observation of more drought-resistant species shifting their water uptake to deeper soil depths is very important to consider. As climate change will cause more and more intense periods of drought. Extracting water from different depths was mentioned in almost all of the literature on sub-tropical forests. Paired with the fact that plants can store water in their stems. These two processes combine to show that in subtropical forest ecosystems, water is stored in and extracted from, different vertical layers.

For biodiversity facilitation in temperate forests, the forest floor cover and soil microbe activity are the most important factors for biodiversity facilitation. The often-combined mentioning of these two concepts shows that they are heavily dependent on each other. With them even improving the other's diversity, and in turn that of the rest of the ecosystem. Within sub-tropical forests, the diversity of the vegetation within the strata is the most important. This is mainly attributed to the niche complementarity effect and facilitation. Where both processes create different niches and ensure that resources are fully utilised. Figure 3.4, shows the difference between the two forest types clearly. As European forests will slowly shift from temperate to subtropic, increasing the vegetational diversity within the different layers will become crucial.

4.3 What are the problems with urban water management?

The second and third sub-questions resulted in scientific and governmental literature. The combination of peer-reviewed and governmental reports strengthens the reliability that the found results reflect current problems that need to be addressed. This also shows that governmental bodies recognize the same challenges that different research has produced. This along with the recency of the literature shows that these problems are very currently pressing and still need to be addressed. It should also be stated that the government reports used academic literature as sources for their information. There were three problems to be found most pressing, namely: Impervious surfaces, infrastructure designed to make rainfall run off, and the combination of sewer and storm drain infrastructure. Impervious surfaces lead to precipitation not infiltrating into the soil and running off on the surface. The runoff of rainwater is mainly a mindset thing within city planning. Which leads to the water infrastructure that has been designed in a way that lets all the water run off, instead of capturing it. And so, rainwater mostly runs off into the domestic sewage systems. These systems are often in need of maintenance, which is already an investment problem for governments. And the increased rainfall intensity will only make them in further need of maintenance.

4.4 What are the problems with urban biodiversity?

A lot of research that was found but filtered out was concerned with the loss of specific species. And thus, not considered in this review. Those studies could have potentially resulted in more concrete barriers for the decline of a species. But this study focuses more on general biodiversity facilitation. And for that goal, the results do show a clear cause for biodiversity decline. The results show that the main drivers of biodiversity loss are habitat size reduction and the isolation of natural habitats. Both are caused by urbanisation, which in turn leads to the increase of impervious surfaces. Biodiversity remains a very complex concept to monitor, especially within urban areas. Habitat loss and fragmentation usually happen at the same time. And so, these processes strengthen the negative effects of each other, further worsening urban biodiversity decline.

Between the second and third research questions, we can see that there is a common problem. Namely, the creation and expansion of impervious surface area by human activity. This not only hinders water capture which in turn increases flood risk. But also contributes to habitat loss and fragmentation. Making this a very crucial element to tackle.

4.5 How can Bioinspiration help to adopt these processes?

The most unique and perhaps difficult sub-question was the fourth and last one. Because this question focussed more on methodologies and strategies that could assist and guide. Rather than concrete, factual, and scientific knowledge. So, in interpreting these results every researcher could interpret and apply some of the found sources differently. The low number of reviewable results can partly be explained by this study not including articles that focussed on Nature-Based Solutions. Especially with the search term of climate change, the most frequent results discussed NBS. The fact that there were far fewer peer-reviewed articles on this topic shows that this is a very new and still developing field. Full of potential for further investigation.

The literary search resulting in two books was also an interesting aspect. As these books have not been read in full, but only select chapters of these books have been read. Which gives the possibility that, if other chapters had been read, the results could have turned out slightly different. Nevertheless, there were clear similarities found across the literature, indicating that the results found are somewhat general. Mainly present were two central themes. These being: Natural inspiration should not simply be copied, but rather functions should be mimicked. And multifunctionality is key to both sustainability and resiliency. These themes can be easily applied to recommendations and future designs of cities. In this case, the alternative literature was very desirable because that is where concrete ideas about translating scientific knowledge to feasible recommendations for design came from. The limited result in this research-question indicate that there is still a lot of room for future research.

4.6 Expectations

The expectation was that a vast number of concepts and processes within temperate and subtropic forest ecosystems would be found, that could be beneficial to human-made cities. While there was a vast amount of literature on forest ecosystems. Most of this was on either a very specific part of the system, such as carbon-dioxide release, or very commercial projects such as production forest. Nevertheless, there was still a good amount of relevant literature that passed the initial criteria. Meaning that this assumption proved to be true. However, the review did show that there was more literature on temperate forests relative to sub-tropic forests. Due to reasons stated in paragraph 4.1.

In turn, the second and third sub-questions were expected to result in the discovery of barriers, limitations, and difficulties in implementing forest ecosystem concepts in European cities. It was also expected that there is a high complexity in forest ecosystem processes, which is similar to the complexity of problems in urban areas. This expectation turned out to be true. As different problems have been identified within urban areas, that are mostly intertwined and related. Meaning that there is indeed a complexity to these problems. However, the expectation of finding barriers did also come true. The research resulted in multiple barriers that act as key leverage points, to be identified.

Another important aspect to consider, is that there are certain limitations to creating recommendations that are generally applicable to multiple cities. This is because every city is different in at least a few, if not a lot of respects. While the causes found for the problems with Urban water management and biodiversity can be seen as universal. Their composition can vary from city to city. What this means is that every city has its specific conditions for implementing new measures. This is something that is omitted in this study because the aim was to devise general recommendations for European cities. Meaning that these recommendations can vary in their success rate and viability from city to city. This is in line with what was expected of the recommendations at the end of the introductory chapter.

4.7 Implications

The results show that biologists and their knowledge of ecosystems, in this case of the forest, are crucial to help with climate adaptation. Furthermore the interplay between translating scientific knowledge and design is key. Where biomimicry can play a crucial role in ensuring circularity and sustainability. As well as ensuring that the underlying natural mechanisms are mimicked. Instead of simply trying to copy the results of these mechanisms. The problems that the research has indicated also show key roles for government officials. Both local and national. Their role is mainly rooted in changing the way we think about and use water. As well as instilling more diverse vegetation. The combination of scientific knowledge and biomimicry is very relevant for solving solutions in a sustainable matter. As many articles focus on scientific knowledge or knowledge of problems within cities. None of the reports have combined different forest ecosystem processes in depth and related them to urban issues. Especially not with the addition of biomimicry. Meaning that this study can serve as a starting point for future studies, that also try to use natural inspiration to solve human problems.

The problems with Nature-Based Solutions have been outlined in the introduction. The bottom line however is that simply adding trees to an urban environment in the hopes that it will act as a forest will never work. There are many different complex interactions at play in forests. What has been observed in the results is that there are forest systems that could be mimicked in cities to have them perform better in terms of biodiversity and water management. These systems could then work in tandem with Nature-Based Solutions/urban trees to have the city function more like a forest than on its own. So, Nature-Based Solutions and mimicked forest processes will strengthen the success of one another. This study initially started with an idea for natural inspiration to solve particular problems. Meaning that the initial step of finding natural inspiration has not been performed here. There are however, many remaining issues to be solved. Which do not necessarily have preconceived ideas for natural inspiration. Therefore it is important to formulate a methodology of finding and implementing natural inspiration for a certain problem. This has to be done in a concrete and practical manner, to make this an widely applicable field.

5 Conclusion

This study started a search for finding alternative ways to address climate adaptation and sustainability in cities. Which currently are being tackled with Nature-Based Solutions. As shown in the introduction, Nature-Based Solutions have limitations that cannot be overcome with how cities function. Also, there are currently no universal measures against climate change for cities to adopt. Furthermore, the rate of climate change will only increase the need for mitigation measures. So, the proposed idea is to take inspiration from a sustainable, circular and climate adaptive system, namely forest ecosystems. Because this study focuses on European cities, temperate and sub-tropic forests have been looked at. Temperate forests reflect the current climate in most of Europe. Sub-tropic forests reflect the southern belt of Europe, but this climate is likely to expand upward with climate change.

5.1 Temperate and subtropic forest processes that can be mimicked to improve urban water management and biodiversity in European cities, for climate adaptation.

This led to the research question: ''*Which temperate and subtropic forest ecosystem processes can be mimicked to improve urban water management and biodiversity in European cities, for climate adaptation?*''. To facilitate this a literature study has been conducted. All with the goal to find and devise systemic improvements for urban water management and biodiversity. In which forest ecosystems could serve as inspiration for improvements. Improvements that are necessary for European cities. Two detailed recommendations toward this goal will be presented in the next chapter.

To answer the research question a set of 4 sub-questions have been devised:

- <u>How do temperate and subtropic forest ecosystems manage water & biodiversity?</u>
  The main finding for this sub-research question concerning water management is that rainfall is stored and valued as a great source of water. This was observed both in temperate and sub-tropic forests. Paired with this is the fact that in sub-tropic forests, different types of plants draw water from different sources and depths in the soil. Or even store water in their stems.
  For biodiversity in temperate forests, the interaction and diversity of floor cover and soil microbes are crucial. For not only can they benefit each other in mutualistic relationships, but they also play key roles in the facilitation of other organisms. In sub-tropical forests, it was found that the diversity of vegetation in the different layers is very important for overall biodiversity.

- <u>What are the problems with urban water management?</u>
  The biggest problems with urban water management are in the infrastructure and mindset of water drainage. Impervious surfaces lead to rainwater surface runoff. Furthermore, rainwater has been designed for to almost entirely run off, instead of being valued and captured. This runoff usually leads into the sewage system. Which coincidentally also has all of the domestic water runoff into it. Putting added pressure on their maintenance.

- <u>What are the problems with urban biodiversity?</u>
  Habitat loss and fragmentation are the main drivers of biodiversity decline. Both of which are caused by human expansion of the built environment. By which we claim habitats, that are then completely changed. This change usually results in many species not being able to use previously available surfaces. Coincidentally, increased fragmentation leads to organisms not being able to travel between habitats. These two processes usually happen concurrently and strengthen their negative effects.

- <u>How can Bioinspiration help to adopt these processes?</u>
  Bioinspiration has two main themes that are useful when translating scientific knowledge of biological systems into concrete solutions for humans. These are the idea that natural systems and functions should not be lazily copy-pasted. But the underlying mechanism can be mimicked to achieve a similar result. Paired with this is the realisation that nothing in nature has only one function. And so multifunctionality should be a key component of human design and society moving forward.

So, to answer the research question, the answers to these four sub-questions have to be combined. Concluding that water storage & diversity of vegetation in different layers are processes from temperate and subtropic forest ecosystems that can be mimicked and combined. These can be used to combat the problems of rainwater runoff and biodiversity decline in European cities, for climate adaptation. These problems also seem to have one common factor, namely that they are both partially caused by impervious surfaces. Luckily, these surfaces can be combated with the found concepts.

These answers can serve as the basis for national and local government officials as well as city planners. Both the forest ecosystems as well as the problems with water management and biodiversity in cities are very complex. The proposed answers also heavily imply and have their success rely on an interdisciplinary approach. Paired with the involvement of many different parties when implementing measures. Because even if the answer comes from one sector or party, the successful execution must come from many different ones.

5.2 Recommendations

Below there are a few recommendations more focused on research and the short term. After that, two recommendations will be discussed for the integration of forest ecosystem processes. To tackle climate adaptation and sustainability in European cities, for the future/long term.

Because of the newness of this field indicated by the low number of peer-reviewed articles focussing on bioinspiration this review served as a starting point. With the result being very promising as well as exciting. And so, a lot of research can still be done to find fitting systems in nature, and implement them to solve human problems. Future research should specifically focus on creating methodologies to best find and implement natural inspiration.

There is also the recommendation to only use integrative databases for finding peer-reviewed literature in the future. To limit the number of duplicate articles that could be found.

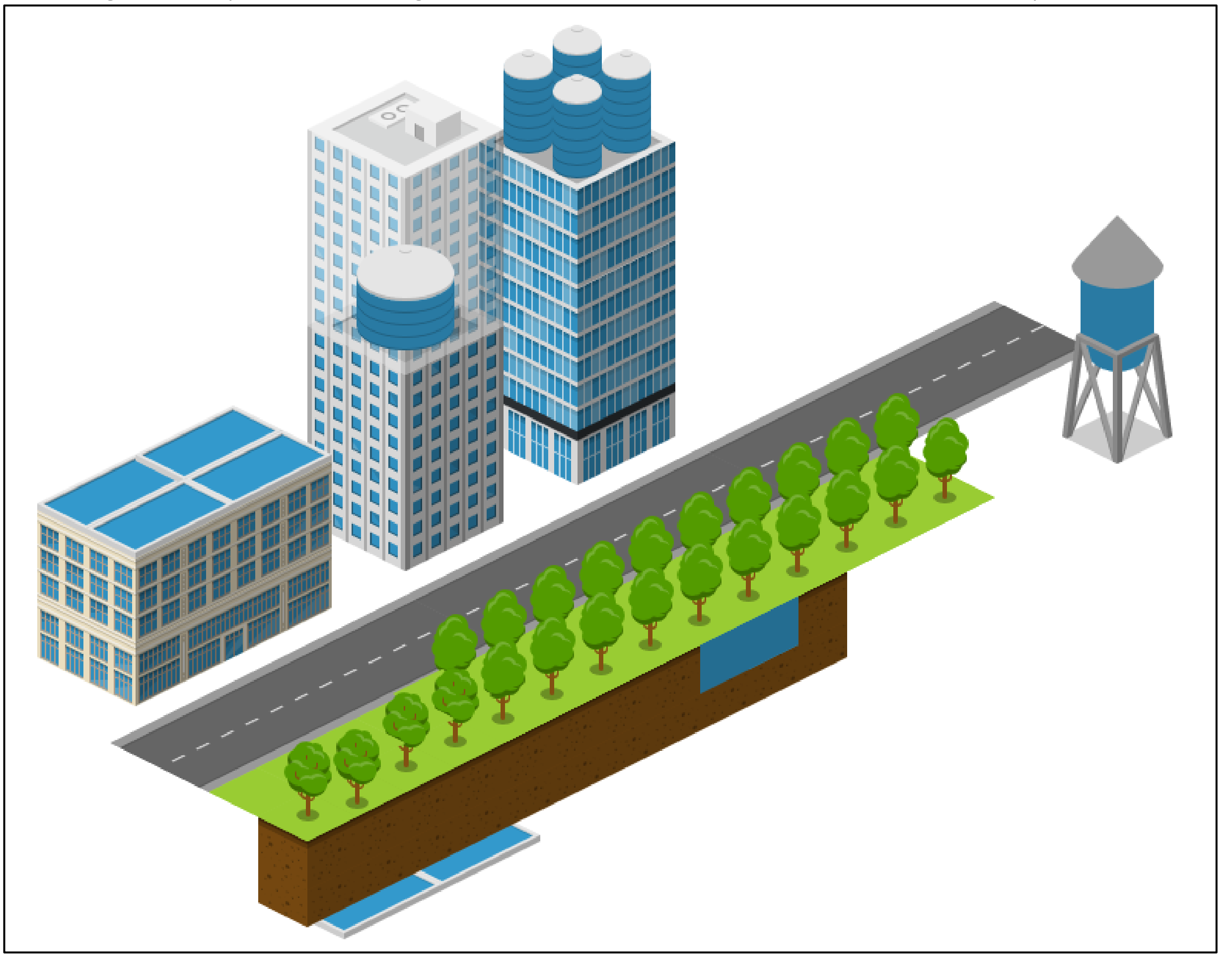
Every city is different in at least a few, if not a lot of respects. What this means is that every city has its specific conditions for implementing new measures. Meaning that there is still further research that can and should be done. It is also recommended to perform research on the specific conditions for a city when implementing new measures.

Nature-Based Solutions can still be used, they just must be designed differently. A city will never be a forest. And adding trees to a city will not suddenly make it a forest. However, the benefits that urban trees provide can be enhanced by having the city function more like a forest. This can be done by mimicking processes from forest ecosystems that will make the city function a bit more like a forest. And so, these two concepts can enhance the effectiveness of one another.

5.2.1 THE FIRST MAJOR RECOMMENDATION: Combine different types of rainwater catchment and storage on different levels.

This recommendation is about storing and valuing rainwater. This should be done at different levels in the vertical dimension, see figure 5.1. Catchments can be placed below and above the ground. This will enable dynamic water storage, improve resilience, and ensure availability in dry seasons. This will need to be combined with initially allocating the different water storage levels with a primary function. Just like different trees take up water from different depths. However, there needs to be the possibility for dynamic change in this functioning if needed. For example, the water stored directly below street level is used for watering the plants as well as providing dynamic ponds. But, when there is a drought occurrence the water that is stored at a deeper water level can then be used to water the plants. So one or multiple levels can act as a buffer. The dynamic water storage can also improve biodiversity. As there will be more water availability and the addition of micro habitats.

Afbeelding 5.1, example of waterstorage at different levels in the vertical dimension within a city.



This recommendation goes a step further from the current thinking about rainwater in cities. It also combats the idea that one water catchment solution can address all the problems at a certain location. To prepare the cities better for climate change it is important to integrate multiple catchments at the same sites. For this is it important for government officials to allow for this infrastructural change and promote this development. For which hydrologists, geologists, architects, city planners and land developers need to work together.

5.2.2 THE SECOND MAJOR RECOMMENDATION: Increase plant diversity and plant abundance among different strata.

The second recommendation is concerned with increasing the vegetational diversity and abundance among different strata, see figure 5.2. By doing this the total amount of fragmented habitats can be increased. As well as reducing the distance between fragmented habitats. This will enable organisms to travel between habitats more easily. Making them act as stepping stones. Paired with the fact that the total amount of plants will increase. Enabling more organism to find food and shelter. The key part is to not focus on one layer of improvement for plant species. But rather the increase of plants in different layers at the same site. With this being done at many different sites. For example, a green roof can be combined with more shrubs, bushes and a green façade. In all these layers it is important to use a variation of different plant species. And not just one or two. Nature-Based Solutions, for example tree planting, will not solve all the challenges we face on their own. For example, urban trees on their own are limited in their potential success. This is due to multiple factors mentioned before. However, the success of urban trees can be improved by adding a more diverse variation of plants in different layers. In this way the niche complementarity effect and facilitation can be stimulated in the urban environment.

Figure 5.2, example of adding more plants and increasing their diversity at different levels in the vertical dimension, within a city.

This recommendation goes a step further from the current thinking about urban green. As usually trees are planted as a with the idea of solving biodiversity problems in a city. To prepare cities better for climate change and biodiversity shifts, it is important to integrate a high diversity of plants at the same locations. For this is it important for government officials to allow and allocate space for vegetation. For which biologists, architects, city planners and land developers need to work together.

Both recommendations rely on the removal of impervious surfaces. And transforming them to semi- or fully permeable surfaces.

LITERATURE

Alberti, V., Alonso Raposo, M., Attardo, C., Auteri, D., Ribeiro Barranco, R., Silva, B. E., & Zulian, G. (2019). *The Future of Cities: Opportunities, challenges and the way forward* (No. JRC116711). Joint Research Centre (Seville site). Retrieved on 16 april 2022, from https://ideas.repec.org/p/ipt/iptwpa/jrc116711.html

Alfieri, L., Feyen, L., Dottori, F., & Bianchi, A. (2015). Ensemble flood risk assessment in Europe under high end climate scenarios. *Global Environmental Change*, *35*, 199-212.

Ali, A., & Yan, E. R. (2017). The forest strata-dependent relationship between biodiversity and aboveground biomass within a subtropical forest. *Forest Ecology and Management*, 401, 125-134.

Ali, A., Yan, E. R., Chen, H. Y., Chang, S. X., Zhao, Y. T., Yang, X. D., & Xu, M. S. (2016). Stand structural diversity rather than species diversity enhances aboveground carbon storage in secondary subtropical forests in Eastern China. *Biogeosciences*, 13(16), 4627-4635.

Axelsson, C., Soriani, S., Culligan, P., & Marcotullio, P. (2021). Urban policy adaptation toward managing increasing pluvial flooding events under climate change. *Journal of Environmental Planning and Management*, *64*(8), 1408-1427.

Baumeister, D., Tocke, R., Dwyer, J., Ritter, S., & Benyus, J. (2011). *Biomimicry resource handbook, A seedbank of knowledge and best practices* (pp. 139-158). The Biomimicry Institute.

Bayulken, B., Huisingh, D., & Fisher, P. M. (2021). How are nature-based solutions helping in the greening of cities in the context of crises such as climate change and pandemics? A comprehensive review. *Journal of Cleaner Production*, *288*, 125569.

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

Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature*. New York: Morrow.

Biomimicry Institute. (2015) *Biomimicry design lens*. Retrieved on 22 May 2022, from https://biomimicry.net/the-buzz/resources/biomimicry-designlens/

Brando, P. (2018). Tree height matters. *Nature Geoscience*, 11(6), 390-391.

Brinkmann, N., Eugster, W., Buchmann, N., & Kahmen, A. (2019). Species-specific differences in water uptake depth of mature temperate trees vary with water availability in the soil. *Plant Biology*, 21(1), 71-81.

Brown, A. D. (2016). *Looking Outward from the Village: The Contingencies of Soil Moisture on the Prehistoric Farmed Landscape Near Goodman Point Pueblo* [Master's Thesis, University of North Texas, Denton, TX]. UNT Digital Library. Retrieved on 18 May 2022, from https://digital.library.unt.edu/ark:/67531/metadc862755/.

Bruyninckx, H. (2021, September). *Sustainable cities: transforming Europe's urban landscapes* (report). European Environment Agency. Retrieved on 14 Januari 2022, from https://www.eea.europa.eu/articles/sustainable-cities-transforming-europes-urban-landscapes

Chen, Y.J., Bongers, F., Tomlinson, K., Fan, Z.X., Lin, H., Zhang, S.B. (2016). Time lags between crown and basal sap flows in tropical lianas and co-occurring trees. *Tree Physiology*, 36, 736– 747.

Chen, Y. J., Schnitzer, S. A., Zhang, Y. J., Fan, Z. X., Goldstein, G., Tomlinson, K. W., & Cao, K. F. (2017). Physiological regulation and efficient xylem water transport regulate diurnal water and carbon balances of tropical lianas. *Functional Ecology*, 31(2), 306-317.

Ciruzzi, D. M., & Loheide, S. P. (2021). Groundwater subsidizes tree growth and transpiration in sandy humid forests. *Ecohydrology*, 14(5), e2294.

Coelho, D. A., & Versos, C. A. (2011). A comparative analysis of six bionic design methods. *International Journal of Design Engineering*, *4*(2), 114-131.

Cortina-Segarra, J., García-Sánchez, I., Grace, M., Andrés, P., Baker, S., Bullock, C., & Ventocilla, J. L. (2021). Barriers to ecological restoration in Europe: expert perspectives. *Restoration Ecology*, 29(4), e13346.

Den Ouden, J., Muys, B., Mohren, G. M. J., & Verheyen, K. (2010). *Bosecologie en bosbeheer*. 1e . Acco Uitgeverij

Dziedzic, S., & Twardoch, A. (2021). European cities facing climate change: water management issue. *Builder*, 25.

EEA. (2021). EEA, Europe's changing climate hazards — an index-based interactive EEA report [WWW Document]. EEA Report no. 15/2021, 10.2800/458052

El Sioufi, M. (2010). Climate change and sustainable cities: major challenges facing cities and urban settlements in the coming decades. United Nations Human Settlement Programme (UN-HABITAT).

European Union. (2011). European Commission, Directorate-General for Regional Policy. Cities of tomorrow: Challenges, visions, ways forward. Publications Office of the European Union.

Fattorini, S., Mantoni, C., De Simoni, L., & Galassi, D. M. (2018). Island biogeography of insect conservation in urban green spaces. *Environmental Conservation*, *45*(1), 1-10.

Fenoglio, M. S., Calviño, A., González, E., Salvo, A., & Videla, M. (2021). Urbanisation drivers and underlying mechanisms of terrestrial insect diversity loss in cities. *Ecological Entomology*, *46*(4), 757-771.

Ferreira, C., Kalantari, Z., & Pereira, P. (2021). Liveable cities: Current environmental challenges and paths to urban sustainability. *Journal of environmental management*, *277*, 111458.

Ferreira, C., Walsh, R. P. D., Nunes, J. P. C., Steenhuis, T. S., Nunes, M., de Lima, J. L. M. P., & Ferreira, A. J. D. (2016). Impact of urban development on streamflow regime of a Portuguese peri-urban Mediterranean catchment. *Journal of soils and sediments*, 16(11), 2580-2593.

French, K. E. (2021). Designing Function-Specific Plant Systems for Sustainable Urban Development. *Frontiers in Sustainable Cities*, 3, 581764.

Freschet, G. T., Roumet, C., Comas, L. H., Weemstra, M., Bengough, A. G., Rewald, B., & Stokes, A. (2021). Root traits as drivers of plant and ecosystem functioning: current understanding, pitfalls and future research needs. *New Phytologist*, 232(3), 1123-1158.

Ganthaler, A., Marx, K., Beikircher, B., & Mayr, S. (2019). Are hydraulic patterns of lianas different from trees? New insights from Hedera helix. *Journal of experimental botany*, 70(10), 2811-2822.

Gawlik, B. M., Easton, P., Koop, S., Van Leeuwen, K., & Elelman, R. (Eds.). (2017). *Urban water atlas for Europe* (research report). Publications Office of the European Union. Retrieved on 22 March 2022, from https://op.europa.eu/o/opportal-service/download-handler?identifier=c296a413-24cc-11e7-b611-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=

Hildebrandt, A. (2020). Root-water relations and interactions in mixed forest settings. *Forest-Water Interactions*, 319-348.

Hilmers, T., Friess, N., Bässler, C., Heurich, M., Brandl, R., Pretzsch, H., & Müller, J. (2018). Biodiversity along temperate forest succession. *Journal of Applied Ecology*, 55(6), 2756-2766.

IPCC. (2022). Climate Change 2022: *Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (research report). Intergovernmental Panel on Climate Change. Retrieved on 1 March 2022, from https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

Kalantari, Z., Ferreira, C. S. S., Walsh, R. P. D., Ferreira, A. J. D., & Destouni, G. (2017). Urbanization development under climate change: Hydrological responses in a peri-urban Mediterranean catchment. *Land degradation & development*, 28(7), 2207-2221.

Kareiva, P. M., Marvier, M., & Silliman, B. R. (Eds.). P.15(2018). *Effective conservation science: data not dogma*. Oxford University Press.

Kennedy, E., Fecheyr-Lippens, D., Hsiung, B. K., Niewiarowski, P. H., & Kolodziej, M. (2015). Biomimicry: A path to sustainable innovation. *Design Issues*, *31*(3), 66-73.

KNMI. (2021, October). *Klimaatsignaal'21. Hoe het klimaat in Nederland snel verandert* (research report). Koninklijk Nederlands Meteoroloigisch Instituut. Retrieved on 20 March 2022, from https://cdn.knmi.nl/knmi/asc/klimaatsignaal21/KNMI_Klimaatsignaal21.pdf

Kovács, B., Tinya, F., & Ódor, P. (2017). Stand structural drivers of microclimate in mature temperate mixed forests. *Agricultural and Forest Meteorology*, *234*, 11-21.

Langeveld, J. G. (2019). *Afkoppelen: kansen en risico's van anders omgaan met hemelwater in de stad*. STOWA.

Liao, K. H. (2012). A theory on urban resilience to floods—a basis for alternative planning practices. *Ecology and society*, 17(4).

Lin, B. B., Ossola, A., Alberti, M., Andersson, E., Bai, X., Dobbs, C., & Tan, P. Y. (2021). Integrating solutions to adapt cities for climate change. *The Lancet Planetary Health*, 5(7), e479-e486.

Liu, Z., He, C., & Wu, J. (2016). The relationship between habitat loss and fragmentation during urbanization: an empirical evaluation from 16 world cities. *PLoS One*, 11(4), e0154613.

Maes, J., Teller, A., Erhard, M., Liquete, C., Braat, L., Berry, P., & Bidoglio, G. (2013). Mapping and Assessment of Ecosystems and their Services. *An analytical framework for ecosystem assessments under action*, *5*, 1-58.

Mason, N. W., de Bello, F., Doležal, J., & Lepš, J. (2011). Niche overlap reveals the effects of competition, disturbance and contrasting assembly processes in experimental grassland communities. *Journal of Ecology*, *99*(3), 788-796.

McGregor, I. R., Helcoski, R., Kunert, N., Tepley, A. J., Gonzalez-Akre, E. B., Herrmann, V., & Anderson-Teixeira, K. J. (2021). Tree height and leaf drought tolerance traits shape growth responses across droughts in a temperate broadleaf forest. *New Phytologist*, 231(2), 601-616.

Milieu Centraal. (n.d.). *Klimaatadaptatie: omgaan met klimaatverandering*. Milieu Centraal. Retrieved on 5 March 2022, from https://www.milieucentraal.nl/klimaat-en-aarde/klimaatverandering/klimaatadaptatie/

Nakahata, R. (2022). Time-varying response of fine root growth to soil temperature and soil moisture in cypress and deciduous oak forests. *Plant-Environment Interactions*, 3(2), 60-73.

Niemeläinen, E., Loimula, K., & Kuosa, H. (2015). Effects of pervious surfacing materials and subbase structures on stormwater ground infiltration. *Geotechnical Engineering for Infrastructure and Development*, 331-336.

Oldfield, E. E., Warren, R. J., Felson, A. J., & Bradford, M. A. (2013). Challenges and future directions in urban afforestation. *Journal of Applied Ecology*, 50(5), 1169-1177.

Oral, H. V., Carvalho, P., Gajewska, M., Ursino, N., Masi, F., Hullebusch, E. D. V., & Zimmermann, M. (2020). A review of nature-based solutions for urban water management in European circular cities: A critical assessment based on case studies and literature. *Blue-Green Systems*, *2*(1), 112-136.

Ouyang, L., He, W., Huang, K., Zhou, C., Gu, D., Huang, Y., & Zhao, P. (2019). Seasonal water use strategy of canopy tree species and possible implication for their coexistence in a subtropical secondary forest. *Ecohydrology*, 12(7), e2129.

Özerol, G., Dolman, N., Bormann, H., Bressers, H., Lulofs, K., & Böge, M. (2020). Urban water management and climate change adaptation: A self-assessment study by seven midsize cities in the North Sea Region. *Sustainable Cities and Society*, *55*, 102066.

Pajares, S., & Bohannan, B. J. (2016). Ecology of nitrogen fixing, nitrifying, and denitrifying microorganisms in tropical forest soils. *Frontiers in Microbiology*, 7, 1045.

Pataki, D. E., Alberti, M., Cadenasso, M. L., Felson, A. J., McDonnell, M. J., Pincetl, S., & Whitlow, T. H. (2021). The benefits and limits of urban tree planting for environmental and human health. *Frontiers in Ecology and Evolution*, 9, 155.

Pot, W. (2019). Anticipating the future in urban water management: An assessment of municipal investment decisions. *Water Resources Management*, *33*(4), 1297-1313.

Rog, I., Tague, C., Jakoby, G., Megidish, S., Yaakobi, A., Wagner, Y., & Klein, T. (2021). Interspecific soil water partitioning as a driver of increased productivity in a diverse mixed Mediterranean forest. *Journal of Geophysical Research: Biogeosciences*, 126(9), e2021JG006382.

Spicer, M. E., Mellor, H., & Carson, W. P. (2020). Seeing beyond the trees: a comparison of tropical and temperate plant growth forms and their vertical distribution. *Ecology*, 101(4), e02974.

Sultan Washington. (n.d.). *Stormwater*. City of Sultan. Retrieved on 21 May 2022, from https://www.ci.sultan.wa.us/187/Stormwater

Tinya, F., Kovács, B., Bidló, A., Dima, B., Király, I., Kutszegi, G., & Ódor, P. (2021). Environmental drivers of forest biodiversity in temperate mixed forests–A multi-taxon approach. *Science of the Total Environment*, *795*, 148720.

United Nations. (2019). *World Urbanization Prospects: The 2018 Revision, Online Edition* (research report). Department of Economic and Social Affairs, Population Division. Retrieved on 29 March 2022, from https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf.

U.S. Environmental Protection Agency. (2003). Protecting Water Quality from Urban Runoff. Document No. EPA 841-F-03-003

Valliere, J. M., Wong, W. S., Nevill, P. G., Zhong, H., & Dixon, K. W. (2020). Preparing for the worst: Utilizing stress-tolerant soil microbial communities to aid ecological restoration in the Anthropocene. *Ecological Solutions and Evidence*, 1(2), e12027.

Westall, F., & Brack, A. (2018). The importance of water for life. *Space Science Reviews*, 214(2), 1-23.

Xie, J., Sun, G., Chu, H. S., Liu, J., McNulty, S. G., Noormets, A., & Chen, J. (2014). Long-term variability in the water budget and its controls in an oak-dominated temperate forest. *Hydrological Processes*, 28(25), 6054-6066.

Yu, D., Yanxu, L., & Bojie, F. (2019). Urban growth simulation guided by ecological constraints in Beijing city: Methods and implications for spatial planning. *Journal of environmental management*, 243, 402-410.

Yuan, Z., Ali, A., Ruiz-Benito, P., Jucker, T., Mori, A. S., Wang, S., & Loreau, M. (2020). Above-and below-ground biodiversity jointly regulate temperate forest multifunctionality along a local-scale environmental gradient. *Journal of Ecology*, 108(5), 2012-2024.

Yuan, Z., Ali, A., Loreau, M., Ding, F., Liu, S., Sanaei, A., & Le Bagousse-Pinguet, Y. (2021). Divergent above-and below-ground biodiversity pathways mediate disturbance impacts on temperate forest multifunctionality. *Global Change Biology*, 27(12), 2883-2894.

Zari, M. P. (2018). *Regenerative urban design and ecosystem biomimicry* (pp. 16-43). Routledge.

Zhang, X., Chen, N., Sheng, H., Ip, C., Yang, L., Chen, Y., & Niyogi, D. (2019). Urban drought challenge to 2030 sustainable development goals. *Science of the Total Environment*, 693, 133536.

Zhang, Y., Chen, H. Y., & Taylor, A. R. (2017). Positive species diversity and above-ground biomass relationships are ubiquitous across forest strata despite interference from overstorey trees. *Functional Ecology*, 31(2), 419-426.

Zhao, P., Cornelis, W., Tang, X., Zhao, P., & Tang, J. (2020). Does damming streams alter the water use strategies of riparian trees? A case study in a subtropic climate. *Land Degradation & Development*, 31(8), 927-938.

APPENDIXES

Appendix I Example of source matric for literature.

Title	Subject/ topic	Date of publication	APA	Peer-reviewed? Yes/No	Core concept	Link
Species-specific differences in water uptake depth of mature temperate trees vary with water availability in the soil	Forest water management	2019	Brinkmann, N., Eugster, W., Buchmann, N., & Kahmen, A. (2019). Species-specific differences in water uptake depth of mature temperate trees vary with water availability in the soil. Plant Biology, 21(1), 71-81.	yes	more drought-resistant tree species are able to shift their water uptake to deeper soil layers when water availability in the topsoil is becoming scarce. different water uptake depths	https://onlinelibrary-wiley-com.proxy.library.uu.nl/doi/10.1111/plb.12907
Long-term variability in the water budget and its controls in an oak-dominated temperate forest	Forest water management	2014	Xie, J., Sun, G., Chu, H. S., Liu, J., McNulty, S. G., Noormets, A., ... & Chen, J. (2014). Long-term variability in the water budget and its controls in an oak-dominated temperate forest. Hydrological Processes, 28(25), 6054-6066.	yes	Soil water storage and maintaining shallow groundwater levels are essential as the climate changes and drought occurance increases.	https://onlinelibrary-wiley-com.aeres.idm.oclc.org/doi/10.1002/hyp.10079
Physiological regulation and efficient xylem water transport regulate diurnal water and carbon balances of tropical lianas	Forest water management	2017	Chen, Y. J., Schnitzer, S. A., Zhang, Y. J., Fan, Z. X., Goldstein, G., Tomlinson, K. W., ... & Cao, K. F. (2017). Physiological regulation and efficient xylem water transport regulate diurnal water and carbon balances of tropical lianas. *Functional Ecology*, *31* (2), 306-317.	yes	lianas rely heavily on soil groundwater because of transpiration rates and trees have water stored in upper trunk compartments.	https://besjournals-onlinelibrary-wiley-com.aeres.idm.oclc.org/doi/10.1111/1365-2435.12724