Arthropods communities on green roofs in Brussels: Influence of the roof vegetationa and landscape context

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Résumé

Face à la crise de la biodiversité que traverse notre planète, les infrastructures vertes sont une des solutions proposées pour l'enrayer. Ce travail s'intéresse à une infrastructure en particulier : les toitures vertes car elles peuvent fournir un habitat et des ressources alimentaires pour la faune et flore des villes. Les scientifiques essaient actuellement de comprendre les variables influençant la biodiversité sur ces toitures.

Cette étude se focalise sur Bruxelles, une des capitales les plus vertes d'Europe. Un inventaire des toitures vertes existantes a été réalisé. Leurs connexions éventuelles au réseau écologique bruxellois ont été étudiées. Afin de comprendre les facteurs influençant la biodiversité des toitures, neuf toitures vertes ont été sélectionnées et des captures d'arthropodes ont été réalisés dessus, avec une attention particulière pour les abeilles. Différentes variables, liées au toit lui-même ou à l'environnement à proximité, ont été testés comme variables explicatives de la diversité en arthropodes sur les toitures vertes. Les assemblages d'arthropodes et communautés d'abeilles ont aussi été analysés.

Les toitures vertes de Bruxelles pourraient être connectées au réseau écologique. La plupart d'entre elles se trouvent d'ailleurs dans les zones les plus imperméabilisées de la ville, déficitaires en espaces verts. Mais seule une faible proportion de la faune bruxelloise bénéficie de ces infrastructures, principalement des espèces généralistes. On retrouve des communautés et assemblages homogènes sur les différents toits. Pour être réellement efficaces, les toitures vertes devraient être adaptées au contexte local bruxellois. En effet, c'est la surface d'espaces ouverts qui influence le plus la diversité en arthropodes et abeilles sur les toits. Les autres variables étudiées ont aussi une influence sur les toitures vertes mais leur rôle individuel n'a pas pu être déterminé.

Mots-clés : toiture verte, réseau écologique, arthropode, Apoidea

Summary

In order to mitigate the biodiversity crisis, green infrastructures are one of the suggested solutions, including green roofs. This kind of roof can provide habitat and food resource for the fauna and flora of cities. Scientists are now trying to understand the factors improving the biodiversity on those infrastructures.

This study focuses on Brussels, one of the greener capitals in Europe. We inventory the existing green roofs. Their possible connections to the ecological network were analysed. To understand the factors improving the biodiversity, we sampled nine green roofs and collected arthropods with three colours pan traps, with a focus on bee species. We tested different variables, linked to the green roof itself or to the surrounding environment.

The green roofs in Brussels could be connected to the ecological network. Most of the existing green roofs are located in the most impervious areas, deficient in green spaces. But only a small proportion of the fauna, especially common and generalist species, benefit from those structures. To be really efficient, green roofs have to be adapted to the local environment. We detected homogeneous arthropod assemblages and bee communities on the roofs. The surface of open areas is the major variable influencing the diversity of arthropods and bees on the roof. Other variables have an influence on the biodiversity but they were too linked together to highlight their individual role.

Keywords: green roof, ecological network, arthropod, Apoidea

Table of content

This master thesis is divided in two parts. The first one, "thematic introduction", provides a synthesis of the literature on green roofs and their biodiversity. It set the scene for the applied study and helps to frame our scientific hypothesis. The second part, "study", is the report on the personal applied study realized during the thesis period. This second part is written as a scientific article.

Thematic introduction

Since the last decades, our planet has faced a major biodiversity crisis, with a high rate of extinctions (Barnosky *et al.*, 2011). One of the causes is the global urbanization and the replacement of natural ecosystems by impervious surfaces. It leads to a decrease of the environmental quality (Getter & Rowe, 2006). To solve those problems, scientists suggest different solutions. Green infrastructures help mitigate biodiversity loss in urban environment. Green roofs are an essential component of those infrastructures (Loftness & Haase, 2013). They can provide a habitat for the wildlife and increase the greening of the cities (Berardi *et al.*, 2014).

Green roofs

Green roofs can be defined as roofs with substrate and vegetation on their final layer (Blank *et al*, 2013; Berardi *et al.*, 2014). They can be also called living roofs, ecoroofs or brown roofs (Francis and Lorimer, 2011). They have a long history behind them. The Babylon's hanging gardens are one of the first examples. This kind of roof was also found in the Roman architecture. Moreover, the Northern European countries have used green roofs since a long time, especially for thermal insulation. The rest of Europe has rediscovered this technology with the Swiss architect Le Corbusier in the twentieth century (Berardi *et al.*, 2014). The technology was modernized and intensively used in Germany in the 1960s (Gedge & Kadas, 2005). France and Switzerland followed the trend. Then it has spread all around the world (Berardi *et al.*, 2014). Now green roofs are becoming common in most of the big cities in the world.

Green roofs are made with different layers. From the vegetation to the roof, there are usually a soil layer with vegetation, a course mat, a drainage mat, a root barrier and a protection course (Figure 1) (CSTC, 2006). The soil layer is the support for the plants and the other ones are present to protect the roof from damages caused by water or vegetation.

Green roofs can be classified in two categories: extensive or intensive roofs. An intermediary class, semi-intensive, is sometimes added. The limits of those categories change following the authors. Extensive roofs have generally less than 10 cm of substrate, semi-intensive roofs have between 10 and 25 cm of substrate and intensive roofs have more than 25 cm of substrate (CSTC, 2006). Another classification was also suggested by Madre *et al* (2013). They classified green roofs on the basis of the vegetation cover in three classes: muscinal roofs composed with mosses and *Sedum sp.*, herbaceous roofs covered on more than 20% of the surface with herbaceous plants and arbustive roofs with 20% of the surface composed by woody plants.

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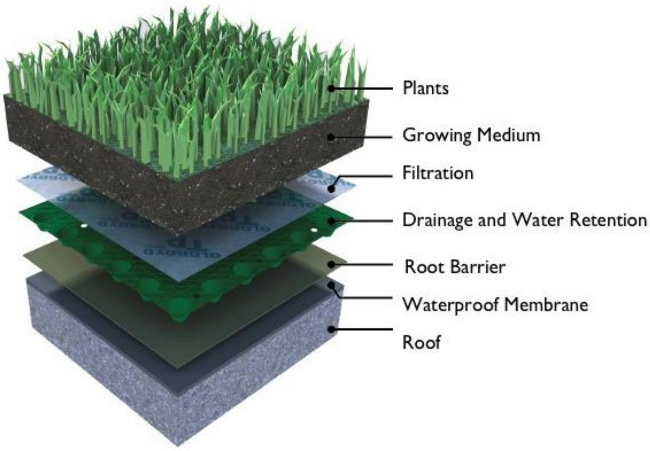

Figure 1: Schematization of the layers of a green roof (Source: http://www.gardenista.com/wp-content/uploads/2015/04/fields/green-roof-membrane-layers-gardenista-700x550.jpg)

The benefits from green roofs are multiple (Getter & Rowe, 2006; Berardi *et al.*, 2014; Vijayaraghavan, 2016). They reduce the energy consumption of the building by increasing the insulation, they mitigate the urban heat island effect with the evapotranspiration of the plants and decrease the air pollution. They extend the lifespan of the roof (Blank *et al*, 2013). They are also well known for the water management in cities. During rainy periods, water is stocked in the soil and part of it is stored in the plants or transpired back in the atmosphere. Those phenomena delay the runoff (Vijayaraghavan, 2016). Green roofs can play a role in sound insulation and noise reduction. Finally, they can be a habitat for the fauna and flora (Berardi *et al.*, 2014). But some of those ecosystem services are very theoretical or they were studied on few green roofs. It is sometimes hard to extrapolate them citywide.

All those benefits are interesting. But improving all the ecosystem services simultaneously is impossible (Dusza *et al.,* 2016). During the conception of the green roofs, it is important to highlight which services are important for the owner of the roof. On this basis, substrate and plants selection can be done in order to reach this goal.

If more and more people understand the benefits from green roofs, there are still barriers against the green roof achievement. The green roof cost is higher from 10% to 14% than a normal flat roof (Carter & Keeler 2008; The Green Roof Centre, 2017). The economic benefits of this technology only come after 20 years, when the flat roof has to be replaced and the green roof is still reliable (David Evans & Associates Inc. and ECONorthwest, 2008). But, without the incentives, the net present value is negative. Therefore, people are less attracted by this technology (Carter & Keeler 2008; Claus & Rousseau, 2012). All those cost-benefit analyses show that the social benefits from green roofs (air pollution, water management, noise reduction…) are higher than the social costs. Another problem is to estimate exactly those social benefits (Berardi *et al.*, 2014).

Green roofs and biodiversity

One of the ecosystem services of green roofs is its capacity to support biodiversity. Biodiversity or biological diversity was defined by the Convention on Biological Diversity as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (United Nations, 1992). Studies show the link between biodiversity and nature’s benefits for people. A biodiversity loss will lead to decrease those benefits (Isbell *et al.*, 2017).

Green roofs were first studied for their interest in water management and energy reduction (Blank *et al.*, 2013). In the last years, more attentions were focused on the biodiversity benefits of those roofs. They can provide habitats and food to many species (Oberndorfer *et al*., 2007; Schindler, Griffith & Jones, 2011). They are often inaccessible and thus offer an undisturbed habitat (Getter & Rowe; 2008). Studies show the presence of birds, spiders, insects, lizards and bats on green roofs (Fernandez-Canero & Gonzalez-Redondo, 2010; Williams *et al.*, 2014; Parkins & Clark, 2015). They can be used as habitat by the bees (Colla, Willis & Packer, 2009; Tonietto et *al.*, 2011). Even rare invertebrates can be found on those structures (Kadas, 2006). Indeed, arthropods can access to green roofs by different mechanisms and timings. They can arrive during the installation of the roof or after, by natural process or human intervention. It is schematized in figure 2 (MacIvor & Ksiazek, 2015). Arthropods provide pest control in the cities and they can be decomposer (Hunter & Hunter, 2008).

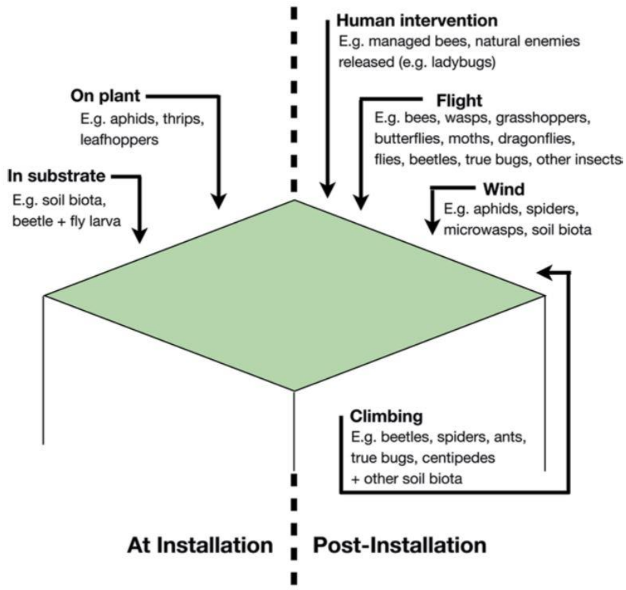

Figure 2: Arthropods colonization on green roofs (Source: MacIvor and Ksiazek, 2015)

Scientists try to understand the factors improving biodiversity on green roofs. Plant diversity on the roof is a key element for improving the biodiversity. Increasing this diversity leads to a rise of ecosystem services on the green roof (Cook-Patton & Bauerle, 2012; Lundholm, 2015a). It might also increase the capacity for hosting living organisms (Cook-Patton & Bauerle, 2012). Having more plant diversity, and thus more feeding resources, will attract more animals (Srivastava and Lawton, 1998; Braaker *et al.*, 2016). Another advantage of increasing plant diversity is that the roof could support more specialist species (Fetridge *et al.*, 2008). Finally, higher plant diversity will enhance the stability of resources. The animal communities have more chance to persist on the long term (Brenneisen, 2004). Plants diversity on the roof is not the only factor improving global biodiversity. Plant composition is also important (Cook-Patton & Bauerle, 2012). Each plant has its own characteristics and will add different effects on the community. An easy way to select the plants is to rely on the functional traits of the plants. Those traits are easy to measure and they are linked to the roof's ecosystem services. Depending on the goal of the roof, the right plants can be chosen to improve the selected ecosystem services (Lundholm, & Williams, 2015; Lundholm *et al.*, 2015). It is also important to have a spatial heterogeneity on the roof to create a diversity of habitats and thus attract a higher animal diversity (Brenneisen, 2003; Braaker *et al.*, 2016). The spatial connectivity between green roofs or between a roof and a green space is also a factor improving the biodiversity of the roof. Short distances between roofs or roofs and green spaces enhance the number of animal species (Thuring & Grant, 2015; Braaker *et al.*, 2016). But it depends on the living organisms. For example, the community of insects with a low mobility is influenced by the surrounding landscape. On the other hand, the community of insects with a greater mobility is more impacted by the connectivity to another green space (Thuring & Grant, 2015).

If the factors influencing biodiversity on green roofs begin to be understood, the practical applications are often far away from the theory. Green roofs companies mostly place extensive roofs because they are lighter and cheaper (Getter and Rowe, 2008). The plant selection is based on practical arguments to ensure a fast cover of the roof and its lifespan. The usual criteria are the aesthetic aspect of the plant, the local environment, the plant characteristics (an easy propagation, a rapid establishment and a high ground cover density) and the substrate. Therefore, succulent plants, especially *Sedum sp.*, are usually used on green roofs. They are adapted for the harsh conditions on green roofs with their mechanisms limiting transpiration and their ability to store water. They are often used in monoculture (Getter & Rowe, 2006). Companies also reused the plant mix of other companies or their selection techniques. It leads to an uniformization of the plants on green roofs (Oberndorfer *et al.*, 2007). But even a roof with only *Sedum sp.* can be used as food resources or habitat for arthropods (Kadas, 2006; MacIvor *et al.*, 2015). Ecologists and architects are working together to promote the biodiversity on those structures (Thuring & Grant, 2015).

The first advice to architects and roof owners is to clearly define on what purpose the green roof is made. Indeed, it is impossible to promote all ecosystem services at the same time (Dusza *et al.*, 2016). If biodiversity is a priority, green roof designers can summarize information about the plant and fauna autecology, how they interact in the ecosystem and with the surroundings of the roof (Dunster & Coffman; 2015). An easier way to promote biodiversity is to use local soil and to vary the depth of substrate. It will create heterogeneity in the plant architecture, which will offer more habitats for fauna (Brenneisen, 2003). Adding woods and rocks on the roof will also create new habitats for the fauna. In the plant selection, a way to enhance biodiversity is to take local fauna into account and select plants that will attract them (Thuring &

Grant, 2015). Attracting pollinators could be a goal for a green roof. In that case, adding woods could promote bees. Another solution is to add potted flowers on the roof (Tonietto et *al.*, 2011). Green roofs are seen as unchanging and wildness is often excluded from their design. But their aspect will usually change over time. Let the time do its job and allow spontaneous dynamics are also recommended solutions for the biodiversity (Lundholm, 2015b). Moreover, each roof will have to face perturbations. To avoid a collapse of the system, it is important to take them into account and even anticipate them (Dunster & Coffman; 2015). Finally, solar panels are not incompatible with green roofs. With their presences, they will create new shadow areas and thus heterogeneity on the roof. It might promote biodiversity (Gedge & Kadas, 2005). Most of those advices can be found in publicly available guidelines (Marie de Paris, 2012; City of Toronto, 2013; Natureparif, 2013).

If the biodiversity above the ground starts to be understood on green roofs, the underground life is largely unknown. The few researches on this thematic show that the soil of green roofs is occupied by a large variety of living organisms. Some researchers also found mycorrhizae in the soil. But this field could be more explored (Thuring & Grant, 2015).

Green roofs could also be an entrance door or a propagation channel for invasive species. If no case is reported yet, the risk exists. To limit this risk, it is important to maintain a dense vegetation cover on the green roof (Kinlock, Schindler & Gurevitch, 2015).

Green roofs and analogue habitats

To limit the biodiversity crisis and the human impacts, ecologists are trying to recreate threatened habitats in natural areas. In the last few years, urban and industrial environments were also investigated as potential candidates for restoration. Indeed, natural areas will not be sufficient to maintain viable populations of the majority of threatened species (Lundholm & Richardson, 2010). Therefore, reconciliation ecology promotes the protection of species in highly altered and anthropogenic areas (Rosenzweig, 2003). And green roofs could be a way to support threatened species in cities (Brenneisen, 2006; Francis & Lorimer, 2011). The concept of analogue habitat is promoted to this goal. Anthropogenic habitats could support and preserve biodiversity because they can have structural and functional resemblances to natural ecosystems. It is important to evaluate the novelty of an ecosystem from a “specie-eye view” (Lundholm & Richardson, 2010). Some novel habitats for human can be perceived similar to natural ecosystems by the fauna and flora. That is why anthropogenic habitats are often recolonized by wild plants. Patches of hard surfaces have similarities with natural habitats such as rock outcrops, cliffs and shingles beaches, for example. But two conditions have to be filled to allow natural recolonizations. Firstly, there must be biotic and abiotic similarities between the human habitat and some natural areas. And secondly, dispersal limitations have to be overcome. Therefore, those highly altered habitats are usually colonized by generalists and opportunistic species. A part of native species failed to settle because of dispersal limitation and a high propagule pressure from others species in the anthropogenic habitat (Lundholm & Richardson, 2010).

Analogue habitats can already exist in cities, like hard surfaces. Or human can create those habitats in the city (Francis & Lorimer, 2011). An example is the use of brown roofs, mostly in the United Kingdom. They mimic brownfields which are lands used for housing or industries but abandoned in the last years. Those landscapes were recolonized by a broad range of fauna and flora (Lorimer, 2008). They hosted threatened species and are some of the most species diverse habitat in the United Kingdom (Kadas, 2006). But the urbanization is growing and those areas are now reused to build dwellings. A solution to avoid the entire destruction of this habitat is its restoration on green roofs (Ishimatsu & Ito, 2013). Researches start to highlight this potential and illustrate it with successful experiments (Kadas, 2006; Molineux *et al.*, 2015). Brown roofs are already included in some guidelines for green roofs (City of Toronto, 2013).

Next to environmental filters, another barrier is the public acceptation. Indeed, people see green roofs as always green. But, when you are trying to mimic natural ecosystem, the vegetation changes overtime and is sometimes brown. It is a challenge to convince the people of the aesthetic aspect of those habitats. But it is also a way to reconnect urban people to nature (Dunnett & Kingsbury, 2008).

Green roofs and native plants

If the factors influencing the biodiversity on green roofs are starting to be understood, there is still an outstanding question: do we have to use native plants or can we put exotic plants on green roofs? Native plants are usually promoted for different reasons. Firstly, an aesthetic reason because native plants are already included in the landscape. They are also seen as more adapted to the local conditions. They will use all the available resources and require less maintenance. They have evolved with the climate and are able to face perturbations. Moreover, they are already included in the ecosystem and their presence will increase the biodiversity. Finally, the probability of native plants becoming invasive species is less important than non-native plants. But, if all those reasons seem valid, there is a lack of scientific evidences (Dunnett, 2006; Butler *et al.*, 2012).

Other researches have also demonstrated the potential of non-native plants for the local biodiversity. Indeed, native pollinators are able to use flower resources of non-native plants (Matteson *et al.*, 2008). Scientists have also highlighted the importance of the structure, functional traits and phenological properties of the vegetation for the promotion of biodiversity. Those factors seem more determinant than the origin of the plants (Oberndorfer *et al.*, 2007). Finally, the conditions on a green roof and on the ground level are not similar. Therefore, a native plant will not necessarily have a better survival rate than a non-native plant. Researches have shown that those two factors are not correlated (Kinlock *et al.*, 2015).

The question of using native plants or not stays open. It will mainly depend of the green roof goal. If the flora or native ecosystem protection is the aim of the green roof, using native plants is a priority. Non-native plants can be used on green roofs, for example, to support native plants. The use of native plants can also help to reconnect people to the surrounding environment, especially if those plants can be found in the parks or in the habitats around the city.

Green roofs and ecological network

Green roof can be a support for the biodiversity protection and they will be more powerful if they are included in an ecological network. This concept was defined as "a coherent system of natural and/or semi-natural landscape elements that is configured and managed with the objective of maintaining or restoring ecological functions as a means to conserve biodiversity while also providing appropriate opportunities for the sustainable use of natural resources" (Bennett, 2004). An ecological network is generally divided in different components (Figure 3). The first one is the core area where the biodiversity conservation is the priority. Around this area, a buffer zone is often identified to protect it from external damages. Human activities can take part in this zone. The core areas are linked together with corridors. In those corridors, biodiversity actions are set up to maintain viable connections (Bennett, 2004).

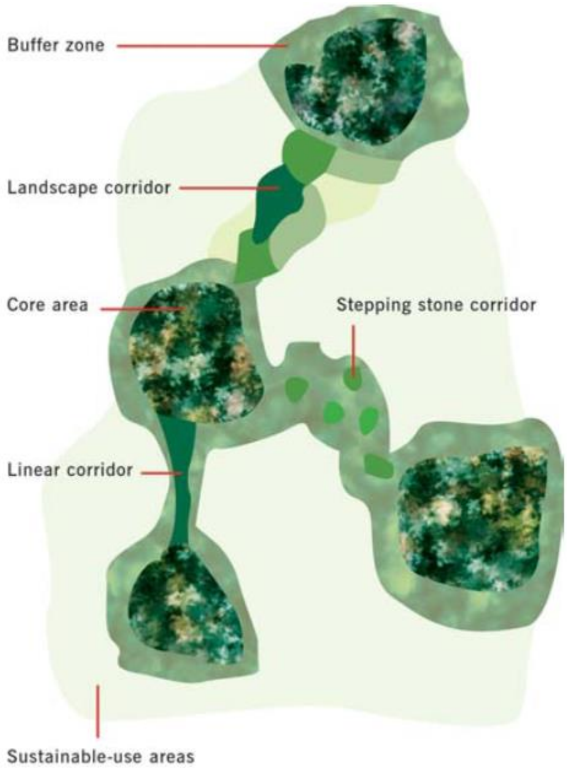

Figure 3: Ecological network (Source: Bennett, 2004)

Researches have shown the importance of the connectivity between two green roofs or between a roof and a green space. A short distance will enhance the number of animal species on the green roof (Thuring & Grant, 2015; Braaker et *al*, 2016). Indeed, green roofs can be used as stepping-stones by the fauna and flora, especially if it is a roof designed for the biodiversity (Thuring & Grant, 2015). Green roofs could be included in the ecological network of a city as part of corridors and could help the different living organisms to reach the center of the city.

Brussels

The region of Brussels, hereafter Brussels, is the capital of Belgium (Europe). It occupies a territory of 16 138 ha, divided in 19 communes (Bruxelles Environnement, 2012). In 2016, more than 1,18 million of inhabitants, a tenth of the Belgian population, live in this city (Statistics Belgium, 2017). 356 000 commuters are added every day. Therefore, Brussels is one of the economic lugs of Belgium (Bruxelles Environnement, 2012).

Brussels is covered on more than 54% of its surface by vegetation, particularly by closed environments (44,3%). Open environments are accounted for only 9,7% of the green areas. The vegetation coverage of Brussels is mapped in the Figure 4. Publicly available spaces represent 35% of the green areas, with a total of 3 037 ha. Each citizen has theoretically 26m² of green spaces for himself. But there is a huge difference between the center of the city, deficient in green areas, and the outskirts, largely covered by vegetation (Figure 4). Brussels has also lost a large part of green spaces during the last years. It can be calculated on the basis of the waterproofing rate. Between 1955 and 2006, this rate raised from 13% to 37% (Bruxelles Environnement, 2012).

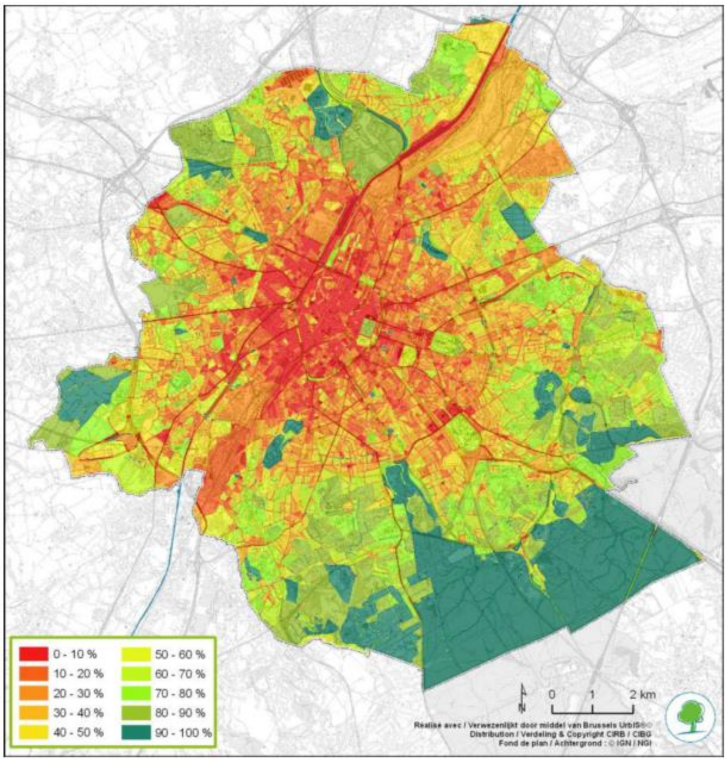

Figure 4: Vegetation coverage of Brussels
(Source : Bruxelles Environnement – IBGE, 2012 – on the basis of Van den Voorde et al., 2010)

A large part of the green spaces in Brussels are protected by law. In total, half of the green spaces have a protection status. Different protection statues exist, like Natura 2000 sites or natural reserves. Each status has its own rules and protection level (Bruxelles Environnement, 2012).

With the aim of protecting green spaces and reconnecting them together, an ecological network was created. Green areas were classified in three categories: the central zones, the development zones and the connecting zones (Figure 5). The central zones include the biggest parks, the wetlands, the Woluwe valley and most of the wooded areas. Smaller parks, gardens, rural areas, cemeteries and brownfields are gathered in the development zones. Finally, the channel, areas inside housing blocks and the vegetation along roads and railways are included in the connecting zones (Van den Balck, 2011). But in practice, this ecological network is subject to problems. There are still discontinuities and barriers for the fauna and flora in Brussels due to the fragmentation of the habitats. Some zones are also faced to management problems (Bruxelles Environnement, 2012). Most of the central and developing zones are not in the city center. And connecting zones are also missing in this part of the city.

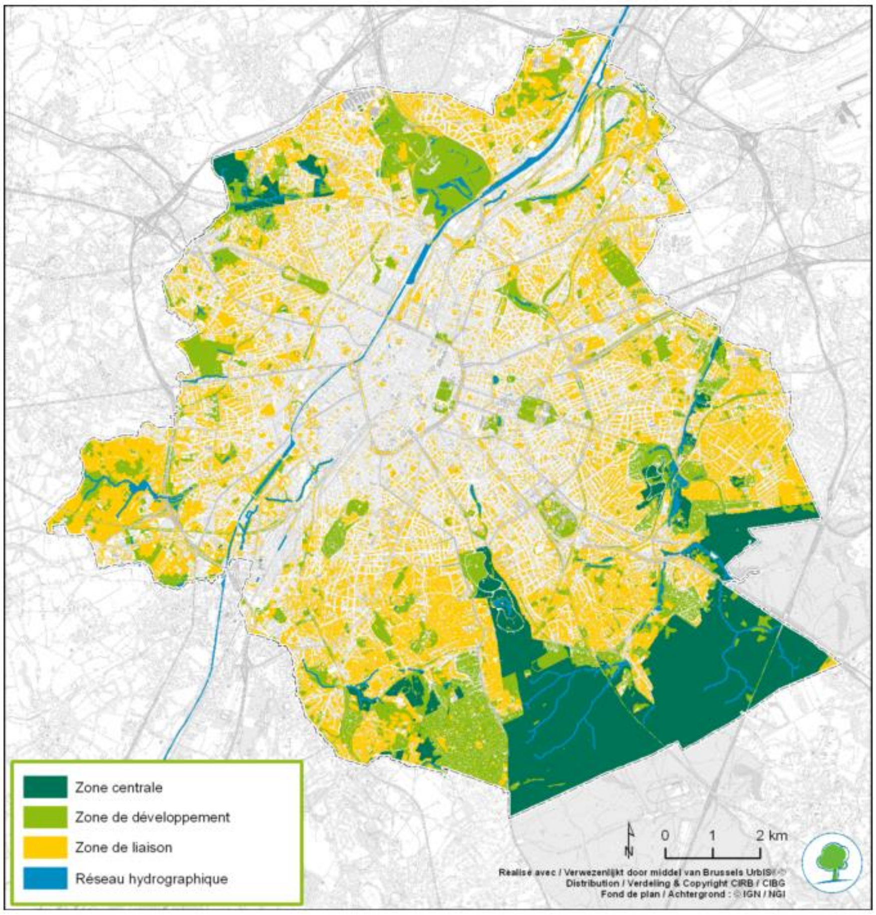

Figure 5: Ecological network of Brussels
(Source :Bruxelles Environnement - IBGE – on the basis of Van den Balck (2011))

The biodiversity in Brussels is mainly affected by the human omnipresence. Humans select some species, fight against others and unconsciously promote, or not, animals and plants. It leads to an overrepresentation of opportunistic species and a high number of exotic species in this city. But Brussels is not poor in biodiversity and local species. Almost 800 Belgian plant species and 45 mammal species can be found in the city. Even rare species are present in Brussels. Particular habitats are also a richness in this capital (Bruxelles Environnement, 2012).

In term of ecological landscape, Brussels can be divided in four subregions: the subregion densely urbanized, the subregion influenced by the forest, the subregion influenced by the agricultural landscape and the wet subregion. Each region has its own characteristics which influence the diversity and abundance of the different species (Bruxelles Environnement, 2012).

In 2012, the Brussels government highlighted five major challenges for the city. Environment is one of them, especially the improvement of the quality of life and the green spaces. The other challenges are related to the population growth, the employment, the poverty and the internationalization. All those challenges are, of course, linked together (Bruxelles Environnement, 2012).

Brussels and green roofs

Several cities have biodiversity policies which include green roofs (Mairie de Paris, 2012; City of Toronto, 2013; Williams *et al,* 2014). Brussels is one of them. In April 2016, a Nature Plan was written for this city. It gives the guidelines for the environment policy until 2020. It is divided in seven objectives and 27 actions. The third and fourth actions are related to green roofs. Brussels wants to increase the greening of buildings and to allow public access to green roofs. A focus is put on public buildings in deficit areas in green spaces. Green roofs will be promoted and, if it is possible, public access to those roofs will be realized (Bruxelles Environnement, 2016).

In this Nature Plan, the government wants to improve the ecological network in Brussels. As explained earlier, there is a lack of green spaces in the city center. There are also discontinuities in the connecting zones in this part of Brussels (Bruxelles Environnement, 2016). Green roofs could fill this absence. They can provide habitat for the wildlife and could be used as connecting zones to reach the center of the city. If the roof has a significant surface, it could also be included in the developing zones. But green roofs are not included in the definition of the ecological network in Brussels yet.

Since 2006, green roofs are an obligation for new buildings or renovations in Brussels. The Urban Planning Regional Regulation states that, if the size of the flat roof is bigger than 100 square meters and if the roof is totally or partially inaccessible, the roof has to become a green roof (Gouvernement de la Région de Bruxelles-Capitale, 2006). An incentive was also given for the establishment of green roofs in Brussels until 2015. Biname (2011) has studied the green roof market between 2007 and 2011 in this city. The market has grown during this period but latest discussions with market players indicate a decrease in the market with the end of the incentives.

The law does not specify the characteristics of a green roof (height of substrate, type of plants…). Architects and property developers are doing the minimum and a large part of green roofs in Brussels is composed of a thin substrate layer and *Sedum sp*. as plants. And without the incentive, people are less attracted by this technology, as demonstrated in Flanders (Claus & Rousseau, 2012). Finally, Brussels has already developed documents about the green roofs and how maximizing biodiversity on it (Bruxelles Environnement, 2015). But roofs owners and architects have sometimes difficulties to find this scientific information (Claus & Rousseau, 2012).

If the nature in Brussels is already well studied, the biodiversity on green roofs is unknown. Studies about this topic were conducted in other countries, such as France, the United Kingdom and Germany (Brenneisen, 2006; Köhler & Poll, 2010; Madre *et al.*, 2014). Neither study has focus on the biodiversity of green roofs in the case of Brussels.

Study

Introduction

Biodiversity faces a major crisis with a high rate of extinctions partly due to global urbanization (Barnosky *et al.*, 2011; Getter & Rowe, 2006). Green infrastructures, including green roofs, help mitigate biodiversity loss in urban environment (Loftness & Haase, 2013). Green roofs can be defined as roofs with substrate and vegetation on their final layer (Blank *et al*, 2013; Berardi *et al.*, 2014). Green roofs can be classified in two categories: extensive or intensive roofs. An intermediary class, semi-intensive, is sometimes added. The limits of those categories change following the authors and are based on the height of substrate, usually less than 10 cm for extensive green roofs and more than 25 cm for intensive green roofs (CSTC, 2006).

Green roofs can provide lots of ecosystem services (Getter & Rowe, 2006; Blank *et al*, 2013; Berardi *et al.*, 2014; Vijayaraghavan, 2016). One of them is the capacity to support biodiversity (Berardi *et al.*, 2014; Vijayaraghavan, 2016). But some of those ecosystem services are very theoretical or they were studied on few green roofs. Extrapolate them to a whole city is a hazardous exercise. And all those ecosystem services cannot be maximized together (Dusza *et al,* 2016). Finally, there are still barriers against the green roof achievement. The cost, higher than a normal flat roof, is one of the main barriers especially without incentives (Carter & Keeler, 2008; Claus & Rousseau, 2012).

Green roofs were first studied for their interest in water management and energy reduction (Blank *et al.*, 2013). In the last years, more attentions were focused on the biodiversity benefits of those roofs. They can provide habitats and food for many species (Oberndorfer *et al*., 2007). Studies show the presence of birds, spiders, insects, lizards and bats on green roofs (Fernandez-Canero & Gonzalez-Redondo, 2010; Williams *et al.*, 2014; Parkins & Clark, 2015).

Different factors influence the biodiversity on green roofs. Some are linked to the roof itself and others to the environment around the roof (Lundholm, 2015a; Cook-Patton & Bauerle, 2012; Braaker *et al.*, 2016; Brenneisen, 2003; Thuring & Grant, 2015).

Plant diversity on the roof is a key element for improving green roofs capacity to support biodiversity. High plant richness enhances the fauna richness and other ecosystem services (Lundholm, 2015a). The roof can also support more specialist species and the different communities are more stable on the long-term (Cook-Patton & Bauerle, 2012; Lundholm, 2015a). The substrate depth is linked to the diversity of vegetation. A higher depth allows the establishment of a higher diversity of plants (Oberndorfer *et al*., 2007). The plant selection is also important (Cook-Patton & Bauerle, 2012). Each plant has its own characteristics and will add different effects on the community. An easy way to select the plants is to rely on the functional traits of the plants (Lundholm, & Williams, 2015; Lundholm, 2015a). It is also important to have a spatial heterogeneity on the roof to create a diversity of habitats (Braaker *et al.*, 2016; Brenneisen, 2003). Next to the green roof variables, the surrounding environment influences the biodiversity on the roof. The connectivity between green roofs or between a roof and a green space is a factor improving the fauna richness (Thuring & Grant, 2015; Braaker *et al.*, 2016). Green roofs can be used as stepping-stones by the fauna and flora, especially if it is designed for the biodiversity (Thuring & Grant, 2015).

To study the impacts of those variables, arthropods are often used as indicators (MacIvor & Ksiazek, 2010). Indeed, plants are usually planted or sowed on green roofs, when insects colonize green roofs spontaneously (Schindler, Griffith & Jones, 2011). A focus is often made on bees for the role in pollination and their recent decline (Colla, Willis & Packer, 2009; Potts *et al.*, 2010; Tonietto *et al.*, 2011).

If the factors influencing biodiversity on green roofs start to be understood, the practical applications are often far away from the theory. Green roofs companies mostly place extensive roofs. The plant selection is often only based on practical arguments to ensure a fast cover of the roof and its lifespan (Getter & Rowe, 2006). People see green roofs as always green and unchanging. It is a challenge to convince people of the interest of native plants or analogue habitats when the plants become brown. But it is also a way to reconnect urban people to nature (Dunnett & Kingsbury, 2008).

Several cities have biodiversity policies including green roofs (Mairie de Paris, 2012; City of Toronto, 2013; Williams *et al,* 2014). Brussels (Belgium, Western Europe) is one of them with the Nature Plan in 2016. The government wants to improve the ecological network in Brussels. Indeed, there is a lack of green spaces in the city center. There are also discontinuities in the connecting zones of the network in this part of Brussels (Bruxelles Environnement, 2016). Green roofs could fill this absence. Since 2006, green roofs are an obligation for new buildings or renovations in Brussels (Gouvernement de la Région de Bruxelles-Capitale, 2006). Green roof market has grown between 2007 and 2011 in Brussels (Binamé, 2011) but it seems to stagnate since the last years.

The nature in Brussels is already well studied but the biodiversity on green roofs is unknown. Studies about this topic were conducted in other countries, such as France, the United Kingdom and Germany (Brenneisen, 2006; Köhler & Poll, 2010; Madre *et al.*, 2014). Neither study has focus on the biodiversity of green roofs in the case of Brussels. And Brussels has the particularity to be one of the greener capitals in Europe with more than the half of the city covered with vegetation (Bruxelles Environnement, 2012). That could influence the arthropods diversity on green roofs.

Research questions

The aim of this study is to characterize the diversity of existing green roofs in Brussels and the arthropods diversity they support. Specifically, we ask two questions:

- What is the diversity of existing green roofs in Brussels and could they be included in the ecological network? Therefore, an inventory of the existing green roofs was realized and their localisations in the urban ecological network were studied.
- What are the major roof and landscape characteristics influencing the arthropods diversity and species communities on green roofs? Arthropods samplings were conducted on different green roofs to highlight the major variables. A focus is also made on bee species because of their role in pollination and their recent decline (Potts *et al.*, 2010).

Materials and Methods

Green roofs and ecological network

Existing green roofs in Brussels were localized based on information collected with different actors, mostly communes, public organisms and some private owners (full list available in Annex 1). Information was mainly extracted from the inventory of the exemplary buildings in Brussels and the listing of the incentives given before 2016. Information about the localisation of green roofs was compiled and each green roof was mapped with ArcMap (ArcGis, version 10.3.1, 2015 Esri) on orthoimages of Brussels in 2012 (Brussels Institute for Statistics, 2012). The localisations of the found green roofs were checked with Google Maps and with the orthoimages of 2012. The type of green roof (extensive, semi-intensive, intensive, extensive and intensive, unknown) was also added to the file.

To analyse the integration of green roofs in the Brussels ecological network, the connections between two roofs or between a roof and a green space were investigated. Those distances were measured with the tool "Near (Analysis)" on ArcMap. The term "green spaces" includes all the parks, forests, natural reserves and Natura 2000 areas because they are often central zones of the Brussels ecological network (Bruxelles Environnement, 2012). The number of roofs, the total area of roofs and the proportion of area occupied by green roofs were also calculated in each zone of the map of permeability on Excel ®.

The number of green roofs with a distance smaller than 100m to the first green space and to the first green roof was calculated on Excel ®. The same calculation was conducted with the distance of 1000m. Those distances are based on the foraging ranges of small bees, around 100-200m, and large bees, more than 1000m (Zurbuchen *et al.*, 2010).

Arthropod assemblages and bee communities

Green roofs for arthropod survey were selected in order to be representative of the diversity of landscape situations in Brussels with areas deficient in green spaces and others with a high proportion of green spaces. The selection is based on the proportion of impervious surface within the roof vicinity. If the proportion of impervious surfaces is important, it is assumed that the proportion of vegetation is low around the roof. A map of the impervious surfaces was made by the Analysis and Statistics Brussels Institute (IBSA) from the study of Vanhuysse *et al* (2006). It divided Brussels in five zones: zone 1 is composed with less than 40% of impervious surfaces, zone 2 with impervious surfaces between 40% and 50% of the zone, zone 3 with an impervious surface between 50% and 70%, zone 4 with impervious surfaces between 70% and 80% and zone 5 with more than 80% of impervious surfaces. A latest map of this indicator was not found. It is assumed that the distribution of impervious surfaces has not changed significantly between 2006 and 2017. The selection of the roofs is based on this map.

The main constraint for the selection was to have an easy and regular access to the green roof. Therefore, public buildings were privileged.

On the basis of this information, nine roofs were selected. They are located in four of the five permeability zones. Only extensive roofs were selected because they represent the most important category of green roofs (Getter & Rowe, 2006). Two roofs, GP and HM, are located in the zone 1 (less than 40% of impervious surfaces). Three roofs, CB, CG and ML, are located in the zone 2 (between 40% and 50% of impervious surfaces). Two roofs, BH and CA, are located in the zone 3 (between 50% and 70% of impervious surfaces) and the last two roofs, VP and BG, are located in the zone 5 (more than 80% of impervious surfaces). More information about those roofs and a map of them can be found in Annex 2.

Arthropods were collected with three colours (blue, white, yellow) pan traps (14,7 cm diameter and 4,8 cm height) (Westphal *et al.*, 2008; Vrdoljak & Samways, 2012). The three bowls were placed in a triangle formation with 50cm between each of them on the selected green roofs. They were filled with water and soap to break the water surface tension (Disney *et al.*, 1982). A trio of colours is the sampling unit. Two units were placed on each roof. The pan traps were placed in the morning on the roof and were collected in the late afternoon. A total of six days of sampling was done for eight of the roofs. It was done once a week for each roof during the six weeks of sampling. The first two weeks were between the 18th and the 28th of April 2017 and the second two weeks between the 22th of May and the 2nd of June. Protections against birds were added on the pan traps for the last two weeks, between the 26th of June and the 7th of July. Those protections were made with nets against birds and two iron wire arcs. For the last roof, CG, only five sampling days were done because of the destruction of all the pan traps by birds on the first of June. Three other bowls were lost on different green roofs. Captured arthropods were kept in alcohol at 70 %.

Arthropods were divided in two categories based on their body size: bigger than 5mm and the smaller ones. Arthropods smaller than 5mm were identified to the family if it was possible or, otherwise, to the order. Individuals bigger than 5mm were prepared with the method describe by Mouret *et al.* (2007) and identified to the family with Mignon *et al.* (2016). The identifications of the individuals from the class Arachnida, the class Collembola and the superfamily Aphidoidea were stopped at those classification levels and considered as the same level as the family identifications. Individuals of the superfamily Apoidea were identified to the species. Identifications to the family were checked by an expert from Gembloux Agro-Bio Tech (University of Liege) and identifications of Apoidea were checked by experts from Gembloux Agro-Bio Tech (University of Liege) and from the Royal Belgian Institute of Natural Sciences. The arthropod richness and abundance, the bee richness and abundance were calculated with Excel ®. The richness is the number of different families for the arthropods or different species for the bees. Information about the bees, if they were generalist or specialist and how they forage for food were collected on the site http://www.atlashymenoptera.net/.

Variables linked the roof itself and others linked to the surrounding environment were collected to understand which variable influences the arthropod assemblages and bee communities.

For the green roof characteristics, the size of the roof was selected as variable. The size was measured with Arcmap. The height of the roof was also selected and calculated as the number of building floors under the roof. For each roof, a phytosociological survey was made with the percentage of cover for each plant species. The plant richness (the number of different plant species), the cover of sedum on the roof and the sedum richness (the number of different sedum species) were calculated on the basis of this survey. A plant Shannon index (Shannon, 1948) was also calculated for each roof with R, version 3.3.2, (R Development Core Team., 2016) in RStudio (Version 1.0.136, 2016 RStudio, Inc.) and the vegan statistical package (Oksanen, 2015).

For the landscape characteristics, green spaces in a circle of 100 m from the roof were mapped. They were divided in four categories:

- Open area: with no tree or shrub, mostly grass.
- Semi-open area: presence of trees or shrubs but without a closed canopy. Private gardens are a large part of those areas with some parks.
- Wooded area: a closed canopy of trees. It is composed of parks and urban forests.
- Isolated trees in the street.

All those categories were mapped on ArcMap with Google Maps and the orthoimage of Brussels in 2012 (Brussels Institute for Statistics, 2012). The total area of each type of surface was calculated. The correlations between all the environmental variables were studied on R.

The distance between the green roof and the nearest green space was measured with the tool "Near (Analysis)" on ArcMap. The same method was used for the distance between the green roofs and the nearest green roof.

To allow a comparison between the roofs, a standardization of the arthropod abundance was conducted to have the same amount of sampling days. For the statistical analysis, only the insects identified to the family were analysed, the others were excluded from the analysis.

Two levels of analyses were made. The first level is at the arthropod families or equivalent. The influence of environmental variable on the arthropod families' richness and on the arthropod assemblages was made with the abundance on families' level. Families present on only one or two roofs and with less than ten individuals were excluded for this level. The second level is at the bee species. The analyses used for the families' level were also made but with the abundance of bee species. Green roofs with less than ten bees in total were excluded from the analyses for the bee level.

To understand the influence of each variable on arthropod diversity on green roofs, the correlations between the arthropod richness, the arthropod abundance and the environmental variables were analysed. Then a generalized linear model (GLM) was made between the arthropod richness and the environmental variables (Dobson & Barnett, 2008). A Poisson distribution was used. Another GLM was done between the total arthropod abundance and the environmental variables, with a Poisson distribution.

The second research question is related to the influence of the environmental variables on the arthropod assemblages on the nine green roofs. Therefore, a principal coordinate analysis (PCoA) was conducted on the arthropod families' abundances to highlight the different assemblages (Legendre & Legendre, 1998). The square root of a Bray-Curtis model was chosen for the dissimilarity matrix (Faith *et al.*, 1987). The environmental variables were fitted to this analysis to understand their influences.

The same analyses were made on the bee level, to see if the same conclusions are conducted with the bee species. The correlations between the bee richness, the bee abundance and the environmental variables were analysed. A GLM was made between the bee richness and the environmental variables. A Poisson distribution was used. Another GLM was done between the total bee abundance and the environmental variables, with a Poisson distribution. A PCoA was also made with the bee abundance, with the square root of a Bray-Curtis model as the dissimilarity matrix. The environmental variables were fitted to this analysis to understand their influences on the bee communities.

All those calculations were made on R with the vegan statistical package (Borcard *et al.*, 2011; Oksanen, 2015). For the graphic representation, the packages corrplot and maptools were used (Grosjean, Ibanez & Etienne, 2014; Taiyun & Viliam, 2016).

Results

Inventory of the green roofs

During the inventory, 453 potential green roofs were found. After verification on Google Earth and the orthoimages, 269 roofs were real green roofs (Figure 4). A total area of 10.04 ha is covered by green roofs in Brussels, smaller than the 3 037 ha of green spaces open to the public.

Most of the green roofs found in Brussels were extensive green roofs and only six percent were intensive (Table 1).

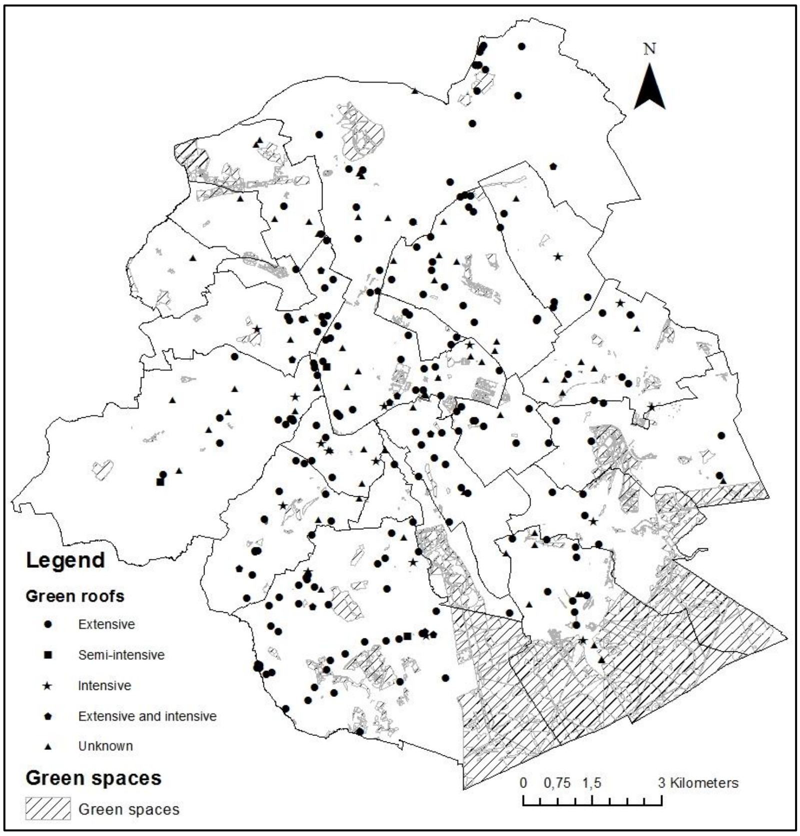

Figure 4 : Map of the green roofs in Brussels

Brussels is covered with a majority of small green roofs. Forty percent of the green roofs have 100m² or less of area and only 9% of the roofs are more than 1000m². The minimal area in this inventory is 4m² and the maximal is 8741m². The average area is 359m².

Table 1: Number of roofs for each type of green roofs

Type of green roof	***Number of roofs***	***Percentage of roofs (%)***
Extensive and intensive	11	4
Extensive	171	65
Unknown	69	24
Intensive	15	6
Semi-intensive	3	1
Total	269	100

Green roofs and ecological network

The average distance between a green roof and the nearest green space is 319m. The median distance is 262m (Figure 5). The minimal distance is 0,4m and the maximal distance to a green space is 1039m. Eighteen percent of green roofs are less than 100m away from a green space and 99% of roofs are less than 1000m away.

The average distance between two green roofs is 265 m. The median distance is 219m (Figure 5). The minimal distance is 0,4m and the maximal distance to a roof is 1647m. Twenty-six percent of green roofs are less than 100m away from another roof and 99% of roofs are less than 1000m away.

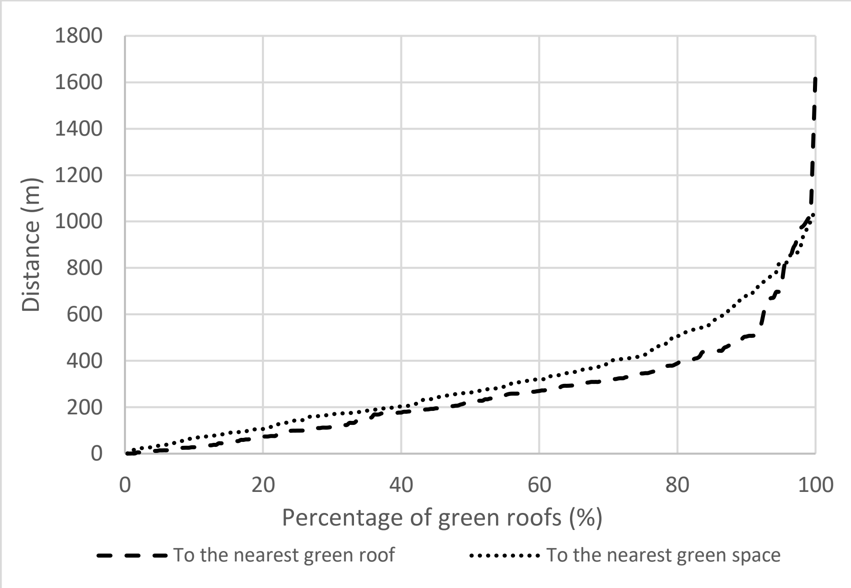

Figure 5: Cumulative percent curve of the green roofs based on the distance to the nearest green roof or green spaces

Most of the green roofs are present in high impervious areas (Table 2). 51 % of the roofs are surrounded by areas with more than 70% of impervious surfaces and occupy an area of 3.87ha.

Table 2: Proportion of green roofs per class of permeability

Classes of percentage of impervious surfaces	*Percentage of green roofs (%)*	*Total green roof area (ha)*	*Proportion of the zone area occupied by green roofs (%)*
<40%	18	1.79	0.03
40-50%	10	1.15	0.08
50-70%	21	3.23	0.08
70-80%	27	2.22	0.10
>80	24	1.67	0.11
Total	100	10.04	0.06

Selected green roofs

Six of the selected green roofs for the arthropods survey (BG, CG, GP, HM, ML and VP) are characterized with more than 50% of the roof surface covered with *Sedum sp.* and a low plant richness between 4 and 9 species. BH and CA are characterized with a low coverage of *Sedum sp.* (30 % for BH and 38% for CA) and high plants richness (15 species for BH and 23 for CA).

Three roofs (BG, BH and VP) are surrounded by more than 1.2 ha of green spaces (all categories confused). CA, CG and HM are surrounded with an area of green spaces between 0.5 and 1 ha. Finally, CB, GP and ML have less than 0.5ha of green spaces around them.

Almost all the roofs are on the first or second building floor. Only BG and VP are higher. All of those roofs are not used by the roof owner or occupants.

Arthropod sampling

During the sampling period, the pan traps stayed seven hours and four minutes in average on the roofs.

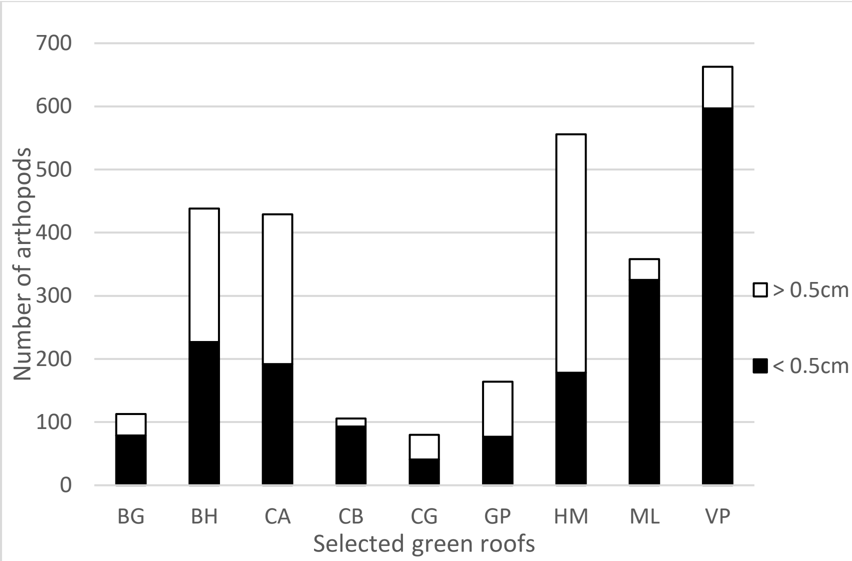

Figure 6: Number of collected insects by green roof and size

A total of 2913 individuals were collected (Figure 6). 1098 are bigger than 0.5mm and 1809 are smaller than 0.5mm. 1413 individuals are identified to the family. Forty families or equivalent were found. Forty-four percent of the individuals are from the order Diptera and 10% from Hymenoptera. The abundance of each taxa is available in Annex 3.

In the Apoidea super family, 179 individuals were collected from 32 species. Only 6 individuals are not identified to the species.

Green roofs and landscape variables

There are high positive correlations (Figure 7) between the size of the roof and the sedum richness (0.64), between the open areas surface and the plant richness (0.65), between the open areas surface and the plant Shannon index (0.79), the semi-open areas surface and the distance to green roofs (0.61), between the isolated trees surface and the sedum richness (0.63), between the plant richness and the distance to a green roof (0.63) and between the plant richness and the plant Shannon index. There is also a high negative correlation between the plant richness and the distance to green spaces (-0.70).

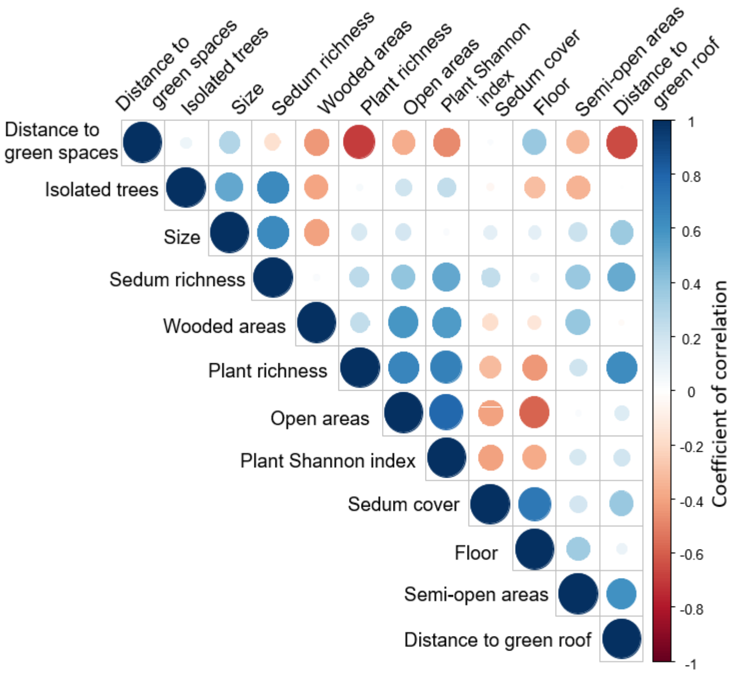

Figure 7: Correlation between the environmental variables

The study of the correlations between the arthropod richness and the other variables indicates high positive correlations with the open areas surface (0.74), with the wooded areas surface (0.56) and with the plant richness (0.66) (Table 3). It is also negatively correlated with the distance to green spaces (-0.52). The GLM indicates that the open areas surface (p-value=0.008) have a significant positive influence and the wooded areas surface (p-value=0.026) have a significant negative influence on the arthropod richness. Four of the variables (the plant Shannon index, the distance to green space and to a green roof and the number of floors) are considered as linear combinations (LC) of the others. It means that their influences are already included in the other variables.

The arthropod abundance is highly correlated with the open areas surface (0.69), the wooded areas surface (0.52), the sedum richness (0.55), the plant Shannon index (0.54) and the vegetation Shannon index (0.59) (Table 3). The GLM indicates that eight of the variables have a high significant influence on the arthropod abundance. Five other variables are considered as linear combinations of the others.

Table 3: Results of the correlations and the GLM on the arthropod richness and arthropod abundance
*('***' = p-value<0.001, '**'=p-value< 0.01, '*'=p-value< 0.05, '.' p-value< 0.1 and LC= linear combinaisons)*

	Arthropod richness			Arthropod abundance		
Variables	**Correlation coefficient**	**GLM coefficient**	**GLM p-value**	**Correlation coefficient**	**GLM coefficient**	**GLM p-value**
Size	0.08	-0.002	0.089 .	0.16	-0.002967	<0.001***
Open areas surface	0.74	12.06	0.008 **	0.69	16.96	<0.001***
Semi-open areas surface	0.37	1.803	0.110	0.37	1.873	<0.001***
Wooded areas surface	0.56	-2.404	0.026 *	0.52	-3.506	<0.001***
Isolated trees surface	0.30	-16.34	0.061 .	0.02	-25.50	<0.001***
Plant richness	0.66	-0.075	0.074 .	0.31	-0.1348	<0.001***
Sedum cover	0.01	0.008	0.057 .	-0.23	0.003721	<0.001***
Sedum richness	0.18	0.058	0.746	0.55	0.5035	<0.001***
Plant Shannon index	0.42	LC	LC	0.54	LC	LC
Floors	-0.40	LC	LC	-0.30	LC	LC
Distance to green spaces	-0.52	LC	LC	-0.27	LC	LC
Distance to a green roof	0.50	LC	LC	0.31	LC	LC

The study of the correlations between the bee richness and the other variables (Table 4) indicates high positive correlations with the open areas surface (0.91), the wooded areas surface (0.54), the plant richness (0.85), the plant Shannon index (0.83) and the vegetation Shannon index (0.67). It is also negatively correlated with the number of floors (-0.77) and the distance to green spaces (-0.53). The GLM indicates that none of the variables have a significant impact on the bee richness. Eight of the variables are considered as linear combinations of the others.

Table 4: Results of the correlations and the GLM on the bee richness and bee abundance
*('***' = p-value<0.001, '**'=p-value< 0.01, '*'=p-value< 0.05, '.' p-value< 0.1 and LC= linear combinaisons)*

	Bee richness			Bee abundance		
Variables	**Correlation coefficient**	**GLM coefficient**	**GLM p-value**	**Correlation coefficient**	**GLM coefficient**	**GLM p-value**
Size	0.13	-0.006	0.290	0.40	-0.006	0.057 .
Open areas surface	0.91	14.96	0.081 .	0.87	14.02	0.003 **
Semi-open areas surface	0.24	3.018	0.179	-0.03	2.353	0.060 .
Wooded areas surface	0.54	-3.320	0.220	0.22	-3.446	0.020 *
Isolated trees surface	0.03	28.08	0.400	0.31	28.41	0.120
Plant richness	0.85	LC	LC	0.82	LC	LC
Sedum cover	-0.18	LC	LC	0.01	LC	LC
Sedum richness	0.15	LC	LC	0.18	LC	LC
Plant Shannon index	0.83	LC	LC	0.63	LC	LC
Floors	-0.77	LC	LC	-0.84	LC	LC
Distance to green spaces	-0.53	LC	LC	-0.34	LC	LC
Distance to a green roof	0.23	LC	LC	0.22	LC	LC

The bee abundance is highly correlated with the open areas surface (0.87), the plant richness (0.82), the plant Shannon index (0.63) and the vegetation Shannon index (0.62). The abundance is negatively correlated with the number of floors (-0.84). The GLM indicates that the open areas surface (p-value=0.003) have a significant positive influence and the wooded areas surface (p-value=0.020) have a significant negative influence on the bee abundance. Eight of the variables are considered as linear combinations of the others.

Arthropod assemblages

The first axis of the PCoA includes 27,4% of the variation and the second axis 17.4% (Figure 8). The axis 1 represents a gradient of the arthropod richness. Green roofs with a higher richness are on the left of the graph and the roofs with a smaller richness on the right. The differentiation based on the axis 2 is due to families found only or in majority on those roofs, such as *Miridae* or *Collembola.*

The correlation circle represents how the environmental variables can explain the assemblage structure. But only the open area surface has a high significant influence on those assemblages (p-value = 0.009), negatively correlated with the axis 1. The selected green roofs with a high arthropod richness are those with the biggest surface of open areas. It is also correlated with the plant richness, the sedum richness and the plant Shannon index. The number of floors and the distance to green spaces are positively correlated with the axis 1. The selected green roofs with a lower richness are on a higher height of the building. All the information on the PCoA can be found in Annex 4.

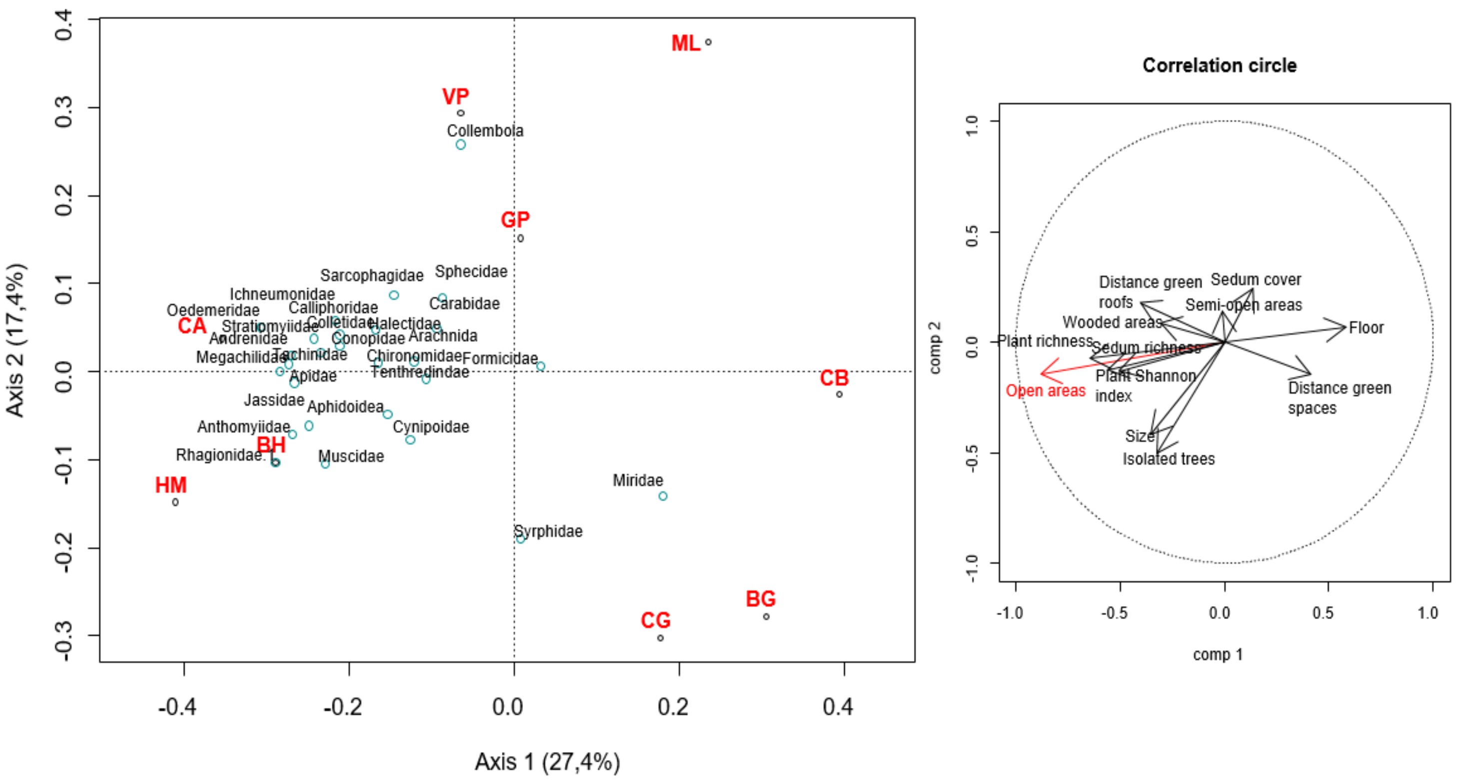

Figure 8: Arthropod assemblages from the PCoA. On the left, the graphic representation of the communities. Arthropod families are represented in black and the green roofs in red. On the right, the correlation circle of the environmental variables

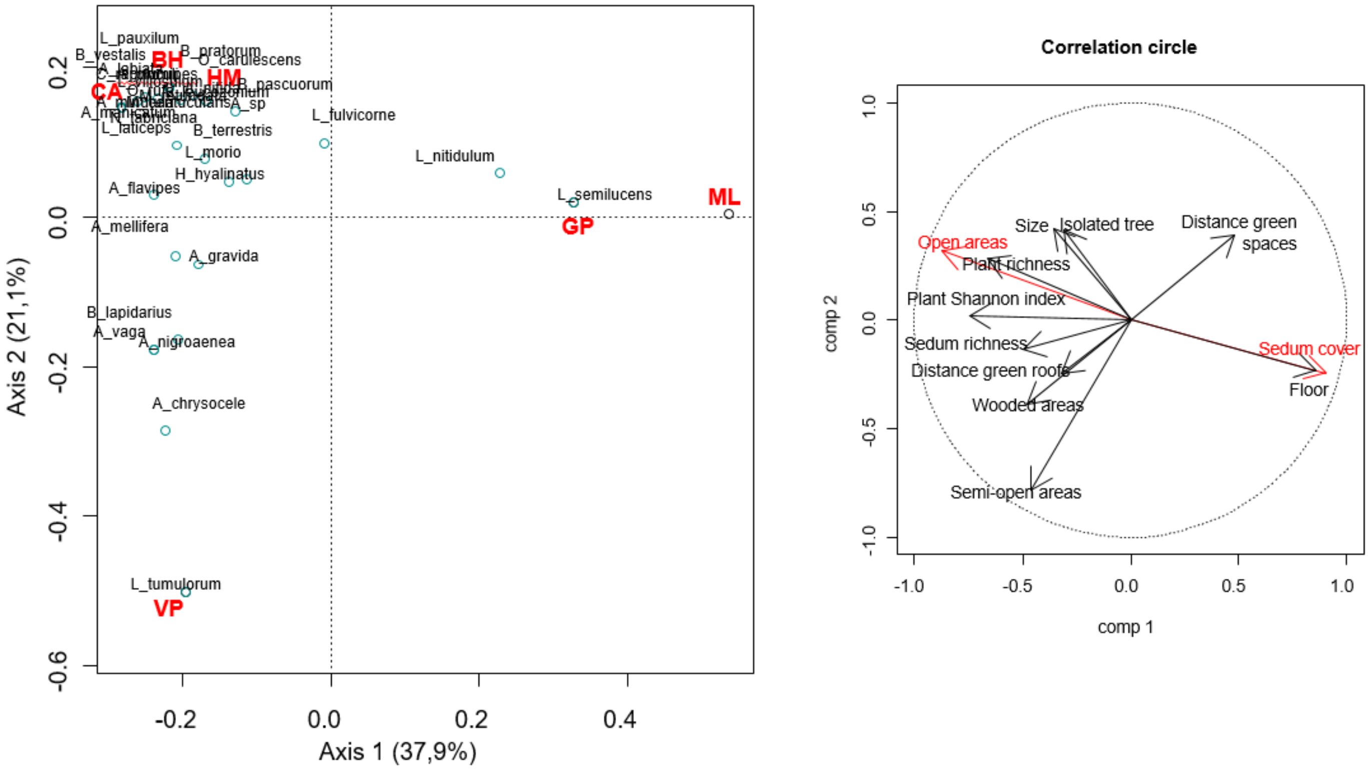

Figure 9: Bee communities from the PCoA. On the left, the graphic representation of the communities. Bee species are represented in black and the green roofs in red. On the right, the correlation circle of the environmental variables.

Bee communities

The first axis of the PCoA includes 37.9% of the variation and the second axis 21.1% (Figure 9). The axis 1 is also a gradient of the taxonomic richness. Green roofs with a higher richness (CA, BH, HM and VP) are on the left and the ones with a lower richness on the right (GP and ML). The division with VP is due to species found only or in majority on this green roof, such as *Lagossium tumulorum*.

The open areas surface has a significant influence on those communities (p-value =0.044) and also the sedum cover (p-value =0.021) but they are pointing in opposite directions. Green roofs with a higher bee richness are the ones with a bigger surface of open areas around them. The open areas surface is correlated with the plant richness. The sedum cover is correlated with the number of floors Roofs with a lower richness are characterized with a higher sedum cover. They are also on a higher height. All the information on the PCoA can be found in Annex 5.

All of the bees in this experiment are generalist and polylectic. Three roofs are missing from this graph: BG because no bees were found on this roof, CG and CB because of the very small number of individuals found on those roofs (1 individual for CG and 3 for CB). The height of the building could be an explanation for this lack of bees on BG as the number of floors is negatively correlated with the bee abundance.

Discussion

Green roofs in Brussels

Most of the green roofs in Brussels are extensive green roofs (Table 1). They are often favourited because of their lower cost and their lighter weight (Getter & Rowe, 2006). With the sampled roofs, we can expect that a majority of green roofs in Brussels is covered with *Sedum sp.*. But some examples show that different types of roofs start to emerge. Two of the sampled roofs present richer vegetation than the other green roofs. And some companies suggest the implantation of original green roofs[2].

Most of the green roofs are located in high impervious areas (Table 2). It corresponds to the will of the Brussels government in its Plan Nature (Bruxelles Environnement, 2016). The distances between two green roofs or with the nearest green space indicate that green roofs could be used as stepping-stones for a part of the fauna, even for small bees. They could also be included in the ecological network of Brussels to replace the discontinuities in the connecting zones in the city center. Indeed, even a roof with only *Sedum sp.* can be used as food resources or habitat for arthropods (Kadas, 2006; MacIvor *et al.*, 2015). But exotic bees are promoted by the sedum, less used by native bees (MacIvor *et al.*, 2015). A large part of the green roofs in Brussels have a small area. This result shows that it is possible to implement green roofs on small surfaces and potentially on a lot of buildings.

It is possible to compare Brussels with another city. Since the last years, Paris has developed its green roof policies (Mairie de Paris, 2012; Natureparif, 2013). A total of 44ha is covered in Paris (intra-muros) with green roofs which represent 0.4% of the surface of Paris. And 80ha could also be converted, reaching 1.17% of the city (Alba *et al.*, 2013). In Brussels, a minimum of 10.04ha is covered with green roofs which represent 0.06% of the city area. Compared to Paris, it seems possible to increase the green roofs area. And this surface is small compared to 3 037 ha of green spaces open to the public (Bruxelles-Environnement, 2012). It is smaller than the Brussels Park, the bigger green area in the city center.

The green roof market has grown between 2007 and 2011 in Brussels (Binamé, 2011). But it is possible that the green roof market will stagnate in the next years because no more incentives are given (Claus & Rousseau, 2012). Discussions with market actors have already highlighted this problem. To avoid worsening this situation, it is important to inform the population of the advantages of a green roof and of the different green roof possibilities. The Brussels government wants to give access to green roofs, like public green spaces. That could raise awareness about green roofs (Bruxelles Environnement, 2016). The higher construction cost, the lack of information or difficult

[2] http://www.fermenospilifs.be/ and http://www.lesetagesbuissonniers.be/

access to it, is one of the main obstacles for the green roof achievement (Binamé, 2011). Even the building occupants of most of the selected green roof in this study did not know about the existence of the green roof and the role of it, what it is made of. But most of the building occupants are not the owners.

The literature indicates that green roofs could be a propagation channel for invasive species but no case is reported yet (Kinlock, Schindler & Gurevitch, 2015). On two of the nine studied green roofs, an individual of *Buddleja davidii* was present. Its survival on the long term is uncertain but its presence indicates a possible risk, especially because no management is done on the selected green roofs.

Arthropod diversity on green roofs

Pan traps are very useful but some categories of insects are missing with them. Only the mobile and flying arthropods are captured. Arthropods on the soil are missing whereas they represent a large variety of living organisms (Thuring & Grant, 2015). Moreover, pan traps have stayed on the roofs during a short period of time because of constraints. Nocturnal arthropods were not captured. The deteriorations of the pan traps by birds suggest that some insects could have been eaten by them during the sampling.

This study focuses on the influence of the environmental variables on the arthropods diversity. One of the limits of this research is the multiple relations between the variables. Many variables are correlated together (Figure 7). The selected green roofs with the higher plant richness are in the greener areas. The results of the four GLM also indicate that a majority of the variables are combinations of other variables (Tables 3 and 4). It is complicated to sort out the real influence of each variable. Another limit is the use of the families as the last identification level for the arthropods. It leads to a bias because some families are more diversified in term of species than other families.

All of the selected green roofs are not used by the occupants and are often inaccessible. They provide an undisturbed habitat for the arthropods (Getter and Rowe; 2008). Forty families were collected in this study. For comparison, the Brussels and surrounding Environmental Commission has identified 54 families of insects in three natural reserves in Brussels (CEBE, 2017). But without an identification to the species it is impossible to determine the real proportion of Brussels arthropods hosted on green roofs. It is clearer for the bees. In this study, 32 species of Apoidea were collected. It represents a very small proportion of the 380 species identified in Belgium (Coppée, 2014). The difficult access to green roofs for less mobile species can explain this situation.

Bees only represent 6% of the arthropods found on green roofs. But it is often the targeted group by the studies for their interest in the pollination (Colla, Willis & Packer, 2009; Potts *et al.*, 2010; Tonietto *et al.*, 2011). It indicates that with this kind of focus, researchers are missing a large part of the biodiversity of the roof.

The GLM on the arthropod richness indicate that the most influent variables are the open areas surface and the wooded areas surface (Table 3). The correlations confirm this result. But it also adds the influence of the vegetation on the roof, mostly the plant and sedum richness. The arthropod abundance is influenced by all the variables according to the GLM. The literature highlights the importance of the surrounding environment and the plant richness on the arthropod richness (Madre *et al.,* 2013; Cook-Patton & Bauerle, 2012; Thuring & Grant, 2015; Braaker *et al.*, 2016). It also indicates the impact of the use of different depths of substrate (Braaker *et al.*, 2016; Brenneisen, 2003). And arthropods are attracted by the presence of wood or stones (Thuring & Grant, 2015). The presence of stones was only noticed on VP and CG. Changes in the substrate depth and the presence of wood were not observed on the selected green roofs.

This bigger influence of the surface of open areas than the connection with green spaces could be explained by the number of small collected arthropods. Indeed, small insects are more influenced by the close environment and the larger insects by the connecting with green spaces (Thuring & Grant, 2015). A majority of the articles in the literature focuses on large insects, like bees.

The GLMs and correlations on the bee richness and abundance highlight almost the same result, with a high influence of the surrounding environment (Table 4). The bee richness is not significantly influenced by a single variable but it could be explained by the small number of sampled species. It is interesting to note that the number of floors had a high negative correlation with the bee abundance when it was less correlated with the arthropod richness or abundance.

This study cannot clearly identify which variables have the biggest impact on green roofs arthropod diversity as most of them are correlated together. An experiment with similar green roofs on different localisations in Brussels could clarify the influences of the variables. This study demonstrates the role of the surrounding environment on the biodiversity of the roof. When a green roof is created in order to host insects, it is important to include the environmental vicinity in the reflection. The low impact of the size of the roof indicates that even a small roof can host a diversity of arthropods.

This study shows the presence of arthropods on green roofs but it does not demonstrate if the arthropods are using green roofs as food resources or habitats. The food resources on those roofs and their utilisation is unknown and could be explored.

Arthropod assemblages on green roofs

The PCoA reveals a homogeneous structure of arthropod assemblage on green roofs, regardless their position in the city or their plant richness (Figure 8). The differences between the green roofs are mainly explained by the richness or poverty of the roof. CB is at the total opposite of most of the roofs because of its small richness and abundance.

The arthropod assemblages are mostly influenced by the surrounding environment, especially the surface of open areas. Like the arthropods abundance and richness, the open areas surface is correlated with the plant richness and with the sedum richness and the plant Shannon index. Other environmental variables are correlated together, confirming the difficulty to highlight the real role of each variable in this study.

Bee communities on green roofs

The results of the bee communities are very similar to the arthropod assemblages. None community emerges from the PCoA (Figure 9). It could be explained by the presence of only generalist species which have the possibility to use a broad variety of habitat. Almost all the bee species were found in three of the nine green roofs (BH, CA and HM). The difference with the three other ones can be explained by a lower richness and the presence of species found only on those roofs, probably by chance.

The significant influence of the open areas surface is similar to another study. Tonietto *et al.* (2011) have already highlighted the importance of the surrounding environment on green roof for bees. The sedum cover has also an impact on the bee communities in this study. A bigger sedum surface on the roof is less attractive for the bees as the arrow on the correlation circle points at the opposite of most of the bee species. In the selected green roofs, those with a lower sedum cover are associated with higher plant richness and bigger open areas surface. The absence of bees on BG could be explained by the height of the building, a variable already highlighted as important for the bee abundance on green roofs (MacIvor, 2015). This variable is also pointing in the direction of the poorer roofs on the PCoA.

Apis mellifera represents only three individuals on the 179 collected. This result indicate that wild bees are more using the selected green roofs than honeybees. The nine green roofs are also preferred by generalist and common bees, a conclusion already done in other studies (Tonietto *et al.*, 2011). This could be explained by the lack of host plant and the omnipresence of sedum on most of the selected green roofs. But others studies, on other groups of arthropods have also show the presence of specialist or rare species (Kadas, 2006; Madre *et al.*, 2013)

Conclusion

Green roofs are becoming more and more common in big cities. It started in Germany and then spread all over the world. Belgium has followed the trend in the last few years. This study shows that green roofs are a reality in Brussels and could be islands of greenery in high impervious areas, often deficient in green spaces. But compared to other cities, such as Paris, Brussels could increase its green roofs surface. The high number of small green roofs indicate that those roofs could be placed on multiple buildings. One of the ways could be to communicate more efficiently on green roofs. Discussions with different actors reflect the global ignorance of the public on this thematic. With the end of the incentives, it is important to highlight the advantages of green roofs to promote them.
The Brussels government wants to give access to green roofs, like public green spaces. That could also a way to promote them (Bruxelles Environnement, 2016).

The literature gives a lot of advantages to green roofs for the biodiversity conservation but the reality is a little bit different. This study shows that green roofs can be connected to the ecological network but only a small part of the arthropod diversity, especially for bees, will have the opportunity to use this kind of structure. Green roofs are attracting generalist and common species. Homogenous assemblage and community were detected on the selected green roofs

To be really efficient in the ecological network, green roofs have to be adapted to the local environment in order to be useful for specialist and endangered species. Indeed, the surrounding environment is the most influential variable for the arthropod diversity. The influence of the other variables is uncertain because of the correlations between them. Green roofs companies should not reuse the plant mixes they create for another country without comparing it to the case of Brussels. The use of analogues habitats could be a way to improve the habitat quality of green roofs. The use of different heights of substrate and the presence of wood were not observed. That could be another technique to improve the reception capacity.

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