

## Factors influencing invertebrate diversity on green rooftops in the

How can diversity in cities be maximized?

Eva Drukker August – December 2018

Bureau Stadsnatuur Rotterdam Rens de Boer

Wageningen University Biosystematics Chairgroup Nina Fatouros



## Summary

Green roofs are an innovative climate stress mitigation strategy in urban areas. The biodiversity aspect of this new type of green areas in cities is currently not well studied, and the possibilities of how to fully optimize them to increase species diversity needs to be explored. The goal of my internship study was to investigate which factors in green roof design and abiotic situation determine invertebrate diversity. I studied several factors like height of a building, surrounding green areas, plant species richness, age of the roof, roof surface, substrate depth and human accessibility for their influence on invertebrate diversity. During the months of August and September of 2018, I conducted field research was on 21 rooftops in four cities throughout the Netherlands. I placed pitfalls and pan traps for 24 hours to collect invertebrates and an carried out an additional 15 minutes of transect sampling using an aerial net. I identified the collected invertebrates to the lowest taxonomic level within the scope of my expertise. To answer which factors were most important in influencing invertebrate diversity, data were analysed using PCA and RDA as well as linear models. To measure diversity, I used several indices like Shannon-Wiener. I collected samples from two different roof types: 12 extensive roofs (with a vegetation structure of mosses and succulent plants) and 9 intensive roofs (with a more complex vegetation structure of herbaceous plants). Factors were tested separately for the two roof types. A total of 123 different taxonomic units were identified. Height of a building had a negative correlation with invertebrate diversity on extensive roofs. Plant species richness and substrate depth both had a positive correlation with invertebrate diversity. The PCA showed a positive correlation of substrate depth with beetle abundance. Surrounding green area, roof surface, age of the roof and human accessibility did now show a significant correlation with invertebrate diversity. The most abundant invertebrate groups encountered were Collembola, Hymenoptera, Diptera and Araneae. A few rare species were found as well, including a new species for the Netherlands. When offered a habitat with a high plant species diversity, a diverse group of invertebrates can colonize heights of up to 70 metres in cities. This explorative research has highlighted the important factors that influence invertebrate diversity and has given an insight on what kind of insects are attracted to this new type of habitat in cities. Design factors like height, substrate depth and plant species diversity can be optimized by green roof developers to improve arthropod diversity and contribute to a better functioning of a green roof.



Sampling on the green roof of the Nemo building in Amsterdam. Picture taken by Judith Tieleman for OneWorld Magazin.

## Content

Summary2
Introduction4
Materials and Methods
Sampling sites8
Environmental and design factors9
Data analysis
Green roof case study11
Results12
Invertebrate diversity12
Water management14
Data analysis15
Green roof case study20
Discussion21
Life cycle events on green roofs21
Increasing invertebrate diversity on green roofs22
Pathways of colonization: is height a limitation?22
Plant diversity23
Substrate depth24
Future research25
Conclusion
References
Appendix



Photo taken on top of the green roof in the Nemo building in Amsterdam

## Introduction

Insects are of major importance in our world's ecosystems. They provide as a food source for higher trophic levels as well as ecological services (e.g. pest control and waste removal) and are important for pollination for a majority of the flowering plants (Hallmann et al. 2017). Up to 60 percent of birds are dependent on insects as main source of food (Morse 1971). About one third of our crops depend on insects for pollination (McGregor 1976) as well as 76 percent of angiosperms around the world (Ollerton et al. 2011). Overall, insects were estimated to have an economic value of at least \$57 billion for the US (Losey and Vaughan 2006). Their importance is inescapably clear, and unfortunately their worldwide decline as well (Hallmann et al. 2017). The use of pesticides, habitat loss and habitat fragmentation as a result of agricultural land use and urbanization are thought to be contributing to this decline in insect populations (McKinney 2008, Tonietto et al. 2011).

Being problematic already, urbanization is expected to even grow. It is predicted that by 2050 over 68% of the world's population will live in urban areas, which constitutes to a growth of 2.5 billion people in the city (United Nations 2018). Governments and municipalities are faced with problems like how to maintain a sustainable living environment in these densely populated urban areas. Maintenance of a liveable environment is challenging as urbanization constitutes to many problems like heat-stress, flooding, pollution, noise disturbance and high usage of energy (Wonga et al. 2003, Getter and Rowe 2006). Providing more green areas in urban regions could counteract to an extent the loss of biodiversity and help maintain a liveable environment in cities. However high land prices make it very expensive.

Green rooftops would provide a feasible alternative as large parts of urban area comprise unused rooftops. Green roofs provide many innovative solutions to our urbanization and climate change problems. They can (1) reduce local sewage overflow during heavy rainfalls, (2) mitigate the urban-heat-island (UHI) effect, (3) improve sustainability of a city by reducing pollution, energy costs and increasing longevity of a roof (Kleerekoper et al. 2012), and (4) have an esthetical value.

- (1) Reduction of local sewage overflow is due to a green roofs' water retention capacities. Cities are only able to absorb about 25% of rainfall, compared to forests where up to 95% is absorbed (Getter and Rowe 2006). Heavy rainfall is predicted to increase all around the globe due to climate change (Calderon et al. 2017), and will therefore increase the risk of flooding in cities. The water retention layer, substrate layer and vegetation layer of a green roof (see figure 1) retain excess water, reducing the load on the sewerage during heavy rains (Mentens et al. 2006). This also reduces energy costs on alternative water retention services, estimated at €500/m<sup>3</sup> (multifunctionele daken-Algemeen et al. 2018).
- (2) Another problem caused by urbanization is the UHI effect. During summer, cities are noticeably warmer compared to rural areas, which is the result of heat absorption by pavements and buildings causing them to warm up dramatically. This increases health risks for vulnerable groups like elderly people and babies during warm periods and heat waves (Li et al. 2014). Green roofs mitigate this by reflecting sunlight, just as effectively as a white

surface, and through evapotranspiration of plants cooling the underlying building as well as the surrounding area (Castleton et al. 2010, Cirkel et al. 2018).

- (3) Green roofs reduce energy costs for cooling and heating buildings and improve the longevity of the roof itself, making them a sustainable innovation for urban areas (Niachou 2001, Wonga et al. 2003). Heat gain is reduced by 70 90% in summer and heat loss is reduced by 10 20% in winter (Castleton et al. 2010). It further provides recreational and agricultural spaces, a significant reduction in air pollution and insulation of a building for sound (Bianchini and Hewage 2012).
- (4) Lastly there are the esthetical benefits; it contributes to a greener and more beautiful city that improves physical and mental health, which could even reduce healthcare costs. The real estate value of a building is estimated to increase with 10% due to the improved aesthetic appreciation, noise reduction and improved productivity and comfort of the residents (multifunctionele daken-Algemeen et al. 2018).

It is thus no wonder that green roofs have become increasingly popular in the last century in highly urbanized countries like Japan, Singapore and Belgium where the government even imposes the use of green roofs (Mentens et al. 2006).

A green roof is a roof that consists of plants and is usually built up of six layers; the root barrier, drainage, filter, water retention layer, substrate layer and vegetation layer (see figure 1). The root barrier serves as a protection layer for the roof itself from damage caused by roots, the drainage layer removes excess moisture, the filter stops soil particles from entering and blocking the drainage layer. The retention layer retains water to reduce run-off speed and to keep the layer above moist. The growing medium houses the roots of the vegetation and then finally there is the vegetation layer itself (Bianchini and Hewage 2012).



Fig. 1. Cross section of green roof's layers.

Figure 1. Cross section of the layers from a green roof (Bianchini and Hewage 2012).

A green roof is often classified in two types: extensive and intensive roofs. The distinction is based on the complexity of the vegetation layer. Table 1 lists the characteristics for these two types.

Roof type	Substrate layer	Vegetation cover	Maintenance
Extensive	~ 60 mm	Bryophytes (mosses), sedum species (succulent plants). Can comprise some grasses and other plants from the surrounding area	Much watering. Removing of unwanted plant species
Intensive	> 60 mm	Bryophytes, sedum species and herbaceous plants. Depending on substrate layer also shrubs and trees.	Little watering (depending on substrate depth). Mowing of grasses.

Table 1. Characteristics of extensive roofs and intensive roofs.

An extensive roof has a relatively thin layer of soil (around 60 mm) and requires little maintenance as its vegetation coverage mostly consists of bryophytes (mosses) and sedum species (succulent plants). If not removed during maintenance, it can also consist of some plants that come with the wind from the surrounding area (Madre et al. 2013). Extensive green roofs have lower installation costs and lower maintenance costs compared to intensive green roofs. However, the beneficial aspects like reduction of storm water runoff, insulation costs and enhancement of biodiversity are lower than with intensive roofs.

An intensive roof needs a good depth of soil (more than 60 mm) and is usually associated with roof gardens. They comprise next to bryophytes and sedum species also herbaceous plants on more than 20% of its surface and can even include woody plants like trees and shrubs (Bianchini and Hewage 2012, Madre et al. 2013). Intensive roofs have higher installation costs, but on the long term have much higher benefits (Bianchini and Hewage 2012). Due to weight limitations of the roof, the layers are all required to be light so that they can also be installed on existing rooftops without having to go through extra construction costs.

Green roofs have only recently made their way into urban areas. Only little research has been done so far on how invertebrate populations manage in these newly developed habitats. This research aims to unravel how green roofs could provide a habitat for invertebrates in the Netherlands and whether green roofs could provide suitable habitats for life cycle events such as pupation, foraging, reproduction and egg deposition.

The thin layer of soil could be a limiting factor for pupation. A study on the pupation rate of the Cabbage moth (*Mamestra brassicae*) found that caterpillars were able to pupate in green rooftop sediments in 110 mm semi-natural environments (Huigens et al. 2015). Caterpillars are therefore expected to be generally abundant on green rooftops. Earthworms however perish in thin substrate as they cannot move to deeper, cooler regions (Brenneisen 2006) and are therefore only expected on green rooftops with a thick substrate layer. Most studies agree on that substrate thickness, together with plant species richness and flowering time are positively correlated with invertebrate diversity (Brenneisen 2006, Kadas 2006, Maclvor and Lundholm 2011, Moerland 2011, Tonietto et al. 2011, Madre et al. 2013, Maclvor and Ksiazek 2015, Braaker et al. 2017, Dusza et al. 2017, Froment 2017). Plant species richness is dependent on the substrate thickness, therefore the latter is suggested to have an indirect

effect on invertebrate diversity. Surrounding green area is suggested by some studies to have no influence (Schindler et al. 2011), whilst other studies suggest that it has an influence on the species composition (Maclvor and Lundholm 2011, Tonietto et al. 2011, Huigens et al. 2015) and should therefore be further studied. Height has been little studied for its influence on invertebrate diversity on green roofs. It could be a limiting factor for the accessibility of invertebrates to green roofs. Two studies on bee population on green roofs suggest a negative correlation with bee diversity and height of a building (Tonietto et al. 2011, Maclvor and Ksiazek 2015). Height is therefore expected to have a negative influence on species diversity in my study. Age of the roof and roof surface were not found to be of significant importance in many of the studies.

Many studies were limited in either the amount of roofs investigated or the sampling effort. Therefore many repeated studies are needed to acquire a better understanding on how these newly developed ecosystems work. Green roof developers can implement this information so that the biodiversity function of green roofs can be fully optimized. In my study, invertebrate diversity was investigated on 21 green rooftops throughout the Netherlands. From these 21 roofs, 12 were extensive and 9 were intensive roofs. This distinction was made based on the thickness of the soil, the plant species composition and the human influence of the roof.

Two questions were addressed:

- (1) Which factors show a significant correlation with invertebrate diversity?
- (2) How can the results of my study be implemented by designers of green roofs to maximize their biodiversity function?

Based on the available literature the following hypotheses were adopted.

- (1) Plant species diversity and substrate thickness are expected to be correlated with each other and to both have a positive correlation with invertebrate diversity.
- (2) Height is expected to effect differences in community composition and to be negatively correlated with invertebrate diversity.
- (3) Surrounding green area is expected to have an influence on species composition.
- (4) Factors like age of the roof and human influence are not expected to significantly influence species diversity but could perhaps explain small differences in diversity between individual roofs.

## **Materials and Methods**

## Sampling sites

Between August 16 and September 28 of 2018, rooftops were sampled throughout four cities in the Netherlands. Eight buildings in Amsterdam, eight in Rotterdam, one in Utrecht and four in Wageningen. Table A.1 in the appendix gives an overview of the buildings that were sampled. The green roofs were located using Google Maps or through green rooftop organisations. Owners were contacted to ask for permission to do research. This resulted in the 21 rooftops sampled in this research. Twelve rooftops were extensive, nine were intensive. Roofs had heights varying between 6 meters and 70 meters, an overview is given in table 2.

Table 2. Height langes for the buildings sampled in this s				
Height range (m)	Amount of buildings			
6 - 15	8			
16 – 26	10			
>30	3			

Table 2. Height ranges for the buildings sampled in this study.

Sampling was done on days under similar weather conditions, so that this would reduce possible noise in the analyses. Materials were provided by Bureau Stadsnatuur Rotterdam (bSR). On every rooftop 6 pitfall traps (with a diameter of 60 mm), and 4 pan traps (2 white, 1 yellow, 1 blue; see figure 2) were placed for 24 hours. Pitfalls are were placed for catching ground-dwelling invertebrates, pan traps for flying invertebrates (Westphal et al. 2008, Buchholz et al. 2010, MacIvor and Lundholm 2011, Braaker et al. 2017). Beside this a survey of 15 minutes was done per rooftop, by catching invertebrates with an aerial net. All invertebrates were identified to family level or species level using field guides or asking taxonomic experts if needed. Specimens of the orders/superfamilies Collembola (springtails), Acariformes (mites), Aphidoidea (aphids), or Thysanoptera (thrips) were not further determined. Also larvae were only determined until order level.



Figure 2. White-and blue pan trap used for catching flying invertebrates.

## **Environmental and design factors**

For all 21 green rooftops, the design factors and environmental factors listed in table 3 were measured or recorded.

Variable	Method
Roof surface area	Calculated using QGIS*
Distance to surrounding area	Calculated using QGIS
Surface surrounding green area in a 300m radius	Calculated using QGIS
Number of trees in a 100m radius	Calculated using QGIS
Water areas in a 100m radius	Assessed using QGIS
Plant species richness	Identified in the field or information was provided by the owners of the building
Height building	Data was gathered on https://ahn.arcgisonline.nl/ahnviewer/
Substrate depth	Measured in the field or information was provided by the owners of the building
Roof type intensive/extensive	Classified in the field
Accessibility/human intervention	Classified in the field
Age of the roof	Information was provided by the owners
Company that placed the green roof	Information was provided by the owners
Weather conditions: temperature (C), relative sunshine (%), humidity (%), precipitation (mm), wind speed(m*s <sup>-1</sup> )	Information was gathered from the KNMI website <u>https://projects.knmi.nl/klimatologie/da</u> ggegevens/
Latitude, longitude	Information was gathered from <u>https://www.gps-coordinaten.nl/</u>

Table 3. Overview of the factors recorded in the research

\* or Quantum-GIS, is an open source geographic information system used in the Netherlands

An additional variable called "Greenness of the surrounding area" was made based on the factors *distance to surrounding area*, *surface surrounding green area in a 300m radius*, *number of trees in a 100m radius*, *water areas in a 100m radius* recorded in table 3. Green areas were based on information from QGIS using "Bestand Bodem Gebruik 2015", Open Topo as well as Google Maps to identify gardens, trees and parcs. Distances for the radius were chosen based on several studies on the influence of surrounding green area on green roofs (Maclvor and Lundholm 2011, Tonietto et al. 2011).

## Data analysis

The data were first log+1 transformed and tested for normality. Data were not normally distributed, so for models based on species occurrence, poisson or negative binomial distribution was assumed. Two species accumulation curves were made, one based on orders

and one on species. The Shannon Wiener index was used in this study and compared with other diversity indices like Simpson, Margalef and Evenness index for validation. These indices were tested for normality and shown to follow a normal distribution. To see if there was a difference in diversity between extensive roofs and intensive roofs, a two-sample t-test was done on the Shannon Wiener index for extensive roofs and intensive roofs. Diversity plots were made to see if there was a relationship between the diversity indices and any of the design and abiotic factors listed in table 3. The diversity indices were calculated using the vegan package in R (Oksanen et al. 2013). The formulas for the indices and interpretations are given in table 4. Table 5 gives an overview of the symbols used in the formulas.

Index	Formula	Interpretation
Shannon- Wiener (Pielou 1966)	H'= -∑ Pi ln Pi , Pi = ni∕ N	The higher this index, the higher the diversity of the roof sampled. The index becomes higher if more species are found and when individuals are more evenly spread out over the species in the sample.
Simpson Diversity (Heip et al. 1998)	C= ∑ Pi <sup>2</sup> , Pi= ni/ N	The probability that two individuals randomly sampled from the sample belong to the same species. In R this index in converted to $1 - C$ , so that the outcome indicates a high diversity in the sample
Evenness index (Heip et al. 1998)	E= H'/ H <sub>max</sub>	The closer it is to 1, the closer the diversity index of Shannon Wiener is to its maximum and therefore the more evenly individuals are spread over the different species.
Margalef (Nugrahaningru m et al. 2017)	DMg= (S-1)/ In N	the number of species found, averaged over the total amount of individuals found in the sample. The higher the Margalef index, the higher the invertebrate diversity

Table 4. Formulas and interpretations for the diversity indices.

Table 5. Meaning of the symbols used in the Diversity index formulas.

Symbol	Meaning
H'	diversity index of Shannon-Wiener
n <sub>i</sub>	the number of individuals belong to family i
Ν	the total number of collected individuals
С	Dominance Index (Simpsons Diversity Index)
H <sub>max</sub>	In(S), value for where Shannon-Wiener index would be maximal
S	the total number of identified families
Ε	evenness index
DMg	Margalef Index
Pi	n <sub>i</sub> /N

For the ordination analysis the vegan package in R was used (Oksanen et al. 2013). Data were tested whether they followed a unimodal or a linear distribution using the function *decorana*.

Values for the first axes were <4, therefore a linear distribution was assumed and Principal Component Analysis (PCA) was used. Three PCA analyses were applied. One based on order, one on family and one on species level. Design and abiotic factors were tested to see whether they could explain patterns in the ordination. Sampling sites were coloured by roof type to see if there was a clustering of extensive and intensive roofs. Rooftops were classified into several height categories and coloured accordingly to see if certain heights clustered together based on invertebrate composition. Rooftops were also classified based on location to test for clustering of closely located rooftops. In total this resulted in nine PCA analyses. Based on the results obtained from the PCA and the diversity plots, linear models were made and tested for significant relationships between invertebrate diversity and design factors.

It was hypothesised that *A. mellifera* (European Honey bee) can negatively impact species diversity of other bees and wasps (Mallinger et al. 2017). To test for this, two separate analyses were conducted by 1) excluding this species from the diversity analyses, 2) conducting a PCA including only Hymenoptera (wasps and bees) and Syrphidae (hoverflies) species, 3) conducting a PCA excluding *A. mellifera* from the analysis.

### Green roof case study

Besides the biodiversity analysis, an inventory was done on the potential of green roofs for cities in the Netherlands. Rooftop owners and organisations were approached to acquire information on whether a building is suitable for a green roof, and how – based on its construction – it can be optimized for biodiversity. Rooftop manager of the DakAkker, Wouter Bauman, was interviewed for information about the construction of the DakAkker in Rotterdam, a green roof with arable land. Harm van Wijnen from Atlas Natuurlijk Kapitaal was asked about the potential of existing rooftops for green roof construction.

## Results

### Invertebrate diversity

In total 5598 individuals were caught of which 68% comprised Collembola (springtails), and in total comprised 123 different taxonomic units. 19 different invertebrate orders were found, and 81 different families. Excluding springtails, 28% of the individuals caught were non-flying invertebrates. Table 6 shows some of the species that were caught in this study. A description of the ecology of this species is given in the remarks, for some indicating in what way these species might have had an interaction with the green roof on which they were found.

Table 6. Overview of some of the invertebrate species caught on rooftops. In the remarks the ecology of the species is described. Information was based on field guides used in this research.

Higher taxonomic level	Species	Number	English name	Remarks
Insecta, Hymenoptera	Idiasta dichrocera	1	A parasitoid wasp	Newly recorded species for the Netherlands. First recorded by <i>Königsmann, 1960 (Braconidae – Alysiinae – Alysiini)</i> . A parasitoid on Diptera larvae. Found on an intensive green roof in Rotterdam. Picture in the appendix, figure A.8
	Agenioideus sericeus	1	A spider wasps	First recorded for Amsterdam, rare species of the genus of wall-climbing spider wasps, caught on 6-meter-high rooftop. Picture can be found in the appendix in figure A.7.
	Lasioglossum leucopus	1	White-footed green furrow bee	First recorded for Amsterdam. Caught on a 23-meter-high rooftop
	Bombus pascuorum	22	Common carder bee	Commonly found on many green rooftops. Common in gardens and urban greenspace. Nests in dense vegetation. Feeds on legumes, labiates, thistles, knapweeds and scabiouses. Parasitized by <i>B. campestris</i> .
	Bombus campestris	4	Field cuckoo bee	Its main host is <i>B. pascuorum</i> .
	Apis mellifera	53	European honey bee	Commonly found. Present in high numbers with presence of bee hives. Often found together with its imitator <i>Eristalis tenax</i> on the green roofs.
	Ancistrocerus spec.	1	A potter wasp	Caught at 25 meters. Species of this genus make nests in walls and feed on fly and beetle larvae.
Insecta, Dermaptera	Forficula auricularia	1	European earwig	Only species of this order, Dermaptera (Earwigs) found in this research. Species

				do not often fly but are able to do so. Feeds on aphids. Needs moist conditions
Insecta, Hemiptera	Cicadellidae	22	Leafhoppers	Encountered in great numbers on many green rooftops
	Aphidoidea	36	Aphids	Encountered in great numbers on many green rooftops
Insecta, Lepidoptera	Polyommatus Icarus	2	Common blue	Butterfly species found foraging at 25 meters.
	Cacoecimorpha pronubana	10	European carnation moth	Large population found on one intensive roof. Host plant: carnations and many herbaceous plants.
Insecta, Orthoptera	Conocephalus discolor	1	Long-winged conehead	Found at 70 meters stridulating. Can be found in rough vegetation. One of the four grasshoppers encountered in this research
Insecta, Diptera	Sarcophaga carnaria	11	Common flesh fly	Commonly found.
	Eristalis tenax	10	Drone fly	Commonly found. A common visitor to flowers in late summer, autumn. It imitates the European honey bee, <i>Apis</i> <i>mellifera</i>
Myriapoda, Chilopoda	Lithobiidae spec	15	Centipede species	In total 15 individuals found, of which some on the building of 70 meters.
Pancrustacea, Isopoda	Isopoda	26	Pill bugs or woodlice	Three different species, a total abundance of 26 individuals
Chelicerata	Phalangium opilio	1	Daddy longlegs	Only species of this order (Opiliones) found in this research
	Lyniphiidae	42	Sheet weavers or money spiders	Family of spiders known for their ballooning behaviour
	Acariformes	76	Mites	Encountered in great numbers on many green rooftops
Annelida	Lumbricidae	3	Earthworm species	Only found on 2 rooftops with a thick substrate
Mollusca, Gastropoda	Succinea oblonga	4	Snail species	If present on rooftop, it was abundant

A moth trap was placed once for a night on an extensive roof. This resulted in the catching of an Ephemeroptera (mayflies) species *Cloeon dipterum*. However due to mal-functioning of the moth traps, this was the only roof that was sampled in this way, so these findings were not further used in the analyses. Collembola (springtails) were found at every site. A total of 25 larvae were found in this research, comprising 12 Lepidoptera (caterpillars), 7 Coleoptera (beetle larvae), 5 Gastropoda (slug larvae) and 1 Diptera (fly larvae). Figure A.1 in the appendix gives an overview of where the larvae were found and in which substrate depths they were found in. All of the larvae were caught in pitfall traps.



Figure 3. Percentage of invertebrate specimens found per taxonomic unit.

The most abundant three families (excluding Collembola) were Phoridae (Diptera, flies) with 499 individuals, Formicidae (Hymenoptera, ants) with 166 individuals and Apidae (Hymenoptera, bees) with 82 individuals.

#### Water management

The summer of 2018 was one of the driest summers since 1906, with an average of 105 mm (compared to a normal average of 225 mm) of rain according to the KNMI (Koninklijk Nederlands Meteorologisch Instituut). Water management on the green roofs showed to be important after this dry summer. The vegetation on a roof with a thin substrate layer (~60mm) and an intensive watering system manages to survive the drought of this summer (figure 4a). A roof with the same substrate layer thickness and no watering system completely dries out (figure 4b). However, the vegetation on a roof without a watering system but with a thick substrate layer (>150mm) survives the hot summer (figure 4c). Other factors like shade could have played a role in maintaining a moist substrate here as well.



Figure 4. Water management on green roofs. (a) A green roof with a watering system. (b) A green roof without a watering system. Both roofs had a substrate layer of around 60 mm. Pictures were taken on 30<sup>th</sup> of august 2018. (c) A roof with a thick substrate layer (> 145mm) and no watering system. Picture taken on 13<sup>th</sup> of September.

### Data analysis

### Species accumulation curve

The species accumulation curves gave insight to whether enough samples were taken to have a good representation of insect diversity on green roofs (see figure A.5 and A.6 in the appendix for the species accumulation curves). The amount of invertebrate orders found reached an asymptote meaning that sampling effort was sufficient to have a representative amount of invertebrate orders (figure A.5). On species level however more samples were needed, as the curve had not reached an asymptote (figure A.6).

### Difference between extensive and intensive roofs

The diversity indices all showed a significant difference between intensive and extensive roofs, indicating a higher invertebrate diversity for intensive roofs. Figure 5 shows a boxplots for the Shannon Wiener index. Extensive roofs have a mean of 2.47 and intensive roofs a mean of 3.17, the two sample t-test resulting in a significant difference of a p-value of 4.225\*10<sup>-5</sup>. The meaning of the values for the Shannon-Wiener index is given in table 7.



Figure 5. Diversity on extensive roofs vs intensive roofs. Boxplot showing the minimum, maximum and median values of the Shannon Wiener index for extensive roof samples and intensive roof samples. Left (red box) are extensive roofs, green (right box) are intensive roofs. Asterisk indicates significant difference according to the two-sampled to test (p-value = 4.225\*10<sup>-5</sup>).

The other diversity indices were checked for validation. In almost all cases the diversity indices showed similar results, which is why only the Shannon Wiener index is shown in this report. Two values for the Evenness index for two extensive roofs differed from all the other diversity indices, which was further analysed and will be shown in the report further below.

Category	Shannon Wiener Index
High	>4
Good	3.0-4.0
Moderate	2.0-3.0
Poor	1.0-2.0
Bad	0.0-1.0

Table 7. Ecological status for the Shannon Wiener index (Nugrahaningrum et al. 2017)

### Principal Component Analysis (PCA)

On species and family level, none of the environmental factors were significant in explaining the ordination, likely due to the fact that not enough species had been caught to show any patterns. However, on higher taxonomic levels such as order, four environmental factors significantly defined the ordination (Figure 6). There was a clear clustering of the extensive roofs (red squares, figure 6). Wind speed, substrate depth, plant species richness, and presence of a bee hive showed to be significant at the 0.05 level for the defining the ordination. Total inertia was 24 and the eigenvalues for the first and second unconstrained axes were 5.535 and 3.280 respectively. The first two axes explain 37% of the variation. VIF factors were below 5 for all four variables, so no multicollinearity between the variables could be assumed. Colouring the roofs by height did not show any clustering.

There was no clustering found for species composition on buildings closely located to each other. The PCA can be found in figure A.3 in the appendix. A PCA with only Hymenoptera (wasps and bees) and Syrphidae (hoverflies) did not show that the presence of *A. mellifera* influenced species composition or diversity (figure A.4 in the appendix). The PCA excluding *A. mellifera* did not change anything about the influence of any of the factors, and only slightly changed the position of Hymenoptera (see figure A.9 in the appendix) to be less correlated to presence of a bee hive.



Figure 6. PCA ordination based on invertebrate order composition. Red squares represent the extensive roofs, green dots represent the intensive roofs. The length of the arrow is a measure of importance of the variables (wind speed, substrate depth, presence bee hive, plant species richness) here significant at the 0.05 according to the permutation test. Arrowheads point in the direction of increasing influence. The green text represents the position of each invertebrate order in the ordination.

### Diversity indices

Diversity indices plotted against the factors recorded in this research showed significant correlations for three factors: height, plant species richness and substrate depth. In this report the plots for the Shannon Wiener index are shown against these three factors. Greenness of the surrounding area, wind, presence of a bee hive and surface of the roof did not show any positive or negative correlations. Age of the roof did not show any correlation with the Shannon Wiener, Margalef and Simpson index, but did show a correlation with the Evenness index.

Roof height had a negative correlation with diversity on extensive roofs represented by the red squares in figure 7. The GLM showed a significant negative correlation (P=0.009). The

model formula is given in table 8. There was no significant correlation with diversity and height on intensive roofs.



Figure 7. Diversity versus height. The red squares represent extensive roofs and are circled. Green dots represent the intensive roofs. On the y-axis the Shannon Wiener index for every rooftop, on the x-axis the height of the building. Numbers indicate the building that was sampled for which further information can be found in the appendix (table A.1).

Plant species richness showed a positive, asymptotic relationship with invertebrate diversity for extensive and intensive roofs based on the Shannon Wiener index (see figure 8), so a linear model with log transformation was made and a significant correlation was found (P=0.001). For extensive roofs alone there was no significant correlation. For intensive roofs alone the correlation was not significant (P=0.052). The data was normally distributed for both extensive as intensive roofs separately.



Plant Species Richness

Figure 8. Diversity versus plant species richness. The red squares represent extensive roofs. Green dots represent the intensive roofs. Correlation between plant species richness (on the x-axis) and Shannon Wiener index, showing increasing diversity (on the y-axis).

The logarithm of substrate depth showed a positive relationship, similar to the plant species richness with species diversity (see figure A.3 in the appendix).

Table 8.	Linear model	of Shannon \	Niener index	against he	eight building	and plant s	species richness.
		••••••••••					

y-variable	Model estimates	Remarks
Shannon-Wiener index	2.92 - 0.02*Height Building	Only for extensive roofs
Shannon-Wiener index	1.95 + 0.82*log(Plant Species Richness)	For extensive and intensive roofs
<b>Evenness index</b>	0.87 + 0.004*Age Roof	Only for extensive roofs

The Evenness index showed aberrant results from the other diversity indices for two extensive roofs, numbers 12 and 16, as visible from figure 9. These two roofs were the oldest roofs sampled with an age of around 20 years old. Age of the roof was therefore plotted against the Evenness index and the linear model indicated a significant correlation for extensive (P=0.005).



Figure 9. Evenness versus age of the roof. Evenness Index on the y-axis, age of the roof on the x-axis. Red squares indicate extensive roofs, green dots indicate intensive roofs. Numbers corresponding to the roof ID's can be found in the appendix (table A.1).

### Green roof case study

Whether a building is suitable for a green roof depends on a few factors. Weight is often a limiting factor, but most modern buildings (built after the year 2000) meet the latest building construction requirements and have therefore a higher potential for the construction of a green roof. Building year for roofs in the Netherlands can be acquired from the Basis Administratie Gebouwen (BAG). A flat roof has more potential for a green roof, as installation is cheaper and opens up opportunities for multiple functions like solar panels and recreation. The water retention capacities are also higher for flat roofs. However, green roof construction on a slope is definitely not ruled out. Atlas Natuurlijk Kapitaal is investigating this right now and will soon publish a report on this matter. More information about construction capacities can also be found on the website of <u>www.multifunctioneledaken.nl</u>.

The DakAkker had the highest invertebrate diversity of all the rooftops in this research. On this old existing rooftop in Rotterdam a successful intensive green roof was built even though large part of the roof could only carry 85 kg/m<sup>2</sup> (ergo 70 mm substrate). This problem was solved by placing less substrate on these weaker parts, while on the stronger parts with pillar points, up to 400 mm substrate was placed. The bistro restaurant that has been built there, is very popular and volunteers are waiting in line to help out with the maintenance of the roof.

## Discussion

### Life cycle events on green roofs

It was shown in this research that green roofs provide an important habitat for certain life cycle events of invertebrates, like foraging, reproduction and egg deposition. The ecological aspects of the species found in my study indicated that a stable ecosystem had been established on many of these rooftops. As listed in table 6, *Bombus campestris* (Field cuckoo bee) and its host *B. pascuorum* (Common carder bee) were often found together on the green roofs. The same for *Apis mellifera* (European honey bee) and its imitator *Eristalis tenax* (Drone fly) that were abundant and foraging on many green roofs. The large population of the European carnation moth was found on a roof with many carnation species (*Dianthus*) and other of the moths' host plants.

The walled green roofs could have provided an important habitat for *Agenioideus sericeus* (spider wasp) and *Ancistrocerus spec* (potter wasp) which make their nests in walls. Their prey was also found to be abundant on these roofs. The encounters of rare species like *A. sericeus*, the parasitoid wasp *Idiasta dichrocera* (a new species for the Netherlands), and *Lasioglossum leucopus* (White-footed green furrow bee) showed that these green roofs should be investigated more as new and rare species can be discovered in these unique habitats.

The overall encounters of stridulating grasshoppers, foraging butterflies and many of the foraging bees and hoverflies indicated that these rooftops provided an important habitat for foraging and evidence for functional ecological aspects.

Green roofs seemed to provide a important habitat for Cicadellidae (leafhoppers). These were encountered in large numbers in this study, which was similar to findings in several other studies (Coffman and Davis 2005, MacIvor and Lundholm 2011) where Cicadellidae were found in greater numbers on rooftops, compared to ground-level habitats.

The caterpillars found in my study showed that Lepidoptera use green roofs to complete certain stages of their life cycle, like laying eggs and perhaps pupation. Pupation is known to be possible on thin rooftop substrates, as found in a study on the pupation rate of the Cabbage moth (*Mamestra brassicae*) (Huigens et al. 2015). However, in their study, pupation was not measured in conditions like frost and extreme drought. Caterpillars were found on substrate depths of 60 mm which showed they were able to survive the extreme droughts of the summer of 2018 in these thin substrates. The sample size of caterpillars was however very small, so more sampling is needed to investigate whether these rooftops are indeed suitable habitats for butterflies. Whether they can also survive frost should also still be investigated (see future research).

### Increasing invertebrate diversity on green roofs

Intensive roofs have a much higher invertebrate diversity compared to extensive roofs according to the Shannon Wiener index. On average the intensive roofs had a Shannon Wiener index of 3.17 which indicated a high diversity of invertebrates (see table 7) and would be comparable to ground-level habitats (Nugrahaningrum et al. 2017). A Shannon Wiener index of 2.47, as for the extensive roofs, indicates a moderate diversity.

The highest invertebrate diversity was found on roof 4 (de DakAkker in Rotterdam), with a Shannon Wiener index of 3.53. Based on literature research and the PCA from my study, this could be explained by the variation in vegetation type (Madre et al. 2013, Dusza et al. 2017), the high vegetation cover (Schindler et al. 2011), the high plant species richness (Madre et al. 2013), variation in relief and substrate depth (Gedge et al. 2012, Pétremand et al. 2018) and the inclusion of local native flora (Moerland 2011). One part of the roof consisted of arable land and many different species of Asteraceae. The other part consisted of a dense vegetation of Fabaceae species and different kinds of grasses. Incorporating different microclimates and microhabitats through variation in relief and vegetation structure shows to increase invertebrate diversity, a hypothesis that is supported by many other studies (Brenneisen 2006, Köhler 2006, Gedge et al. 2012). A thicker layer of substrate improves biodiversity and the effective functioning of a green roof, although the weight that a roof can carry is often a limiting factor. The case study on the DakAkker was an interesting example of how to get around weight limitations and create a multifunctional roof with arable land, by creating relief and making use of the stronger pillar points from certain parts of the roof. The DakAkker is a great example of how to properly implement a green roof and maximize its biodiversity function. How plant species diversity and substrate depth have had an influence on invertebrate diversity is further elaborated below in the Plant Diversity and Substrate Depth section.

Other ways to increase invertebrate diversity is by incorporating certain objects on the roof. Artificial nesting areas can greatly enhance diversity for wild bees. This can be in the form of wood logs, piles of sand near sheltered areas and piles of stones (Moerland 2011, Huigens et al. 2015). Important is that these objects are heavy enough so that they will not fall off the roof. Roof surface was not found to influence invertebrate diversity in my study, which was also found in other studies (Schindler et al. 2011, Braaker et al. 2014), however a larger surface could provide opportunities for incorporating more niches and microhabitats (Gedge et al. 2012) and could therefore increase diversity.

Age of a roof did not show to increase invertebrate diversity according to most diversity indices, except for the Evenness index. This indicated that diversity is not per se high on older rooftops, but individuals are more evenly divided over the different taxonomic groups found on these older roofs.

### Pathways of colonization: is height a limitation?

In this study it was shown that a wide range of invertebrates are able to colonize green roofs of different heights. There are many ways in which invertebrates can colonize green roofs.

They can be brought with the installation, brought by visiting humans/birds, by flying, crawling up or as "air plankton" (Chapman et al. 2004).

The presence of Lepidoptera (butterflies), the many Hymenoptera (wasps and bees) and Diptera (flies) species in my research showed that if provided with the right conditions, invertebrates will colonize roofs in heights up to 70 meters. Insects can be found carried by the wind as "air plankton" up to 200 meters (Chapman et al. 2004), so it can be expected to find insects at even greater heights. However, height did show to negatively impact invertebrate diversity on the 12 extensive green roofs in my study. Similar results were found on a study on bee diversity where a negative correlation was found with increasing heights (Maclvor and Ksiazek 2015).

For intensive roofs there was not a significant correlation between invertebrate diversity and height. This could be because not enough intensive roofs of different heights were sampled and/or because the variation in vegetation is more dominantly determining invertebrate diversity. The intensive roof at 70m had the highest Shannon Wiener index compared to all the extensive roofs. This indicated that with increasing heights, intensive roofs are better to implement for increasing invertebrate diversity. It did have a low Shannon Wiener index compared to the other intensive roofs, indicating that also for intensive roofs there might be negative correlation with increasing height.

Of the invertebrates found in this research, 28% were non-flying species. *Succinea oblonga* (Gastropoda, snail species) was encountered on a few green roofs. According to the study of *Moerland, 2011*, this is a species that is not very common for urban areas and is therefore likely to have been delivered together with the installation of the green roof (Moerland 2011). Non-flying invertebrates like Chilopoda (centipedes), Collembola (springtails), Araneae (spiders), Isopoda (wood lice) and Gastropoda (slugs/snails) were regularly encountered on green roofs. Spiders likely get to green roofs through ballooning, a method of air travel which could aid them in roof colonization. Spiders of the Linyphiidae family were most abundant in this research and this family is best known for their ballooning behaviour (Blandenier 2009).

Earthworms were found on only two sites in this research, on roof 4 (with varying depths from 60 to 400 mm) and roof 17 (with varying depths from 60 to 680 mm). On roof 4 the worms were brought with the compost for the Wormhotel. This was probably the case for roof 17 as well. The presence of these earthworms show that they are able to survive on green rooftops with at least a soil depth of 400 mm. Earthworms were expected to perish in thinner substrate as they cannot move to deeper, cooler regions (Brenneisen 2006).

### **Plant diversity**

From my study it was clear that an increase in plant species is strongly correlated with an increase in invertebrate diversity. Which plant species to use on green roofs is dependent on how much soil the plant needs, its flowering time and its attractiveness for certain invertebrate species. These features will be discussed in this section with the findings from my research and literature research.

Sedum acre (wallpepper), Trifolium repens (white clover), Sedum album (white stonecrop) and Dianthus armeria (a carnation) were found to attract the highest abundance of bees, butterflies and hoverflies in a study on the difference of three types of sedum mats from Sempergreen BV (Huigens et al. 2015). These plant species were found in my study as well, showing that they are capable of surviving the conditions on green roofs like extreme droughts.

Fabaceae (legume family) species are important for many butterfly species (Chinery 2012), show to retain water very effectively (Dusza et al. 2017) and many species within the family can be important nitrogen fixators (Stewart 1966) which contributes to a healthy soil and therefore a well-functioning roof. In the study of *Dusza (2017)*, it was found that Fabaceae species retain twice as much water compared to species of the Crassulaceae, Asteraceae, Caryophyllaceae or Poaceae (Dusza et al. 2017). Representatives of the Fabaceae family were found on many of the rooftops in my research, showing that these are suitable species to grow on green roofs.

Combining different plants on green roofs incorporates the different functions of a green roof. To mitigate the heat island effect it is better to use species like *Koeleria pyramidata* (species of grass) due to its high evapotranspiration capacities, while for water retention it is better to use Fabaceae species (Dusza et al. 2017). Polycultures have also shown to enhance mutual functionality of different plant species in natural environments, as well as increase biodiversity of flora and fauna (Lundholm 2015, Dusza et al. 2017, Yahya et al. 2017).

Flowering time is important for invertebrate diversity as it is the main source of food for many species (Moerland 2011). Planting species with flowering time at different times of the year can therefore greatly enhance invertebrate diversity. Including local flora species will be more attractive to the local fauna as these will be more familiar to them (Moerland 2011).

A dense vegetation cover is very important for increasing invertebrate diversity according to a green rooftop study on vegetation cover (Schindler et al. 2011), which was also observed in my study on roof 4. The rear part of the roof, with a denser vegetation cover with many grasses and clovers, had a higher invertebrate diversity in the pitfalls compared to the arable front part. Invertebrate diversity in the pan traps however was the same for both parts.

## Substrate depth

In this study, substrate depth was shown to have a positive correlation with beetle abundance (from the PCA) as well as invertebrate diversity (from the diversity index analysis). The PCA indicated that substrate depth has its own effect on invertebrate composition, seeming to be positively correlated with beetle abundance. This was also found in the study of *Pétremand et al. (2018)* where ground beetle abundance was positively correlated with substrate depth (Pétremand et al. 2018).

The diversity indices showed that substrate depth has a similar effect on invertebrate diversity as plant species richness. A thicker substrate layer is thought to have an indirect effect on invertebrate communities as a deeper substrate leads to better plant growth and higher water retention (Dusza et al. 2017). Water retention is one of the most important functions of a

green roof. The more water it retains, the better it will perform its function as a green roof; mitigating the heat-island-effect, decreasing the load on the sewerage systems during heavy rains, as well as increasing biodiversity. Water retention has been found to be significantly influenced by substrate depth, substrate type and plant family (Dusza et al. 2017). According to the study of *Dusza et al (2017)*, there was a significant increase in water retention found with deeper soil, which was also observed in my study (figure 4).

My study showed that a roof with a substrate depth of 150 mm and no watering system, does not dry out, unlike roofs with a substrate depth of 60 mm and no watering system that had completely dried out. Shading could also have aided in retaining more water on this roof. It is therefore recommended to have a minimal depth of 150mm on a roof, in combination with shaded areas. It is thought that plant succession could be negatively impacted with thinner soils, as plants are not able to root properly in these thin substrate layers. This however has yet to be studied on green roofs.

Natural substrates are often found to promote insect diversity as it reaches out to the local flora and fauna (Brenneisen 2006). Natural substrates have shown to improve the abundance of beetles and spiders on rooftops in other studies (Gedge et al. 2012, Pétremand et al. 2018).

The application of relief has shown to be very effective in promoting biodiversity (Huigens et al. 2015, Pétremand et al. 2018). Sandy elevations with shelter from the south side are suitable for wild bee nesting habitats (Moerland 2011). Relief stimulates biodiversity through the increase of microhabitats (Brenneisen 2006). Elevations of only 4 - 10 cm are enough to create changes in the microclimate through variation in exposure to sun, wind and rain. This promotes diversity in plants as well as in invertebrate communities (Gedge et al. 2012). The DakAkker, with the highest invertebrate diversity in this study, had much variation in relief, so this could have contributed to the high diversity on this rooftop.

### **Future research**

This explorative research can be improved by repeating the measurements and increase sampling effort as well as improving the selection of the chosen buildings.

Repeating the measurements and increasing the sampling size is important as wind showed to have influenced the PCA in my study (see figure 6) and the species accumulation curve had not reached an asymptote (see figure A.6). Pitfalls are an effective way of catching ground-dwelling invertebrates and give an overview of the less mobile species that can be found on green roofs. I would therefore recommend to use pitfall trapping methods for future research. Pan traps are an effective way to catch flying invertebrates, however many of the invertebrates that I observed flying around were not caught in the pan traps. I would therefore suggest additional catching by means of a transect per rooftop with a leaf vacuum cleaner, as used in the research of *Moerland 2011* in combination with net catching. As there was one roof with a pond in this research (number 11) I suggest doing water sampling here, which could shed light on the reproduction possibilities a pond on a green roof could provide.

For the selection of roofs I would suggest to select more buildings, evenly distributed over the (four or more) different cities. Factors like height and roof type (intensive/extensive) should

be evenly represented per city. The surrounding green area did not show to be of significant influence in my study. However with this set-up, the differences between location (in this case the cities) could be tested. The type of the surrounding green area was not tested in my study, so this would also be recommended for future research. The surrounding green area is thought to influence species composition (Huigens et al. 2015, Gabrych et al. 2016) so increasing the sampling size could improve the PCA based on species composition and perhaps show the influence of the surrounding green area.

The succession of invertebrates and plants as well as the pathways of colonization should be further studied by repeated measurements over consecutive years. Butterflies are attracted to the green roofs to lay there eggs. My research could not show whether life cycles can be completed on these green roofs. Green roofs might form a trap, as the thin substrates decrease development and pupation rates of these butterflies.

The presence of solar panels establish a cooling-symbiosis with a green roof: solar panels provide shaded areas which can help keep the green roof moist and cool. In turn, the cooling effects of a green roof have a positive influence on the functioning of solar panels (Hui and Chan 2011). How the presence of solar panels influence invertebrate diversity is still unknown, so this should be further studied.

# Conclusion

My study showed that an increase in plant species richness has a strong positive effect on invertebrate diversity on green roofs. Plant species richness is dependent on substrate depth and its water retention capabilities. An increase in substrate depth showed to also positively influence invertebrate diversity. When installing green roofs it is important to either invest in a good watering system, or a thick substrate layer, or both. A good watering system will be favourable if the building cannot endure too much weight and can only support a thin substrate layer. A thicker substrate layer would be optimal, starting with at least a depth of 150 mm. A thicker substrate has its advantages in that it reduces energy costs for watering, increases its insulation and water retention capacities, and provides more space for more plant species to root. Fabaceae species are shown to grow well on rooftops, attract many different species of butterflies and retain water better than other plant families. Including Fabaceae species on green roofs would therefore be favourable. Creating microclimates by incorporating relief and different vegetation types greatly enhances invertebrate diversity. Including native plants and natural substrates creates habitats on green roofs resembling the surrounding green areas and will support the native fauna effectively. Heights of 70 meters still support a high diversity of invertebrates. However extensive roofs show a decline in invertebrate diversity, indicating that with increasing heights, intensive roofs will be more efficient in supporting invertebrate diversity. Ageing of green roofs results in a more stabilized ecosystem with a more even distribution of species. Other factors like roof surface and surrounding green areas did not significantly contribute to invertebrate diversity in this study. Facilitating a higher diversity on green roofs in turn induces an array of beneficial green roof services such as water retention, mitigating the UHI-effect and insulation, making biodiversity an integral part of green rooftop functionality.

## Acknowledgements

I want to thank my supervisors Rens de Boer and Nina Fatouros for all their feedback and help with my work. I want to thank the whole crew from Bureau Stadsnatuur Rotterdam greatly for all the help with identifying, discussing the results and the *gezelligheid* at the office. I want to thank Max Veeger who helped with the start-up of this research. I want to thank Gerard Korthals from NIOO for the corporation with green rooftop research, as well as Albert Vliegenthart from the Vlinderstichting. I want to thank Jan Smit from EIS who helped me with identifying the rare Pompilidae species (see also appendix figure A.7) and Kees van Achterberg for identifying *Idiasta dichrocera*, a new species for the Netherlands. I want to thank the Diptera sectie from the NEV for helping me out with identifying some of my teeny tiny flies that I caught on my roofs, and teaching me all about the difficulties of identifying Dipteras. I want to thank all the rooftop owners for giving me access to their roofs and for their enthusiasm about my research. I want to thank my brother Daan Drukker and his girlfriend for all their help and letting my stay over at their place when I was conducting research on the rooftops of Amsterdam.

## References

- Bianchini, F., and K. Hewage. 2012. How "green" are the green roofs? Lifecycle analysis of green roof materials. Building and environment **48**:57-65.
- Blandenier, G. 2009. Ballooning of spiders (Araneae) in Switzerland: general results from an elevenyear survey. Arachnology **14**:308-316.
- Braaker, S., J. Ghazoul, M. Obrist, and M. Moretti. 2014. Habitat connectivity shapes urban arthropod communities: the key role of green roofs. Ecology **95**:1010-1021.
- Braaker, S., M. K. Obrist, J. Ghazoul, and M. Moretti. 2017. Habitat connectivity and local conditions shape taxonomic and functional diversity of arthropods on green roofs. Journal of Animal Ecology **86**:521-531.
- Brenneisen, S. 2006. Space for urban wildlife: designing green roofs as habitats in Switzerland. Urban habitats **4**.
- Buchholz, S., A.-M. Jess, F. Hertenstein, and J. Schirmel. 2010. Effect of the colour of pitfall traps on their capture efficiency of carabid beetles (Coleoptera: Carabidae), spiders (Araneae) and other arthropods. European Journal of Entomology **107**.
- Calderon, M. R., B. P. Baldigo, A. J. Smith, and T. A. Endreny. 2017. Effects of extreme floods on macroinvertebrate assemblages in tributaries to the Mohawk River, New York, USA. River Research and Applications **33**:1060-1070.
- Castleton, H. F., V. Stovin, S. B. Beck, and J. B. Davison. 2010. Green roofs; building energy savings and the potential for retrofit. Energy and Buildings **42**:1582-1591.
- Chapman, J., D. Reynolds, A. Smith, E. Smith, and I. Woiwod. 2004. An aerial netting study of insects migrating at high altitude over England. Bulletin of entomological research 94:123-136.
  Chinery, M. 2012. Nieuwe Insectengids. Tirion Natuur 9.
- Cirkel, D., B. Voortman, T. van Veen, and R. Bartholomeus. 2018. Evaporation from (Blue-) Green Roofs: Assessing the Benefits of a Storage and Capillary Irrigation System Based on Measurements and Modeling. Water **10**:1253.
- Coffman, R. R., and G. Davis. 2005. Insect and avian fauna presence on the Ford assembly plant ecoroof. Pages 4-6 *in* Third annual greening rooftops for sustainable communities conference, awards and trade show.
- Dusza, Y., S. Barot, Y. Kraepiel, J. C. Lata, L. Abbadie, and X. Raynaud. 2017. Multifunctionality is affected by interactions between green roof plant species, substrate depth, and substrate type. Ecology and evolution **7**:2357-2369.
- Froment, C. 2017. Arthropods communities on green roofs in Brussels: Influence of roof vegetation and landscape context.
- Gabrych, M., D. J. Kotze, and S. Lehvävirta. 2016. Substrate depth and roof age strongly affect plant abundances on sedum-moss and meadow green roofs in Helsinki, Finland. Ecological Engineering **86**:95-104.
- Gedge, G., G. Grant, G. Kadas, and C. Dinham. 2012. Creating green roofs for invertebrates–a best practice guide. Peterborough: Buglife.
- Getter, K. L., and D. B. Rowe. 2006. The role of extensive green roofs in sustainable development. HortScience **41**:1276-1285.
- Hallmann, C. A., M. Sorg, E. Jongejans, H. Siepel, N. Hofland, H. Schwan, W. Stenmans, A. Müller, H. Sumser, and T. Hörren. 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PloS one 12:e0185809.
- Heip, C. H., P. M. Herman, and K. Soetaert. 1998. Indices of diversity and evenness. Oceanis 24:61-88.
- Hui, S. C., and S. Chan. 2011. Integration of green roof and solar photovoltaic systems. Pages 1-12 *in* Joint symposium.
- Huigens, M. E., B. Merkens, A. Groot, A. Stip, and A. Vliegenthart. 2015. Vlinders en bijen op een groen dak. Rapport VS2015. 030, De Vlinderstichting, Wageningen.
- Kadas, G. 2006. Rare invertebrates colonizing green roofs in London. Urban habitats **4**:66-86.

- Kleerekoper, L., M. Van Esch, and T. B. Salcedo. 2012. How to make a city climate-proof, addressing the urban heat island effect. Resources, Conservation and Recycling **64**:30-38.
- Köhler, M. 2006. Long-term vegetation research on two extensive green roofs in Berlin. Urban habitats **4**:3-26.
- Li, D., E. Bou-Zeid, and M. Oppenheimer. 2014. The effectiveness of cool and green roofs as urban heat island mitigation strategies. Environmental Research Letters **9**:055002.
- Losey, J. E., and M. Vaughan. 2006. The economic value of ecological services provided by insects. AIBS Bulletin **56**:311-323.
- Lundholm, J. T. 2015. Green roof plant species diversity improves ecosystem multifunctionality. Journal of Applied Ecology **52**:726-734.
- Maclvor, J. S., and K. Ksiazek. 2015. Invertebrates on green roofs. Pages 333-355 Green roof ecosystems. Springer.
- MacIvor, J. S., and J. Lundholm. 2011. Insect species composition and diversity on intensive green roofs and adjacent level-ground habitats. Urban ecosystems **14**:225-241.
- Madre, F., A. Vergnes, N. Machon, and P. Clergeau. 2013. A comparison of 3 types of green roof as habitats for arthropods. Ecological Engineering **57**:109-117.
- Mallinger, R. E., H. R. Gaines-Day, and C. Gratton. 2017. Do managed bees have negative effects on wild bees?: A systematic review of the literature. PloS one **12**:e0189268.
- McGregor, S. E. 1976. Insect pollination of cultivated crop plants. Agricultural Research Service, US Department of Agriculture Washington, DC.
- McKinney, M. L. 2008. Effects of urbanization on species richness: a review of plants and animals. Urban ecosystems **11**:161-176.
- Mentens, J., D. Raes, and M. Hermy. 2006. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape and Urban Planning **77**:217-226.
- Moerland, W. 2011. Ecologische waarden op drie groene daken in Rotterdam.
- Morse, D. H. 1971. The insectivorous bird as an adaptive strategy. Annual Review of Ecology and Systematics **2**:177-200.
- multifunctionele daken-Algemeen, M., G. Rotterdam, S. Arosa, and D. De Heuvel. 2018. LIFE@ URBAN ROOFS.
- Niachou, A. 2001. Analysis of the green roof thermal properties and investigation of its energy performance. Energy and Buildings **33**:719-729.
- Nugrahaningrum, A., M. F. Harianja, and H. Nugroho. 2017. Macroinvertebrate diversity role in water quality assessment of Winongo and Gajah Wong rivers, Yogyakarta, Indonesia. Bonorowo Wetlands **7**:31-37.
- Oksanen, J., F. G. Blanchet, R. Kindt, P. Legendre, P. R. Minchin, R. O'hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, and H. Wagner. 2013. Package 'vegan'. Community ecology package, version 2.
- Ollerton, J., R. Winfree, and S. Tarrant. 2011. How many flowering plants are pollinated by animals? Oikos **120**:321-326.
- Pétremand, G., Y. Chittaro, S. Braaker, S. Brenneisen, M. Gerner, M. K. Obrist, S. Rochefort, A.
  Szallies, and M. Moretti. 2018. Ground beetle (Coleoptera: Carabidae) communities on green roofs in Switzerland: synthesis and perspectives. Urban ecosystems 21:119-132.
- Pielou, E. C. 1966. Shannon's formula as a measure of specific diversity: its use and misuse. The American Naturalist **100**:463-465.
- Schindler, B. Y., A. B. Griffith, and K. N. Jones. 2011. Factors influencing arthropod diversity on green roofs. Cities and the Environment (CATE) **4**:5.
- Stewart, W. D. P. 1966. Nitrogen fixation in plants. Nitrogen fixation in plants.
- Tonietto, R., J. Fant, J. Ascher, K. Ellis, and D. Larkin. 2011. A comparison of bee communities of Chicago green roofs, parks and prairies. Landscape and Urban Planning **103**:102-108.
- United Nations. 2018. World Urbanization Prospects: The 2018 Revision. <u>https://esa.un.org/unpd/wup/publications/Files/WUP2018-KeyFacts.pdf</u>.

- Westphal, C., R. Bommarco, G. Carré, E. Lamborn, N. Morison, T. Petanidou, S. G. Potts, S. P. Roberts,
  H. Szentgyörgyi, and T. Tscheulin. 2008. Measuring bee diversity in different European
  habitats and biogeographical regions. Ecological monographs 78:653-671.
- Wonga, N. H., S. F. Taya, R. Wonga, C. L. Ongb, and A. Siab. 2003. Life cycle cost analysis of rooftop gardens in Singapore. Building and environment **38**:499-509.
- Yahya, M. S., M. Syafiq, A. Ashton-Butt, A. Ghazali, S. Asmah, and B. Azhar. 2017. Switching from monoculture to polyculture farming benefits birds in oil palm production landscapes: Evidence from mist netting data. Ecology and evolution **7**:6314-6325.

## **Appendix**



Figure A.1. (a) Overview of the different orders of larvae found. Numbers represent the number of individuals found per order. (b) The different substrate depths de larvae were found in. 64% was found substrate of 60 mm or less. 36% was found in substrates over 60 mm. (c) Overview of where the larvae were found.



Figure A.2. Diversity vs Substrate depth. Shannon Wiener (y-axis) plotted against the Logarithm of the substrate depth (x-axis). Numbers indicate the Roof ID (see table A.1, Appendix). Red squares represent extensive roofs, green dots represent intensive roofs.

Rooftops colored by location



Figure A.3. Ordination with rooftops coloured by location. PCA based on orders, rooftops are represented by dots, coloured based on location. Red dots were rooftops located in Rotterdam. Gold/yellow represents Amsterdam, green represents Wageningen and blue is Utrecht. There are different shades of red, as well as gold depending on how far apart the buildings in either Rotterdam or Amsterdam were located. There is no clustering for similar locations based on species composition as is visible in the figure.

Number	Roof ID	Location
1	Zalmstraat	Rotterdam
2	CBK Rotterdam	Rotterdam
3	Het Nieuwe Instituut	Rotterdam
4	De DakAkker	Rotterdam
5	Joost Banckertsplaats	Rotterdam
6	Alexandrium	Rotterdam
7	Kattenburgerstraat	Amsterdam
8	Plantage Middenlaan	Amsterdam
9	Nemo	Amsterdam
10	Boelelaan	Amsterdam
11	Johan Huizingalaan	Amsterdam

Table A.1. Overview of the numbers used in the figures and the corresponding rooftop. Specifically for rooftop owners to trace back the results for their own rooftops.

12	Kalverstraat	Amsterdam
13	Accenture	Amsterdam
14	Gustav Maherplein	Amsterdam
15	NIOO hoofdgebouw	Wageningen
16	Lumen	Wageningen
17	Erasmus MC	Rotterdam
18	Theil EUR	Rotterdam
19	NIOO zonnepanelen	Wageningen
20	NIOO lag	Wageningen
21	Stadskantoor Utrecht	Utrecht



Figure A.4. Ordination with Hymenoptera species and Syrphidae (hoverfly) species, to see influence of *Apis mellifera* (European Honey Bee). Red dots represent the extensive roofs, green dots represent the intensive roofs. The length of the arrow is a measure of importance of the variables (wind speed, substrate depth, presence bee hive, plant species richness) here significant at the 0.05 according to the permutation test. Arrowheads point in the direction of increasing influence. The green text represents the position of each species in the ordination.



Figure A.5. Species accumulation curve. Newly found orders per sampling site. Y-axis shows the number of orders newly found, the x-axis shows the sampling sites.



Figure A.6. Newly found species per sampling site. Y-axis shows the number of species newly found, the x-axis shows the sampling sites.



Figure A.7. *Agenioideus sericeus*. A rare Pompilidae species, first one recorded for Amsterdam. Picture was made with help from my roommate Cas van den Bomen.



Figure A.8. *Idiasta dichrocera*. New species for the Netherlands. Picture and identification by Kees van Achterberg.

#### Rooftops colored by vegetation type



Figure A.9. Invertebrate composition based on orders excluding *Apis mellifera* (European Honey Bee). Red dots represent the extensive roofs, green dots represent the intensive roofs. The length of the arrow is a measure of importance of the variables (wind speed, substrate depth, presence bee hive, plant species richness) here significant at the 0.05 according to the permutation test. Arrowheads point in the direction of increasing influence. The green text represents the position of each invertebrate order in the ordination.