Wildlife on Your Doorstep

Ecosystem Services of Private Urban Gardens

Research Report

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Bachelor thesis on behalf of Stichting Operatie Steenbreek

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Date of defence	June 27th, 2016

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“Many small people, who in many small places do many small things can change the face of the world.”

African saying

Preface

This bachelor thesis was carried out in the framework of the BSc programme Animal Management with the major Wildlife Management at Van Hall Larenstein University of Applied Science in Leeuwarden (NL). The project was on behalf of Stichting Operatie Steenbreek and took place between February and June 2016. The client was Wout Veldstra form Stichting Operatie Steenbreek. The lecturers Christa van der Weyde and Berend van Wijk supervised the project, while Arjen Strijkstra assessed the intermediate and final products.

I conducted the present study within a work group of three students, who wrote their final theses for Stichting Operatie Steenbreek. The other two projects complemented my work with topics concerning the added value of Stichting Operatie Steenbreek for municipalities and the contribution of private gardens to the urban ecological structure of the city of Leeuwarden.

During the course of the research, I developed a new perception of nature protection. The project sensitised me for the importance of nature on our doorsteps. With this report, I would like to share my knowledge about and passion for private gardens and how we can improve their naturalness. These garden will pay their owners back eventually and provide vital ecosystem services, which raise the quality of life in the urban environment immensely.

This project would not have been possible without the help of others. Firstly, I want to thank my supervisors Christa van der Weyde and Berend van Wijk, who invested their time to guide and support me. Their expertise and calm manner helped through all unforeseen obstacles. Secondly, I like to express my thanks to my assessor Arjen Strijkstra for his focused guidance and fair assessments. Furthermore, I want to thank the members of Stichting Operatie Steenbreek for their obligingness to answer all my questions. In particular Wout Veldstra for making this research possible and his professional input. I also like to thank Benjamin Daniels from RWTH Aachen University for advising me and encouraging me in my work. Last but not least, I am thankful for all the support my family has given me throughout the project.

Summary

In the Netherlands, as well as many other countries, the area of sealed impervious materials is constantly extending. One of the concomitants of the increasing pace of urbanization is the loss of green spaces in the city. Private gardens are likewise facing higher sealing rates. The higher proportion of impervious areas has manifold negative effects on the urban environment such as high chances of flooding and higher temperatures than in the surroundings. As a response, the national Dutch foundation Stichting Operatie Steenbreek (SOS) was initiated in 2015. The goal of this group of specialists is the encouragement of citizens to cover their gardens with greenery and to reduce the area of sealed surfaces. SOS is eager to set up an extended database of the influences of gardens on the urban environment to reach and convince as many people as possible. These influences are evaluated by means of ecosystem service (ES) provision. Ecosystem services are all benefits that people obtain from the natural environment, including gardens. These are for example provision of food and material as well as regulating services such as pollination and air filtering. Many studies assessed the provision of ES by public green spaces. The role of private urban gardens however is up to now only evaluated in a limited number of studies. This research presents an insight in the characteristics and effects of ES provision in private urban gardens. By means of a literature review, the specific circumstances under which ES can be provided are elaborated. Interviews with experts and authorities of Dutch municipalities supplement the research with information on the detailed application of the review results. Based on the apparent need for accessible and intelligible information, a website framework is developed to inform private garden owners about the sealing problem, SOS and the effects of their gardening measures. The results of the research provide essential information about the role of private gardens for urban ecosystems. They show that almost all ES can in theory be directly or indirectly delivered by private gardens. Provisioning services such as food show are increasingly demanded by urban gardeners. Urban Agriculture offers substantial application potentials for private gardens. Regulating services such as pollination and climate regulation require a minimum connectivity or area size of favourable conditions to be able to deliver services efficiently. These favourable conditions are predominantly based on low sealing rates and high levels of vegetation. The same conditions are beneficial for supporting services, namely a good soil quality. The last category of cultural services is characterized by providing benefits solely for the human population. These services depend on a subjective valuation in particular the preferences of the garden owner. Most of the ES are improved by greener gardens. ES are furthermore strongly connected with biodiversity and connectivity levels. Higher levels of these are demonstrated to improve ES provision. ES are also interconnected, which creates a network of interacting systems and processes. Combinations of several ES generates supportive synergies, which yield better services than single ES. Several generally favouring conditions for ES provision appeared predominantly throughout the literature research. They are: a minimized area of sealed surfaces and a high green volume and structural diversity. The consequences of the findings are discussed and recommendations are made for private garden owners as well as for the work of authorities. Different promotion methods are advised for the various ES, based on the scale of the needed effort and expected effectiveness. This report forms a basis which can be used by SOS to pursue its objectives. By means of this report the work of SOS becomes and similar initiatives more effective and efficient. It provides sound evidence of the potentials of private urban gardens and enables the information transfer about these potential to owners and authorities.

Samenvatting

In Nederland alsook veel andere landen groeien de terreinen met versteend oppervlaktes voortdurend. Een van de bijverschijnselen van het versnellende tempo van de urbanisatie is het verlies van groene ruimte. Ook in particuliere tuinen worden steeds vaker planten door tegels vervangen. Een hoger aandeel van versteende oppervlaktes heeft veelvuldige negatieve effecten op het stedelijke milieu zoals een verhoogde kans op overstromingen en hogere temperaturen dan in de omgeving. Daarom wordt in 2015 de landelijke Stichting Operatie Steenbreek (SOS) opgericht. Het doel van de groep van experts is het enthousiasmeren van burgers voor groenere tuinen en het reducerend van betegelde oppervlaktes. Om zo veel mensen als mogelijk te bereiken en overtuigen wil SOS een wetenschappelijke kennisbank van de invloeden van tuinen op het stedelijke milieu opbouwen. Deze invloeden worden aan de hand van ecosysteemdiensten gemeten. Ecosysteemdiensten zijn in het algemeen de voordelen die mensen genieten van hun natuurlijk omgeving. Te denken valt daarbij aan de voorziening van voedsel en bouwstoffen maar ook regulerende diensten zoals de natuurlijke bestuiving en zuivere lucht. Veel onderzoeken hebben de verzorging van ecosysteemdiensten in openbare ruimtes geëvalueerd. De rol van particuliere tuinen is tot nu toe maar in een beperkt aantal studies opgenomen. Dit onderzoek geeft inzicht in de kenmerken en effecten van ecosysteemdiensten in particuliere, stedelijke tuinen. Met behulp van een literatuuronderzoek zijn de specifieke omstandigheden uitgewerkt waaronder ecosysteemdiensten geleverd kunnen worden. Interviews met experts en medewerkers vanuit de gemeenten vullen het onderzoek met informatie over de toepassing van de resultaten inde praktijk aan. Ten laatste wordt een website raamwerk opgesteld om tuinbezitters over het versteningsprobleem, SOS en de effecten van hun tuinactiviteiten te informeren. De resultaten van het onderzoek geven essentiële informatie over de rol van privé tuinen voor stedelijke ecosystemen. Zij laten zien dat bijna alle ecosysteemdiensten in principe door particuliere tuinen direct of indirect geleverd kunnen worden. Productiediensten zoals de teelt van voedsel worden steeds vaker door stedelijke tuiniers gevraagd. De urbane landbouw biedt aanzienlijke toepassingsmogelijkheden voor particuliere tuinen. Regulerende diensten zoals bestuiving en klimaatregulatie hebben een minimale connectiviteit of oppervlakte van gebieden met wenselijke omstandigheden nodig om ecosysteemdiensten effectief te kunnen leveren. Deze wenselijke omstandigheden worden vooral uitgemaakt door een lage mate van versteende oppervlaktes en een hoge mate van vegetatie. Deze omstandigheden zijn verder voordelig voor ondersteunende diensten met name een goede bodemkwaliteit. De laatste categorie zijn de culturele diensten welke uitsluitend baten voor mensen opleveren. Deze diensten zijn afhankelijk van een subjectieve waardering vooral de preferenties van de tuin bezitter. De meeste ecosysteemdiensten woorden verbeterd door groenere tuinen. Ze zijn verder sterk verbonden aan het level van biodiversiteit en connectiviteit. Onderzoeken tonen aan dat hoger levels van biodiversiteit en connectiviteit de voorziening van ecosysteemdiensten verbeteren. Ecosysteemdiensten zijn verder met elkaar verbonden waardoor een netwerk van onderling beïnvloedende systemen en processen ontstaat. Combinaties van meerdere ecosysteemdiensten genereert ondersteunende synergiën die meer betere diensten opleveren dan enkele ecosysteemdiensten. Enkele algemene wenselijke omstandigheden voor de voorziening van ecosysteemdiensten zijn voornamelijk in de literatuur genoemd. Deze zijn; een minimale betegelde oppervlakte en een omvangrijke vegetatiestructuur en een grote structurele diversiteit. De gevolgen van deze resultaten worden gediscuteerd en aanbevelingen gemaakt voor particuliere tuinbezitters en het werk van overheden. Verschillende promotie methodes zijn geadviseerd voor de ecosysteemdiensten gebaseerd op de benodigde inspanningen en verwachte effectiviteit. Dit verslag vormt een basis waarmee SOS zijn doelwitten kan bereiken. Door het voorliggende verslag wordt het werk van SOS en soortgelijke initiatieven effectiever en doelgerichter. Het verslag biedt wetenschappelijke bewijzen over het potentiaal van particuliere tuinen en bevordert de informatieverspreiding van dit potentiaal naar tuinbezitters en overheden.

Content

1 Introduction

Urban areas accommodate half of the human population and will be the centre of the world's population growth over the next 30 years (UN-Habitat, 2010). The ongoing urbanization involves far-reaching consequences for the environment. Although the concentrated accumulations of people in metropolitan areas decrease the pressure of human settlements in the surrounding rural areas, the conflict of interests between human and nature within the cities intensifies (Mathey et al., 2011). Therefore the necessity to find solutions for this conflict is of growing priority. Looking back in history, the dilemma exacerbates with the tendency of humans to settle in species-rich areas (Ricketts & Imhoff, 2003). The importance of nature within cities is thus significant and even increases with the restricting quality of the alternative rural areas for nature. Exploited agricultural areas often suffer from the decline of species richness (Billeter et al., 2008). The increasing demand for agricultural land to supply food for the human population puts the remaining natural areas in jeopardy and calls for more integral solutions to the coexistence of people and nature.

One of the concomitants of the ongoing urbanization is the expansion of sealing surfaces. National studies show, that the area of impermeable materials in the Netherlands is constantly increasing. Within the EU, the Netherlands have the second highest sealing rate of 8.1%, only exceeded by the island country Malta (Prokop et al., 2011). Additionally, between 2000 and 2006, every year nearly 6000 hectares of land were transformed into artificial surfaces in the Netherlands (Prokop et al., 2011). The effects of soil sealing are of particular significance for the environmental and social conditions within the cities. These conditions can be measured in the form of ecosystem service provision. Ecosystem services (ES) are all benefits, people can gain from their natural environment (MEA, 2003). Urban soil sealing jeopardizes ES in many ways (for example Radford & James, 2013). A brief selection of examples includes firstly the effect on water cycles. As the term implies, surfaces become impermeable to water and prevent any form of plant growth. Rainwater cannot seep away and accumulates in the gutters. During heavy weather the sewage systems can collapse and cause flooding of streets and buildings (Tjallingii, 2011). Secondly, Wolfe and Mennis (2012) examined the relation between crime rates and vegetation abundance and confirm a positive correlation of vegetation and lower rates of assault, burglary and robbery. Next, there are numerous studies about the health benefits deriving from green spaces, for instance the positive correlation between nearby green spaces and improved health and well-being (see e.g. de Vries et al., 2003; Gidlöf-Gunnarsson & Öhrström, 2007). Moreover, without sufficient green spaces the temperature during warm days can increase tremendously. Plants normally have a cooling effect through evaporation and provision of shade. Buildings and ground coverings absorb the heat and reradiate it, creating the so called Urban Heat Island (Grant, 2012). Green roofs can mitigate this phenomenon, also contribute to urban biodiversity, food production and water management (Tanaka et al., 2016). Lastly, the importance of biodiversity for ES, nature resilience and health is described in numerous studies (e.g. Russell et al., 2013; Sandifer et al., 2015).

The importance of biodiversity and connectivity for these ES becomes more and more important within the urbanized environment. Yet,. Urban floral and faunal communities have critical thresholds of habitat size and connectivity to remain resilient and survive (European Commission, 2013a). If these thresholds cannot be met, ecosystems and corresponding services will collapse. Yet, the high complexity of urban ecosystems hampers integral examinations of urban processes and formulations of specific threshold values. Generally speaking, higher proportions of green spaces within the city mainly increase the quality of life for all living organisms, including humans (Mader et al., 2011). Among others, horizontal and vertical greening can help to balance the climate in urbanized areas by buffering variations in temperature and improving the air quality (e.g. Francis & Lorimer, 2011).

Many studies assessed the provision of ES by public green spaces (Hansen & Pauleit, 2014; Kronenberg, 2015). The role of private urban gardens however, is up to now only evaluated in a limited number of studies (e.g. Barratt et al., 2015; Beumer, 2014). One of these is the Climate Proof Cities research programme which is conducted by Dutch universities and knowledge institutes. The results indicate that unsealing private gardens can be a generic measure to prevent damage through flooding (Rovers et al., 2014). There are further promising studies showing that an appropriate lay-out of the garden can significantly increase local biodiversity (among others Burkhard et al., 2009; G. D. Daniels & Kirkpatrick, 2006; R. M. Smith, Gaston, et al., 2006; Sperling & Lortie, 2010). The evaluation of biodiversity along the rural-urban gradient remains controversial, as several studies proposed a decreased level in urban areas (Fontana et al., 2011; Radford & James, 2013), whereas others claimed the opposite (Banaszak-Cibicka & Zmihorski, 2012; Larondelle & Haase, 2013). More research is needed to detect the underlying reasons for this apparent contradiction. Apart from that, Hartig et al. (2014) remarked the absence of a review about the effects of gardens on human health. An interdisciplinary approach is needed to examine the provision of ES by residential landscapes (Cook et al., 2012). This review aims to provide an overview of the existent information on ES and biodiversity of private gardens.

The importance of green spaces within the city is indisputable, but the most effective design is to date not described in scientific studies. Compared to the reasonably studied public urban greens, the effect of different garden designs on ES remains largely unresolved (Mathieu et al., 2007). Specifically, the diverse influences within particular environmental contexts are not yet considered sufficiently. The legal conditions of the private territory furthermore form both an asset and a liability for the character of the urban infrastructure. The government has hardly any authority on this field, which minimizes the options of a top-down approach. Citizens are often concerned about over-regulating municipalities and enforced regulations without clear explanations and beneficial results (Dewaelheyns et al., 2016). Due to the often small size of individual urban gardens, the lack of authority control and the complex state of multifarious decision-makers, the role of gardens is often overlooked in the assessment of ES (Lead et al., 2011). Even if one garden alone is small in size, taken together their impact can be immense (Goddard et al., 2010). Proof of the applicability and significance of urban farming is historically given during periods of food shortage due to world wars or trade embargos (Altieri et al., 1999; Gómez-Baggethun & Barton, 2013; Lead et al., 2011).

While the ongoing urbanization destroys more nature to expand, citizens express a demand for natural areas in the close vicinity. Surveys have shown that the majority of the population (German and Dutch) wants to be outside and feels happy when surrounded by nature (Kloek, 2016; Küchler-Krischun et al., 2016). Today's life has become more stressful and gruelling, especially in cities. People therefore seek a place of rest and steadiness in the constantly changing environment. The spare time has gained more importance as well as relaxing sites which are in close proximity and permanently accessible. Private gardens can satisfy these demands and more. Coolen and Meesters (2012) demonstrated that private gardens deliver unique services that be substituted by the services of public sites. Thus, gardens potentially provide multifarious ES that are unique for the particular circumstances.

The growing trend of soil sealing has also been documented in private gardens. Studies reported a shift towards the use of more impermeable materials in the front and back gardens (for example Zwaagstra, 2014). Several extensive studies about urban gardens have been conducted in Great Britain such as the Urban Domestic Garden series (among others Thompson et al., 2003). A case study in five British cities showed that about 22% of the total urban areas are private gardens (Jenks and Jones, 2009). This offers a huge potential for the provision of essential ES within the urbanized environment. However, considering the present trend of paved gardens, the cityscape is changing from green to grey with all the concomitant effects of soil sealing on the environment both nearby and far-away. Between 1975 and 2000, urban vegetation decreased from 38% to 33% in Merseyside (UK) (Pauleit et al., 2005). In a similar study in Leeds (UK), Perry and Nawaz (2008) reported an increase of paved surfaces in front gardens by 19% over 33 years, reaching 90% in 2004. As a response,

several local and national authorities issued guidelines and policies to combat sealing trends (BMUB, 2015; Lead et al., 2011; Moons et al., 2013).

These reports testify the international topicality and pressure of the problem. As a response, a work group of specialists launched the national Dutch foundation 'Stichting Operatie Steenbreek' (SOS) in 2015. The group consists of experts from various NGO's and research institutions. Their goal is to encourage citizens to cover their gardens with greenery (Operatie Steenbreek, 2015). As of June 2016 twelve Dutch municipalities are participating under the framework of SOS (Veldstra, 2016). Those cities are serving as role models for other interested cities. The organisation aims to enlarge the number of associated cities to at least 20 by 2017 (Veldstra, 2016). One of the participating cities is Leeuwarden with a population of about 100.000 inhabitants (CBS, 2014). The local division of SOS in Leeuwarden has an extensive network of cooperating organisations including Van Hall Larenstein, University of Applied Sciences, the Friesian Environmental Federation (Friese Milieu Federatie), the water board of Friesland (Waterschap), the Knowledge Centre for Citizens and Biodiversity (Kenniscentrum Burgers en Biodiversiteit) and the municipality. This ensures a broad foundation for the execution of plans and actions. One of the major tasks of Van Hall Larenstein within SOS is the promotion of access to and dissemination of knowledge. To communicate the benefits of greener gardens, SOS requires an extended database of the influences of gardens on the urban environment. The aim of the present project is therefore, to *evaluate the characteristics and potentials of ecosystem service provision in private gardens.*

For the effective achievement of the aim, the main question and connected sub questions are:

Under which conditions can private urban gardens provide ecosystem services?

- Which types of ecosystem services can be provided by private urban gardens?
- Which types of ecosystem services can be provided by private urban gardens with a high proportion of vegetation compared to (mainly) sealed private urban gardens?

The results of this study provide essential insights concerning the influence private gardens on urban ecosystem services. Different garden designs (high or low proportions of vegetation) are evaluated and resulting recommendations for beneficial garden designs are made. Implications of the findings for every ecosystem service are given for authorities and private garden owners respectively. Furthermore, the relationship of ES and biodiversity and the resulting significance for urban gardens is explained. This report essentially improves and optimizes the work of Operatie Steenbreek and other interested parties. The initiative can promote desirable garden designs and inform citizens about the potentials of their garden space. In addition, the results can be implemented for complementary targets. Germany, for example, subsidizes municipal climate protection and adaptation concepts (BMUB, 2015). Cities can thus adopt the inspirations and recommendations of this study for their concepts to promote ecosystem service provisioning in gardens.

Based on the apparent need for easy to access and understand information (Bendegem et al., 2015; Peters et al., 2016), the results of this review are presented by means of a website. The framework of the website is presented in Appendix I. It is developed in accordance with the consultations with SOS experts and municipalities. As a goal, this website will illustrate the ES in private urban gardens and provide applicable and intelligible information about the different garden designs and their impact on ES.

2 Methods and Material

The role of private urban gardens was partly investigated in other situations, which revealed contradictory outcomes. The nature of the topic was thus complex and needed to be sketched out thoughtfully. It was therefore chosen to conduct a literature research and complementing interviews with experts. Similar methodologies were applied in related study set ups (Dewaelheyns et al., 2016; Kowarik, 2011; Lin et al., 2015). They were accordingly taken as examples and adapted for the present study. First some definitions of relevant terms are given. Thereafter the methodology of the literature research and the complementing arrangements are described.

2.1 Definitions

For the better understanding of the research, the most important methodological terms are briefly defined here.

Ecosystem services (ES)
The term *ecosystem services* was introduced to a broader public in the publication of the Millennium Ecosystem Assessment in 2003 (MEA, 2003). The given definition is:

> *"Ecosystem services are the benefits people obtain from ecosystems."*

The framework further classifies the ecosystem services in the categories provisioning, regulating, cultural and supporting services (MEA, 2003).

Ecosystem disservices
For *ecosystem disservices* on the other hand there is no official definition. However, there is a number of scientific studies about them of which the research by Lyytimäki and Sipilä (2009) is used here. It states that ecosystem disservices are defined as *"functions of ecosystems that are perceived as negative for human well-being"*.

Private urban garden
According to the Oxford Dictionary *urban* is defined as: "in, relating to, or characteristic of a city or town". (Oxford Dictionaries, 2016). In this study it is used as a delineation from private gardens located in rural areas, which are often characterized by a more agricultural landscape. Only private gardens within the borders of a town or city are included in this study.
The term *private garden* describes open spaces that belong to a residential building. These spaces can consist of a front and/or back garden and are mostly maintained by one household for personal use. Consequently the definition used here excludes public green spaces like parks and graveyards and also community gardens, allotments and commercial green spaces like tree nurseries.

Garden design
For the purpose of this study, *garden design* is used as an overarching concept for the lay-out of the respective garden. This includes plant species and abundances, green volume and structure, climatic conditions, size and proportion of sealed surfaces.

2.2 Literature research

2.2.1 Conceptual approach

For the conceptual approach, a ranking system for the relevance of the various ES has been developed. The ranking system delivered a method to evaluate the searching effort and relevance of the ES for the purpose of this thesis. The definition and categorization from the Millennium Ecosystem Assessment (MEA, 2003) were taken as a basis. In the following step, a ranking method was elaborated to define the relevance of the various ES for the research. The rank determined the targeted number of relevant publications in order to cover the topic sufficiently.

Table 1 illustrates the system; ES which are ranked 0 were not covered in this review based on the preliminary literature research. From 1 to 4 the relevance of the subject was growing along with the growing number of publications. Table 2 provides a list of the ES with their respective rankings. For instance, *water regulation* has been regarded as a central issue of this research based on the high topicality and relevance in the urban garden context (e.g. Zwaagstra, Radford and James). Accordingly, *water regulation* was ranked 4 (Table 2). This implied to find at least 15 relevant publications about *water regulation*.
On the other hand, several ES such as fibre production and storm protection of gardens were unlikely to be scientifically covered. They were consequently ranked 0. By elaborating at least one ES per category (provisioning, supporting, regulating and cultural) in greater detail, this report demonstrated the importance of all categories for the urban environment. Further notably relevant issues were ranked high based on the evaluations of experts (2.3 Complementing arrangements). Food provisioning, soil quality, pollination, climate and water regulation as well as health and well-being were accordingly rated 4.

Hyphens in the third column of Table 2 indicate that these ES are included within other chapters. Most of the provisioning services are combined under food provision. Likewise, erosion control was covered by soil formation and primary production was covered by climate regulation. On the other hand, findings that could not be assigned to a single ES are described in an additional chapter (4 Additional findings). The developed ranking system formed the basis for the evaluation of the services provided by private urban gardens.

Table 1 Ranking system to define the number of publications needed to cover the respective subject adequately

Rank	Relevance for research	Targeted number of publications
0	not covered in research	-
1	limited relevance	1-5
2	moderate relevance	5-10
3	moderate to high relevance but not key topic	10-15
4	high relevance topic and key topic	>15

Table 2 List of the ecosystem services with examples and the developed ranking. (Adapted from Butler et al., 2003)

Ecosystem service	**Examples**	**Rank**
	Provisioning	
Food	fruit, vegetables, herbs, eggs, meat,	4
Fibre	jute, hemp in principle included in *food provision*	-
Fresh water	included in *water regulation*	-
Fuel	wood, dung in principle included in *food provision*	-
Bio chemicals	natural medicine, medicinal herb in principle included in *food provision*	-
Genetic resources	conservation of rare plant species, species diversity	1
Ornamental	flowers, shells in principle included in *food provision*	-
	Regulating	
Pollination	distribution, abundance, and effectiveness of pollinators	4
Temperature	regulation and mitigation of Urban Heat Island	3
Climate regulation	sequestration, carbon storage capacity includes: *primary production* and *nutrient cycling*	4
Air quality	filtering of polluted air	2
Disease regulation	respiratory diseases, pest regulation	2
Water regulation	runoff, flooding, water purification includes: *fresh water provisioning*	4
Storm protection	protection against hurricanes and waves	0
Erosion control	included in *soil formation*	-
Noise	influence of garden (vegetation) on noise levels	1
	Supporting	
Soil formation	soil quality, accumulation of organic matter Includes: *erosion control*	4
Nutrient cycling	included in *CO_2 and other greenhouse gases*	-
Primary production	included in *CO_2 and other greenhouse gases*	-
	Cultural	
Social relations	social cohesion through design of garden and gardening	2
Education	children learning about nature and nature protection, learn to be(come) more self-sufficient	3
Aesthetic	flowers and other features (hedges, flowering bushes)	3
Spiritual and Sense of place	value of gardens for spiritual well-being, personal valuation of the place, self-realization	2
Recreation	recreation, leisure time spent in the garden	2
Cultural heritage	cultural landscapes, culturally significant species	0
Health and Well-being	psychological and physiological health benefits	4
Security	crime rates, accident safety of streetscapes	1

2.2.2 Data collection

Following the conceptual approach, the research project was continued by gaining a comprehensive overview of the available literature and research results of related studies. Accordingly, a range of sources has been consulted. Those were in particular, but not exclusively, scientific internet search engines, scientific databases, science citation indices and (university) libraries. Different methods for the use of search engines were applied, among others the snowball method, the citation method, the key-word based search and the search for 'similar articles'. During the data collection, peer-reviewed research articles and scientific books were preferred which were supplemented by grey literature, theses, dissertations, magazine articles, manuals, guidelines and brochures. Current global and local developments induced a high topicality of this review, so more recent publications are given priority over older ones. It was aimed to consult only literature which is published in the year 2000 or later. Exemptions were made where the added value for the present research was warranting and no more recent publication could be found.

The review is mainly covering studies conducted in Western and Central Europe and similar cultural and climatic regions. Exemptions were made for unique or particularly contributing publications. According to the international character of the present study, publications in English German and Dutch are included. Therefore, search terms and engines were used in English, Dutch and German respectively.

During the research it became apparent, that there is no uniform use of terminology throughout the publications. Two main reasons could be identified. Firstly, differences in British and American English such as *garden* (British English) and *yard* (American English). For the purpose of this review, it was decided to use the British form. Nevertheless, search terms in British and American form are used equally. Secondly, numerous denominations exist for gardens and other urban green spaces. For instance, *private* is often substituted by *domestic, own* or *residential*. Therefore table 3, lists the applied terms and their possible substitutions for searching purposes.

Table 3 Application of terms in search engines and their alternatives

Term	Alternatively and complementarily used search terms (non-exhaustive list)
garden	lawn; yard; court; streetscape; adding: front, back, rear,
private	domestic; own; residential; home
urban	city; dwelling; metropolis; developed area
ecosystem services	resilience; biodiversity; habitat; connectivity; specific ecosystem services separately
green space	green infrastructure; green area/site; ecological infrastructure; vegetation; corridor; environmental indicators; natural landscape
sealing	impermeable, permeable, impervious, pervious, paved

2.2.3 Data analysis

An ongoing process of the literature research was the evaluation of the saturation. The first overview revealed that there were only few publications, which completely match the subject of this review and a vast range of studies whose results could only be transferred with caution and reservations. Consequently, the saturation of the knowledge regarding each (sub) category was revised continually. The expert consultations built upon the foundation of the literature research by covering outstanding topics. In the following, the methodology of these arrangements are described.

2.3 Complementing arrangements

The literature research formed the basis for some complementing arrangements. The work for SOS provided an overview of the experts, who are concerned with the topic of ecosystem services in private urban gardens. There were two means of expert contributions. Firstly, via symposia and secondly, via direct interviews with experts.

Symposia
On 20th April 2016, the Dutch institute for nature education and sustainability (IVN) held a symposium on the green environment around private properties (IVN, 2016). A second symposium, organized by SOS, was held on 8th June 2016 in Leiden (NL). It dealt with the distribution of knowledge and competencies among the associated and interested municipalities of SOS. Both occasions yield information for further research and valuable statements about the present state of research. This information is adopted for the literature review and processed in the results.

Interviews
Consultations with experts formed a supplementing part of the qualitative research. Firstly, the RWTH Aachen University (Rheinisch-Westfälische Technische Hochschule Aachen) was a valuable consultant based on the resemblance of this study and a research at the university. Members of the working group “Community Ecology and Ecotoxicology” evaluated and mapped the ES provided by the parks within the city of Aachen (Wilke, 2014). The approach showed many similarities to the project at hand. Within the course of the project, several consultations with the Benjamin Daniels, a member of this working group could be realized. These provided inspiration and valuable experience exchange for this work. Experts and representatives of SOS and participating municipalities were consulted to guarantee the practicality for the foundation. SOS consists of a panel of experts which contribute their knowledge to the progress of the initiative. Appendix II lists the agenda of the conducted interviews.

3 Ecosystem services in private urban gardens

In the following, the results are presented per ecosystem service. The structure is consistent throughout the chapters 3 and 4; firstly, a general review about the relevant found literature is given; secondly, the most important findings are written in **bold**; and lastly, the key message and supplementary information is provided for

(ii) authorities; SOS and like-minded organisations, municipalities and other governmental organisations and neighbourhood associations (red textboxes) and

(i) garden owners (green textboxes).

3.1 Provisioning Services

Urban green spaces can provide various services and goods. Those are in particular, but not exclusively, food (vegetables, fruit, milk, honey), compost, flowers, genetic resources, medicines, fibre (wood, jute, hemp) and water (Lead et al., 2011). The respective range of application varies considerably between the different types of green spaces. Private gardens, for instance, are unlikely to produce notable amounts of hemp. Yet, no provisioning service is inconceivable, consequently all can be proposed and promoted. Describing all in detail, would exceed the scope of this research, so this study focuses on a selection of ES based on their dominance in the prevailing research. As private garden mostly produce for the own consumption and cultivation choices are made by the owner, the following review of food cultivation could be easily transferred to other provisioning services. Different conditions might apply for keeping livestock as it demands other resources than floral production.

3.1.1 Food

The cultivation of edible plants and the keeping of production animals in cities has a long tradition and became particularly important for human survival during periods of food shortage due to national and international crises (Altieri et al., 1999; Gómez-Baggethun & Barton, 2013; Lead et al., 2011). In the past and today, various outstanding examples for city- or even nation-wide movements of local agriculture can be named. During World War II, so called Victory Gardens to increase self-sufficiency had been famous in the United States (Miller, 2003). After the collapse of the socialistic bloc, Cuba had major losses of trade and was forced to find alternative solutions for its food demands. As a consequence, it launched a far-reaching and successful programme of private urban farming, which supplied about 50% of the fresh produce demand of each citizen (Altieri et al., 1999). Today, cities such as Todmorden (Great Britain) and Andernach (Germany) provide vivid evidence of the success of vegetable cultivation in public spaces (Meyer-Rebentisch, 2013; Paull, 2011). In recent years, the term Urban Agriculture (UA) has been established with a steadily growing popularity among citizens (Jansson & Polasky, 2010; Lin et al., 2015).

There are **multiple motivations** to engage in UA. They range from;

(i) sustainability issues such as increasing environmental awareness, relief of agricultural landscapes and shorter distances for workers and goods (Langemeyer, 2015; Lead et al., 2011; Lin et al., 2015);
(ii) rising costs of food (Lead et al., 2011);
(iii) the demand for organic produce and food security concerns (Lead et al., 2011; Lin et al., 2015);
(iv) social issues such as community building and education about malnutrition and obesity (Deutsch et al., 2013; European Commission, 2013b; Lin et al., 2015) to
(v) reconnection with nature (Deutsch et al., 2013; European Commission, 2013b; Langemeyer, 2015).

One of the most important arguments for UA is the substitution of commercial agriculture. Global food production is closely connected with numerous other ES, which are mostly jeopardized by intensive agriculture. A detailed inventory of those relationships is developed by Deutsch et al. (2013).
Present publications attribute high potentials for food provisions to UA. Deutsch et al. (2013) compared three possible future scenarios of urban agriculture. The most promising was the **Ecologically Integrated System**, with the aim of maintaining all ES instead of focussing on food production alone. Following this path could increase the cultivation of food in urban and peri-urban areas from the present 15% to a potential maximum of 30%. For urban areas alone, estimations vary between 15-20% of the global food supply (Lin et al., 2015). A study by Lead et al. (2011) estimated that a garden plot of 250 m² can save more than 1,400 € annually. Smit et al. (2001a) indicated, that UA can be by far more productive than rural agriculture, concluding that expanding UA would conserve a multiple area for biodiversity in the countryside. To which degree these calculations are general valid, requires further investigations but they prove the universally large potential of private gardens for food production.

Gardens

Studies by Langemeyer (2014) reported, that community gardens, compared to private plots, slightly neglect food provisioning ES. Consequently, private gardens are more preferable for food production services. In addition, private owners have full autonomy to design the garden without the necessity to compromise or reconcile with other users. Today's multifarious range of seeds and plants, in combination with the ongoing technological development, sets hardly any limits to cultivation plans. Gardeners can for example choose for organic plants, old and rare breeds or highly productive varieties. The urban environment bears some beneficial circumstances, which expand the growing season and potential yield (Smit et al., 2001a, 2001b). The sheltering from extreme weathers and easy water supply from rain harvesting systems enables extended cultivation possibilities. Soil fertility can be increased by manure and compost applications (Langemeyer, 2014), which additionally reduce waste production (see 3.3.1 Soil quality). Where garden space is limited or missing, alternative cultivation spaces are feasible. Those include window-sills, balconies, patios, vertical spaces and rooftops (Smit et al., 2001b). Successful systems for the latter provide multifunctional services in particular food, temperature and water regulation (for example Tanaka et al., 2016).

Figure 1 White currant bush (Ribes rubrum) in a private garden

Urban gardens show a variety of faunal species which are, apart from popular ornamental flowers, often edible and medicinal plants (Cook et al., 2012). Besides, social-economic factors influence the design of residential areas. Firstly, vegetable beds are rarely located in the front garden, due to concerns about vandalism, theft and emission pollution (Smit et al., 2001b). Secondly, the status and social class seem to play an important role for the choice of plants. In Africa, residents of pauperized districts rely on the cultivation of food in the gardens, whereas wealthy garden owners often focus on exotic, ornamental plants and regulating services (Cilliers et al.,

2013; Kowarik, 2011; Lubbe et al., 2010). These findings are supported by Galluzzi et al. (2010), who reported a decreasing diversity and utility of plants with progressing economic developments. The authors added that these plants are often replaced by ornamental and low-maintenance perennials.

Figure 2 Green bean (Phaseolus vulgaris) in a private garden

UA can become more relevant, if the agricultural sector is struggling to meet future demands (European Commission, 2002). The ongoing trend of UA results in growing numbers of new 'urban farmers' without any experience in cultivating food. Their general enthusiasm is testified by the success of particular campaigns such as the vegetable garden campaign from a Dutch supermarket (AH moestuinen) (Veen, 2016). Food cultivation has furthermore a social component. Gardeners can give and receive seeds, plants and crops (Stowa, 2016). This promotes social cohesion, genetic conservation, environmental awareness and knowledge exchange.

Implications for authorities

These studies show that UA, particularly in private gardens has an immense potential, which is only partly exploited so far. Various motives for UA are found that can be used to convince citizens. Especially the autonomic factor of private gardens compared to urban spaces and shared gardens could be promoted. Local initiatives and urban planners should respond to the trends to inform and guide citizens and especially create a long-term enthusiasm for urban gardening. Special care must be taken by the concomitants of the social stratification. Wealthier citizens might need other incentives to grow food. In these cases, emphasizing regulating factors such as pollination and water regulation can be more effective than food production or money saving arguments.

Further information

- Ecologically Integrated System by (Deutsch et al., 2013) [English]
- Information about Urban Agriculture: http://www.jacsmit.com/index.html [English]

Implications for garden owners

Gardens can yield substantial amounts of food for the personal use. The owner can choose the type of crop, knows how the food has been treated (pesticides, organic, fertilizer, soil type) and unrestricted access to the resource. Moreover, growing food has positive effects on the social relations, environmental awareness and carbon footprint.

Further information

- Tips and inspiration for small-scale urban gardens: https://stadstuinieren.wordpress.com/ [Dutch]
- Inspiration and tips to design and maintain the garden in a natural and sustainable way: http://www.wildeweelde.org/index.php [Dutch]
- Original promotion video for Victory Gardens: https://archive.org/details/victory_garden [English]
- Article about food cultivation in Todmorden (UK): http://orgprints.org/19523/1/Paull2011TodmordenFM.pdf [English]

3.1.2 Genetic resources

Ecosystems contain various genetic resources that are used or potentially will be used for breeding and biotechnology (MEA, 2003). They furthermore provide a gene pool that can support ecosystem resilience. The conservation of genetic resources in cities by private gardens in particular or green spaces in general has hardly been explored (Lead et al., 2011). Yet, several publications indicated, that gardens can have a potential contribution in that matter. Kowarik (2011) concluded that rare species are more likely to occur in pristine landscapes, but owing to the agricultural intensification, the value of alternative habitats such as urban gardens increases. This theory is supported by Lead et al. (2011), who emphasized the importance of urban gardens for the genetic diversity of horticulture and crops. Specifically varieties of the latter can raise resilience in local food provision and potentially offer a broader diversity than the local market (Barthel et al., 2014). Rare species often owe their conservation to the affection and commitment of individual gardeners (Galluzzi et al., 2010). Private gardens are capable of the deliberate conservation of a high local genetic variability (Galluzzi et al., 2010; Langemeyer, 2014; Savard et al., 2000). However, the cultural influences in highly developed societies jeopardize the genetic diversity by promoting homogenous, exotic plant communities and reduced range of produce varieties on the market. As a response, some companies specialized in offering old and rare plant varieties.

Implications for authorities
Authorities can help to conserve genetic resources by promoting the diversification of gardens. They have to combat the homogenization of gardens. Many people might not be aware about the issue so the first step would be to raise awareness. Authorities can furthermore convince dealers of plants and seeds to offer a broader range of native and rare species.

Implications for garden owners
Gardeners can inform themselves about the genetic value of your garden plants. There are many interesting and beautiful native plants to buy. Old species are often more robust and better adapted to the local climate than exotic species. The topic is extensively described in chapter 4.1 Exotic species.

Further information

- Inspiration and tips to design and maintain the garden in a natural and sustainable way: http://www.wildeweelde.org/index.php [Dutch]
- Websites for seeds of native garden plants: http://docplayer.nl/15671215-Kwekerij-de-zonnehoed.html [Dutch]
- Shop for wild, native and rare garden plants: http://www.morgensterzaden.nl/ [Dutch]
- Platform to swap and give plants and seeds: https://degroenevinger.net/ruiltuin/ [Dutch]

3.2 Regulating Services

3.2.1 Pollination

The topicality of pollinating services is undisputable not only since the growing public interest in the impacts of local and global bee mortality. Although many people seem to be informed about the problem, their direct contribution by means of appropriate garden design has not yet been sufficiently elucidated (Dewaelheyns et al., 2016; Leeuwen et al., 2015; Polwijk et al., 2015). Many scientists studied pollinator richness and abundance, but researches in the urban surrounding are scarcer (R. Gill et al., 2016). In the following a brief summary of the situation in urban green spaces is given after which the publications with a relevance for private gardens are discussed. Due to their prevalence in current publications, most of the described results refer to bees. Results and recommendations intend to apply for the whole group of pollinators in general.

A common method of pollinator abundance and diversity studies is by assessing them along a gradient (Banaszak-Cibicka & Zmihorski, 2012; Bates et al., 2011; R. Blair & Launer, 1997; Jha & Kremen, 2013). Comparisons between rural and urban pollination services by bee and hoverfly assemblages in Birmingham (UK) revealed lower diversity and abundance values for the urban sites (Bates et al., 2011). Although some species were more common there, the majority was negatively associated with highly developed areas. But high quality habitats specifically the presence of flowering plants positively influenced pollinator communities. Banaszak-Cibicka and Zmihorski (2012) likewise reported that bee species differ in their ability to survive in urbanized environments, although no difference in diversity and richness was detected. They were able to detect pollinator traits that serve as a predictor of bee abundances in urban environments and assume that 'city bees' somehow benefit from the local conditions. Taking these two studies, it becomes evident that pollinator ecology in the urban habitat is a complex field of study. Hernandez et al. (2009) reviewed 59 publications to assess the knowledge and implications of urban bee ecology. Their findings suggest that species richness decreases with increasing urbanization. Particularly specialist species which visits open flowers (rather than tubular ones) (Geslin et al., 2013) and ground-nesting species were less abundant. On the other hand, cavity-nesting bees performed better in urban settings. These results were also found for commercially reared bumble bees in Leeuwarden which had better nest developments in urban sites than in rural sites (Graça & Kolbe, 2016). However, within urban environments, green area was furthermore strongly related to colony growth. Similarly, sealing rates were found to be a significant factor in two other publications (Jha & Kremen, 2013; Radford & James, 2013).

Research showed that bees and other pollinators in the city can be supported by sensible green space designs. Several studies found resource availability like floral abundance as a crucial factor for pollination (Cook et al., 2012; Matteson & Langellotto, 2010; McFrederick & LeBuhn, 2006). Pollinators, in contrast to many other invertebrates (described in chapter 4.4.1 biodiversity) are not restricted to one suitable habitat so distances and connections between suitable sites need to be considered as well (Andersson et al., 2014). Butterfly species, for instance, show a higher positive response to heterogeneity than to area size (Jarošík et al., 2011).

Gardens

A study in Leeuwarden (NL) found that gardens have positive influences on local bee populations (Spijker, 2014). Bees require a dense network of habitats, which can be provided by gardens with food and sheltering resources. Goulson et al. (2010) measured the effects of the landscape on bumblebee nest densities and survival in rural areas. They found that gardens within a 750m and 1000m radius positively influenced nest survival of one species and the number of nests of another species. The results can be transferred onto the urban conditions, even if the study was set in an agricultural environment. They showed that bumblebees

benefit from natural gardens as habitats in an otherwise barren environment. To reach their resources, some bumblebees are capable to travel one kilometre or more through unsuitable territory.

In line with the general paragraph, garden specific studies emphasise the impact of the garden design on pollinator abundances. **Two factors prevail; first the recommendation to provide a variety of structures and second to avoid exotic and double flowers**. Double flowers are artificial traits of plants, where the blossom is filled with another blossom. For this purpose pollen-producing stamen was bred out, resulting in a plant that is sterile and barren for pollinators and seed-feeding animals (Corbet ea 2001).

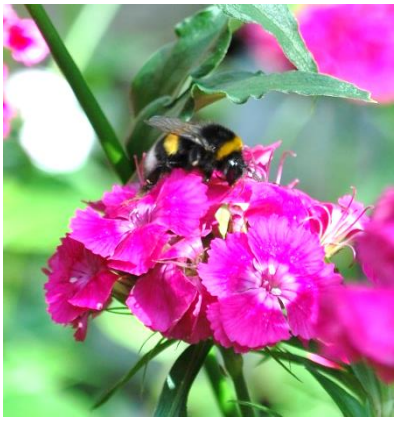

Figure 3 Wild bumblebee on Sweet William (Dianthus barbatus)

Shwartz et al. (2013) reported a greater diversity of pollinators in small public gardens, where more sub-habitats such as unmanaged corners, flowering meadows and ponds were available. Comparable to other invertebrates patch heterogeneity had a higher priority than area size (Jarošík et al., 2011).

In cultivations with native vegetation, a noticeably higher pollinator diversity was measured compared to non-native garden sites (Goddard et al., 2010). These findings agree with a study by Corbet et al. (2001), who reported that exotic and double flowers are mostly avoided by pollinating insects. The authors argued that no native pollinator coevolved with the exotic plants and double flowers cannot produce nectar to attract insects.

Finally, a group of researchers tested the attractiveness of 32 popular summer flowers on local pollinators in Sussex (UK) (Garbuzov & Ratnieks, 2014). They conclude that the preferred flowers are all inexpensive, widely sold ornamental plants so conservation actions do not have to conflict with ornamental or financial considerations.

The current state of knowledge concerning pollinator ecology in private urban gardens is very limited. More research is needed to understand how gardens can interact and complement each other to maintain viable pollinator populations. Nevertheless, a large potential of gardens is indicated, as the majority of the publications agree that urban green spaces can be a vital habitat for pollinators and, as a consequence, essentially contribute to their conservation (for example Banaszak-Cibicka & Zmihorski, 2012; Pellkofer, 2011).

Implications for authorities

Citizens are often not aware of the importance of local pollinators. In a first step, they need to be informed about the direct consequences of their gardening design and practices. Therefore, native, single flowering plants as well as the provision of shelter should be promoted. In addition, the connectivity between suitable habitats and resources for pollinators became apparent. Authorities can respond to that by stimulating pollination enhancement as a communal goal, where every garden can and should take its part.

Further information

- United Nations Environmental Programme Report: “Pollinators Vital to Our Food Supply Under Threat” [English]
- Video about wild bee research by students of Van Hall Larenstein: http://www.rtvnoord.nl/nieuws/149904/Studenten-gaan-achter-de-bijen-aan [Dutch]

Implications for garden owners

Gardens can contribute to urban pollination by offering shelter and food for insects. After all, the survival of many flowers and the development of most of the crops depend on pollination. Gardens do not have to be large to support pollinators. Pollinators benefit most from gardens with high structural diversity and native, single flowers.

Further information

- Tait M (2006) Wildlife gardening for everyone. Think Publishing, London. [English]
- Documentaries such as 'More than honey', 'Silence of the bees' and 'Vanishing of the bees' [English]
- http://www.bestuivers.nl/bijenradar [Dutch]
- http://www.bijenhelpdesk.nl/pld/Index.htm [Dutch]
- Biodiversiteit in Tytsjerksteradiel en Achtkarspelen [Dutch]
- Biodiversiteit in tuin en plantsoen [Dutch]
- Bijenbungalow bouwtekening [Dutch]
- Information how gardens can help biodiversity: http://perennialpower.nl/tuin-helpt-biodiversiteit-te-bevorderen/ [Dutch]
- Initiative from garden designer to stop sealing with information about low-maintenance plants: http://stopdeverstening.nl/ [Dutch]
- Inspiration and tips to design and maintain the garden in a natural and sustainable way: http://www.wildeweelde.org/index.php [Dutch]
- Website from garden designer with inspiration and tips for rain gardens: http://www.marklaurence.com/index.html# [English]
- Ecological Plant Database: http://nfrec.ifas.ufl.edu/ecological-plant-database/ [English]

3.2.2 Temperature regulation

The climate of an urbanized environment is often substantially different from the surrounding rural areas. One of the altered aspects is the increased average temperature. This phenomena called Urban Heat Island is the focus of many environmental scientists and urban planners. This chapter examines the extent of the Urban Heat Island and how green spaces in general and private gardens in particular can mitigate its impacts.

In the Netherlands, the Urban Heat Island peaks in the summer season and in areas with high population densities (Wolters et al., 2011). Vegetation can mitigate this effect by evaporating ground and rain water. This is most effective when the air humidity is low (Gómez-Baggethun & Barton, 2013). In a long-term study in the UK, Pauleit et al. (2005) compared soil sealing rates and average temperatures in an residential area in 1975 and 2000. The results indicated a 7% rise of sealed surfaces, a decrease of vegetated areas by 6%, on average 0.3 °C higher minimum temperatures and 0.9 °C higher maximum temperatures. The authors further remarked that the increased paving rate was mostly due to sealed front gardens, which had a severe negative effect on the surrounding environment.

Elevated average temperatures not only affect the human inhabitants but likewise local organisms. Flowers display phenological changes and earlier temperature rises in spring lead to extended growing seasons and early migratory bird arrivals (Kowarik, 2011). The higher temperatures during the winter further attract animals and plants from the surrounding areas (Schuetze et al., 2011). As a result, Urban Heat Islands not only affect human inhabitants but alter the life circumstances and community structures of all local organisms.

This assumption is supported by several scientists who compared the temperatures of different land cover types. Impervious materials have no positive effect, whereas all types of vegetation and bare soil have moderate to very high positive effects on temperature reduction (Mathey et al., 2011). The greatest cooling effects were measured on meadows and forb communities. Scalenghe and Marsan (2009) found similar results, stating that sealed surfaces raise air and surface temperatures. So every soil area that is not sealed can contribute to a mitigation of the Urban Heat Island. In a study in Indiana (USA) the direct relationship between a higher leaf area and surface temperature decreases could be demonstrated (Hardin & Jensen, 2007). **In a comparison of the ES of several European cities and their rural-urban gradients, promising potentials for tree cooling and evapotranspiration were recorded in cities with a lower rate of imperviousness** (Larondelle & Haase, 2013). Measurements on large urban trees showed that about 450l of water can be used per tree per day for transpiration, which requires 1000MJ of heat energy (Bolund & Hunhammar, 1999). The authors conclude that thereby summer temperatures can be naturally reduced.

Gardens

Effects of single gardens on urban temperatures are difficult to assess. Only a few publications are dealing with this topic so the state of knowledge is very limited. Most of them measured the impact on the neighbourhood level. The study by Gill et al. (2007) in highly populated residential areas calculated that a 10% higher vegetation cover can decrease the maximum surface temperature by 2.2-2.5 °C. Concerning single gardens, significant factors for heat mitigation could be the ground and canopy cover, soil temperature, plant species composition and irrigation methods (Cook et al., 2012; Rovers et al., 2014). Besides gardens at ground level, rooftop gardens revealed successful results for cooling measures (Tanaka et al., 2016).

Implications for authorities
Two generally applicable findings emerged throughout the research. Firstly, sealed surfaces are performing worst when it comes to urban heat reduction. And secondly, larger vegetation is usually more beneficial than shorter. The advertisement of other measures such as higher irrigation rates are also possible, but only in combination with sustainable water usage.

Implications for garden owners
The evidence base of effects on the individual garden scale is relatively thin. However, comparable studies show that sealed surfaces exacerbate Urban Heat Islands and larger vegetation such as a tree can help to mitigate them. Therefore, it is recommended to replace soiled surfaces by larger vegetation structures to compensate for extreme temperatures.

3.2.3 Climate regulation

This chapter reviews the effects of private garden on climate regulation such as greenhouse gas emissions and sequestration in the urban environment. For the scope of this research, carbon dioxide (CO2) has been chosen as a representative for all greenhouse gases. Vegetation can reduce CO2 levels by sequestering carbon in their plant structures.

Mostly, the degree of sealing in a city is directly related to the potential to store carbon. However, this should not be generalized to depreciate urbanized areas as they hold a high potential that should be considered in city planning processes (Larondelle & Haase, 2013). Larger vegetation structures such as tall shrubs and trees retain more carbon than lower vegetation so most publications focus on the effect of urban trees. For example, deciduous trees with a diameter at breast height of 50cm are estimated to sequester 45kg of carbon per year (Mcpherson et al., 1994). No significant difference in carbon sequestration were found between core cities and rural areas, probably due to the low potential of agricultural sites (Radford & James, 2013). Intermediate sites with imperviousness rates between 5% and 50% performed best for carbon sequestration, however differences were not significant. Mathey et al. (2011) reported that the size of a green space matters, as larger sites have a higher climatic effect than smaller ones. Calculations of the carbon sequestration of urban vegetation are complex as they depend on various local and environmental factors. Formulas to evaluate urban carbon sequestration and urban denitrification established by Russell et al. (2013) represent a first approach to this complicated subject. However, the results of many studies should only be transferred with great caution as the circumstances may vary considerably between sites (Strohbach & Haase, 2012).

Gardens
Similar to the potential effects on city or neighbourhood scale, precise data about CO2 sequestration of private gardens is difficult to generate. Most of the gardens do not have large mature trees so results of city wide studies cannot be transferred to the garden scale. A study by (Davies et al., 2011) reported low above ground carbon densities of the city of Leicester (UK), similar to herbaceous vegetation covers. The authors based these results on the findings that about one quarter of the gardens are sealed and normally contain no trees. According to the results, **one additional tree in every tenth garden would already yield a total of 927 tonnes of carbon sequestration in the city**. Citizens, who are willing to reduce their carbon footprint, can perhaps rather be convinced to plant a tree than restrict the personal lifestyle by e.g. reduced car usage. Haase (2013) agreed that well-maintained trees in back gardens decrease carbon footprints of the citizens.

In a study about carbon sequestration and storage in Barcelona (Spain) and the surrounding countryside, the low-residential class, which includes private gardens, stored more than 23 t/ha of carbon (Baró et al., 2014). The gross sequestration ratio was 1.45 t/ha and the net carbon sequestration ratio of 1.33 t/ha was the highest among all land use classes. The latter takes the decomposition emissions from dead trees into account. The authors assumed that the high net ratio was based on healthy vegetation and consequently low decomposition emissions.

The sequestration of CO2 is closely connected to the performance of the nutrient cycle. **A healthy and intact food web can secure the (re)cycling of nutrients, thereby providing vital direct and indirect ES** (Faeth et al., 2005). Gardening can significantly influence these cycles. Especially fertilization and irrigation of lawns cause nitrate (NO_3^-) leaching and low or even negative methane (CH4) consumption rates (Cook et al., 2012). In contrast, more soil organic matter, plant species composition and longer undisturbed periods were positive factors for nutrient cycling.

Other greenhouse gases

Apart from carbon sequestration by the garden vegetation, other possibilities to improve the local climate are feasible. Vegetation around and on the facades of the house provides, shade, insulation and reduces wind speed, resulting in lower costs for heating and cooling (Bolund & Hunhammar, 1999). Different gardening practices can further improve the personal carbon footprint. Additionally to the avoidance of soil sealing, motorized tools such as leaf blower and burning of garden waste increase carbon emissions (Balder, 2008). Plants that are pruned and overwatered cannot maintain their natural water balance and store less carbon (Cook et al., 2012). The negative effects of peat use are described in detail in chapter 3.3.1 Soil services and research suggests that even small substitutions by compost can have a positive influence on the environment (A. Smith et al., 2001). Other positive steps are recycling, the use of recycled materials as well as using green energy for electrical garden devices (Tessin, 2001).

Implications for authorities

The studies show that, concerning climate regulation, every kind of vegetation is better than sealed surfaces. Especially trees are vital to store carbon. Increasing the number of trees in a neighbourhood can be a valuable contribution to better climate regulating services. However, not everyone wants to have a mature tree its garden, so alternative actions need to be developed. Those are for example, planting other large vegetation structures, reducing the individual carbon footprint and stimulating a healthy food web.

Further information

- De klimaatactieve stad [Dutch]

Implications for garden owners

A thoughtful garden design can substantially improve the carbon footprint of its owner. A high vegetation structure is generally linked with better carbon storage capacities. Sealed surfaces have no above ground carbon storage capacity and also very limited below ground capacities (see chapter 3.3.1 Soil quality). Garden owners furthermore need to consider, if activities such as leaf blowing and fertilizing are worth the direct and indirect greenhouse gas emission rates.

Further information

- De klimaatactieve stad [Dutch]

3.2.4 Air quality

The filtering of air is an important ecosystem service in the urban environment. Cities suffer from higher pollution rates than the surrounding regions, due to increased traffic volumes, industrial emissions and higher population densities. The measured air quality of certain a location depends on various factors, such as weather, wind speed and direction and local vegetation. Therefore it can vary considerably. This chapter reviews several publications about the impact of vegetation on the wind speed and its capacity to filter pollutants.

Russell et al. (2013) developed a formula to estimate the pollutant removal of urban vegetation by means of a GIS based model. This approach, however, does not include the type of vegetation, which is a meaningful factor for the filtering capacity (Bolund & Hunhammar, 1999). Due to their larger leaf area, trees and bushes filter more pollutants than grasslands. Pollution rates peak in winter so coniferous trees perform better than deciduous as they do not shed their leaves. On the other hand, they are more sensitive to air pollution so the authors recommend a mix of species and structures.
In metropolises, large streets can serve as so called wind tunnels. They transport pollutants from the city centre to the surrounding areas. Street vegetation slows down and hampers these wind tunnels (Mathey et al., 2011). The changed local wind conditions heighten local emission rates in the city. The filtering rates of street vegetation cannot compensate for this, so local air quality might be compromised (McDonald et al., 2007). Consequently, the influence of vegetated front gardens in streets that function as wind tunnels need to be evaluated. Though the number of those streets in a city is presumably very limited.
Green urban areas only provide low capacities for air quality regulation (Burkhard et al., 2009). Research indicated that larger vegetated areas are necessary to have a significant filtering effect (Balder, 2008). Pataki et al. (2011) concluded that the evidence for effective air filtering capacities of urban green spaces is very thin. Hence, the authors urged to conduct further research to resolve the relationships between urban vegetation and air pollution removal.

Gardens
Nevertheless, this does not mean that gardens are a lost cause. In an experimental study about the effect of indoor plants in an office, respondents reported higher perceived air quality after the introduction of plants (Nieuwenhuis et al., 2014). This indicates that vegetation in the direct environment can trigger some sort of (placebo-)effect which increases the personal well-being.

Implications for authorities
The number of studies about air quality services of private urban gardens in marginal. As a consequence, authorities can rather combine the efforts to enhance air quality with another ES. While there is some about the extent of the pollution filtering there is none about the general capacity. So authorities can safely advocate the expansion of vegetation areas as well as structures.

Implications for garden owners
The present state of research is not unanimous about the best practice regarding air filtration of private gardens. However, plants can hardly be detrimental for the air quality so garden owners will always benefit from vegetated gardens. Until physical benefits are fully investigated, garden owners can benefit from the psychological advantages of green gardens (see also chapter 3.4.6 Health and Well-Being).

3.2.5 Disease regulation

The number of studies dealing with the effect of private gardens on local disease regulation is very limited. The debate about the causes of growing ailments connected to asthma and allergies are not yet settled. Sandifer et al. (2015) reviewed several studies about the human immune system and the development of allergies. They concluded that greener environments are more beneficial than detrimental as the exposure to allergens and microbes in the early years can train the immune system against hyper-responsiveness. On the other hand, some plants cause allergic reactions in affected people, so these plants should be avoided in susceptible households (Lyytimäki et al., 2008). More research is needed to be able to make sound statements about the influence of greener surroundings on the possibility and development of respiratory conditions and allergies (A. E. van den Berg & van den Berg, 2015).

Pest regulation

Urban food webs include predators and parasites which directly and indirectly provide pest control (Faeth et al., 2005) Parasitoids are common pest regulators in natural ecosystems. Their abundance was considerably higher on properties with high diversity of flowers, whereas parasitoid diversity declined on locations with high sealing rates (Bennett & Gratton, 2012). Artificial resource provision such as insect hotels (Figure 4) can attract beneficial insects which control pests and diseases (Beumer, 2014). Compost applications can furthermore encourage natural food webs to provide a natural pest regulation (Bell et al., 2008). In general, a healthy food web is likely to provide the best pest regulation services. Sealed areas are barren environments for all kinds of organisms. They impede healthy soils, which normally control pest and pathogens (Yadav et al., 2012). Healthy soils in turn are the foundation for all other ES (see chapter 3.3.1 Soil quality). Presumably, sealed surfaces jeopardize pest populations but also all beneficial ecosystem processes. More research is needed to produce reliable information and recommendations about pest species and food webs in private urban gardens.

Figure 4 Insect hotel in a private garden

Implications for authorities

The present state of knowledge is too limited to provide any sound implication recommendations.

Implications for garden owners

The present state of knowledge is too limited to provide any sound implication recommendations.

3.2.6 Water regulation

Today's cities are facing the exacerbating challenge of provident water regulations. The water cycle of an ecosystem is fairly complex and related ES are water purification, fresh water provisioning, runoff regulation and flooding protection. In the following, the capacities of urban green spaces and gardens in particular to deliver these services are described. Most of the studies investigated runoff and flooding regulations, but based on their close interconnection, the other water-related ES are implemented hereby.

Urban environments with high sealing rates, offer little opportunities for rainwater to seep away. If the present trend of using impervious covers in residential areas reinforces, these areas will become more vulnerable to extreme weathers. Thus, urban planners and scientists are forced to find solutions to adapt cities to the impacts of the climate change (Radford & James, 2013; Verbeeck et al., 2011). In a first step, several scientists compared the infiltration and evapotranspiration potential of different land cover types. Based on that, sound recommendations about suitable steps can be made.

Towns with 50-100% sealed surfaces have a significantly lower potential of rainfall retention than other settlements (Radford & James, 2013). Estimations of evapotranspiration of land covers with regard to the precipitation quantity are shown in table 4 (Mathey et al., 2011). The authors remarked that impacts on the runoff might be limited to the local scale, as the highest peaks of precipitation coincide with the colder seasons when deciduous plants have no leaves to take up and evaporate the water.

Table 4 Proportional evapotranspiration of the precipitation per land cover (Mathey et al., 2011)

Land Cover	Evapotranspiration of the precipitation quantity in %
bare soil	29
lawn	50-58
wet meadow	135
deciduous forest	62
coniferous forest	46

In a study in Manchester (UK) by Gill et al. (2007) estimated that enhancing the green cover in housing areas by 10% can lower runoff by 4.9%. Alternatively, a similar growth in tree cover would lower runoff averages by 5.7%. The positive contribution of urban trees is verified by Xiao and McPherson (2002) who calculated 0.8m³ of rainfall interception for a tree with 3.5 cm diameter at breast height and 20.8m³ for a mature tree with 38.1 cm diameter at breast height.

These publications agree with evaluations of infiltration rates of the annual precipitation of land covers. Perry and Nawaz (2008) measured that **bare soils take up 50% of the rainfall in contrast to only 5% on asphalt**. They calculated that 12.6% more impervious covers heighten the average annual runoff by 12%. According to Bolund and Hunhammar (1999) only 5-15% of the rainwater runs off in vegetated areas. Cities with low vegetation need to consider that 60% of rainwater is going to end in the storm water drains. These publication demonstrate that water retention varies considerably between different covers. As a result, authorities need to consider these performances in their water management policies. Countermeasures such as sustainable draining techniques, extension of urban green areas including higher vegetation covers can improve infiltration and evaporation rates (Radford & James, 2013; Tessin, 2001). In addition, the temperature of soil and surface as well as appropriate irrigation methods can positively influence evapotranspiration and water flux values (Cook et al., 2012).

Gardens

Combining the aforementioned results, the average runoff after 40 l/m²/h of precipitation for several land covers in shown in table 5 (Pauleit & Duhme, 2000). Assuming that the land cover characteristics of allotment gardens are comparable to private gardens, these sites perform somewhat poorer than parks but much better than buildings. Therefore they can have a significant contribution to the local water regulation. However, sealing trends do not leave water runoff values of private gardens unaffected. Between 1975 and 2000, a significant rise in surface runoff and imperviousness rates was reported in residential areas in Merseyside (UK) (Pauleit et al., 2005). Zwaagstra (2014) found similar relationships between paving and runoff for the city of Groningen (NL). Paving the home garden influences water cycles beyond the property borders. Street and neighbouring vegetation are negatively affected by surfaced gardens, because of more intense flooding and drought events (Rovers et al., 2014).

Table 5 Average water runoff after 40 l/m²/h of precipitation for several land covers (Pauleit & Duhme, 2000). Runoff of buildings depend on the type of the building.

Land cover	Average runoff in l/m²/h
meadow	2.7
park	4.2
allotment garden	5.5
building	>12

Figure 5 Rainwater barrel with automatic watering system in private garden

While urban green areas only occasionally contribute to flood protection, they do have a relevant capacity for groundwater recharge (Burkhard et al., 2009). However, in more arid climates urban gardens can negatively influence water balances by causing so called 'hydrologic draughts' (Niinemets & Peñuelas, 2008). Thereby drinking water is used for irrigation, resulting in lower groundwater levels. Rainwater harvesting systems are suitable alternatives for the use of drinking water. Figure 5 shows an example of a rainwater barrel with integrated watering system. Rainwater from the roofing is collected and automatically given to the plants underneath the roofing.

After all, care must be taken when transferring the findings of the studies. Runoff performances vary substantially between sites and depend on several (local) factors including the slope of the site and the soil composition (Zwaagstra, 2014). The author added that a rise in runoff water also deteriorate the quality of the water. Pervious soils filter pollutants from the water, thereby delivering the vital water purification ES. Sealed materials, on the other hand, pass the polluted water onto the nearest pervious grounds (Scalenghe & Marsan, 2009).

Implications for authorities

Water regulation is a communal task and should be treated as such. Not least because more natural gardens are compromised by the sealing malpractices of the neighbouring properties. Since the amendment of one garden alone might not have direct, measurable effects on the urban water regulations, authorities should emphasize the communal and social aspect of the problem.

Further information

- The New York City Department of Environmental Protection launched a grant programme to reduce storm water runoff. Green infrastructure projects of private property owners can thereby by funded. (New York City Department of Environmental Protection, 2016) [English]
- De klimaatactieve stad [Dutch]
- Article: Why Ecosystem Services Will be the Next Frontier in Livable Cities http://www.archdaily.com/773258/ecosystem-services-what-they-are-and-why-we-need-them [English]

Implications for garden owners

Various land cover types have distinctive effects on runoff intensities. While vegetation can take up considerable amounts of water for evaporation or storing, sealed soil have no such qualities. Therefore impervious surfaces provide ecosystem services to a larger extend and should always be preferred in in private urban gardens. Water regulation is a communal task and should be treated as such. After all, inhabitants are affected equally and are able to contribute together to more sustainable and safe conditions.

Further information

- De klimaatactieve stad [Dutch]
- News report from NPO EenVandaag: Afvoer hemelwater problematisch; stop de verstening. http://buitenland.eenvandaag.nl/tv-items/62589/afvoer_hemelwater_problematisch_stop_de_verstening [Dutch]
- Initiative from garden designer to stop sealing: http://stopdeverstening.nl/ [Dutch]
- Website from garden designer with inspiration and tips for (rain) gardens: http://www.marklaurence.com/index.html# [English]
- Initiative from Amsterdam to reduce flooding and other water related problems: https://www.rainproof.nl/ [Dutch]
- Calculator for rainwater collection: http://ateliergroenblauw.nl/regenwateropvang/index.php [Dutch]
- Informational website about rain gardens: http://www.sacbee.com/news/state/california/water-and-drought/article63416467.html [English]
- Natuurlijk! De watervriendelijke tuin: http://www.tuinbranche.nl/vrijepagina/waterpagina [Dutch]

3.2.7 Noise

Peer-reviewed publications about the potential of urban gardens to provide noise reductions are scarcely available. Noise pollution is extremely high in developed areas mainly deriving from traffic noise (Gidlöf-Gunnarsson & Öhrström, 2007). Besides, urban areas have considerably less potential to buffer noise disturbances than more rural locations (Radford & James, 2013). Green areas that can be used as quiet places of retreat in the close vicinity are crucial for the well-being of the citizens (Gidlöf-Gunnarsson & Öhrström, 2007). Soft lawns, compared to concrete surfaces, can reduce the level of sound by 3dB(A) (Bolund & Hunhammar, 1999). Larger vegetation structures are furthermore mitigating the noise pollution (Loram et al., 2008; R. M. Smith et al., 2005). Apart from these general studies, no relevant study for garden could be found. The state of knowledge is yet too limited to give a clear view of the relationship between gardens and noise regulation. More research is needed to assess the conditions and effects in small sites as urban gardens.

Implications for authorities
The present state of knowledge is too limited to provide any sound implication recommendations.

Implications for garden owners
The present state of knowledge is too limited to provide any sound implication recommendations.

3.3 Supporting Services

3.3.1 Soil quality

Supporting services such as soil quality form the foundation for all other categories of ES. Supporting services are less prominent and have often indirect effects on effects the environment (MEA, 2003). The soil is a multifunctional element of the urban environment. It can store carbon and mineral nutrients, degrade pollutants and forms a vital component of the hydrologic cycle as it absorbs, stores and delivers water (Setälä et al., 2014). Hereafter, the potential of urban areas to provide a good soil quality, control erosions and accumulate organic matter is described.

Though, these services are negatively influenced by disturbance and sealing (Lead et al., 2011). The urban soil is exposed to unnatural circumstances, which alter its structure. Beniston and Lal (2012) described, that the urban soil suffers from a reduced proportion of organic matter, an altered water balance, accelerations of heavy metal and compression. The European Commission (2012) published a Soil Thematic Strategy, wherein soil sealing and associated land take are covered. Vital soil functions such as food production, water filtration and storage are lost as a result of sealing procedures. The impervious cover further reduces the carbon sequestration and storage capacity, while the drought conditions additionally increase the local seismic motion (Scalenghe & Marsan, 2009). Consequently, studies attributed a relevant capacity for erosion regulation and carbon storage to green urban areas (Burkhard et al., 2009; Scalenghe & Marsan, 2009).

Gardens

In a study about urban soils in the United States, Pouyat et al. (2006) calculated that residential lawns store 14.4 kg/m² of carbon, whereas sealed soils store on average 3.3 kg/m². Private gardens can even exceed soil carbon storage capacities of surrounding landscapes (Cook et al., 2012). Both publications ascribed these findings to the gardening methods of fertilization, irrigation and returning grass clippings (Cook et al., 2012; Pouyat et al., 2006). If the garden is used for food cultivation, Lin et al. (2015) added mulching, cover cropping, using raised beds and piping as possible methods to improve soil conditions.
Soils show signs of maturation, as they stabilize and diversify over time, offering a unique niche (Schrader & Böning, 2006). Consequently, private gardens can provide a vast range of soil habitats which in turn enhance the local biodiversity. In an experiment by Sperling and Lortie (2010), the addition of bare soil increased invertebrate abundance and diversity, seed recruitment and aboveground vegetation.

Intact soils play a substantial role for the environmental waste management. Urban food webs, including plant-soil-interactions can support the degradation of pollutants and wastes (Faeth et al., 2005). Vauramo and Setälä (2011) studied these interactions and described the potential of plant communities to positively influence the nutrient dynamics of urban soils. According to the authors, special vegetation structures can restore ES of disturbed soils and promote decomposition of pollutants. These findings can be especially relevant for heavily contaminated urban soils, where cultivation of food is impossible so far.

Compost and peat

Until recently, peat was commonly used in private gardens as a soil and mulching for plantings. The combination of high rates of peat digging and the slow growth of the medium resulted in shrinking peatlands (Jeffery et al., 2010). Peat digging also emits various greenhouse gases and destroys unique habitats (C. Berg, 2003). As an alternative, home composting saves money and is more sustainable. Barton et al. (2008) compared the emission of greenhouse gases from commercial compost productions and peat extraction and the impacts on the soil condition. The results suggested slightly higher impacts of peat production in the form

of offsetting emissions. Other comparisons of compost and peat production resulted in savings of 183-192kg CO2 per tonne of fresh compost waste (Boldrin et al., 2009). Excluding emissions associated with peat harvesting and transport, Smith et al. (2001) calculated a saving of 29kg CO2 per tonne of fresh waste. Moreover, **a compost pit can yield 400 kg of compost per tonne of green waste**, showing that composting can pay off even at a small scale (Figure 6). Additionally, a compost reduces the amount of household waste, delivers a considerable contribution to the waste management of the household and municipality, replaces the application of inorganic fertilizer and herbicides and reduces soil erosion (Boldrin et al., 2009).

Figure 6 Compost heap in a private garden

Even if the magnitude of the benefits differ between the studies, all showed an advantage of compost above peat. As a consequence, the creation of a compost pit and the subsequent use of instead of peat should be widely promoted.

Implications for authorities

Consistently, recent studies emphasize the importance of unsealed soil for a healthy and stable urban environment. The present evidence shows, that soil sealing is massively diminishing the ecosystem services of urban soils. Several countermeasures are suggested in this chapter, which can be promoted in urban gardens.

Even if the magnitude of the benefits differ between the studies, all showed an advantage of compost above peat. As a consequence, the creation of a compost pit and the subsequent use of instead of peat should be widely promoted.

Further information

- Overview of best practices for limiting soil sealing or mitigating its effects in EU-27 http://ec.europa.eu/environment/soil/sealing.htm [English]

Implications for garden owners

Soil sealing is massively diminishing the ecosystem services of urban soils. Recommended countermeasures are among others; avoidance of sealed surfaces, organic fertilization, composting. Most of them can be applied in the private garden and contribute to multifarious gains in ecosystem services.

Further information

- Importance of healthy soil and worms for the city: http://wormenhotel.foodguerrilla.nl/ [Dutch]

3.4 Cultural services

The three previously described categories of provisioning, regulating and supporting services are each more or less beneficial for humans as well as the surrounding nature. Cultural services, however, are solely for the purpose of humans. The focus of the following chapters is more on the society than on ecology. The chapter structure is therefore no longer divided into public green and private gardens.
The assessment of cultural services is less straightforward than for the other ES. Their valuation is often based on more elusive and subjective indicators (Gómez-Baggethun & Barton, 2013). Methodologies such as quantifying diversity, ecosystem functions or willingness to pay cannot properly reflect cultural meanings of an area (Voigt & Wurster, 2014). The perception rather depends on the individual and cultural background. As a consequence, publications about the social aspects of private urban landscapes are, compared to the natural science disciplines, underrepresented in current urban ecology publications (Cook et al., 2012).
The variety of cultural values connected to private gardens is reflected by the multifarious designs and maintenance customs among citizens. The 'tyranny of small decisions' is a potentially emerging menace of this situation (Cooper et al., 2007). Due to a deficiency of coordination and information, small-scale garden management decisions can compromise local biodiversity (Goddard et al., 2010). The apparent dilemma can, after all, hold numerous possibilities to support the structural and biological diversity within the urban environment. The different social-ecological dynamics possibly complement each other to provide a broad range of ES (Andersson et al., 2014). Yet, thoughtfully elaborated coordination and cooperation are an essential prerequisite. Contradictory to this individualism stands the phenomena of 'neighbourhood mimicry', where front gardens have (vegetation) designs corresponding to those in the close vicinity (Zmyslony & Gagnon, 1998). At first sight this might be regarded as an impediment for streetscape greening, but it also provides the opportunity to turn the tables and use it as an advantage. Several experts agree that it is easy to convince the citizens, who already care for their garden and the environment (for instance Beumer, 2016; Roo, 2016). When they effectively restructure their front gardens, the surrounding neighbours may follow and mimic this transformation. This approach is already adopted by the municipality of Seattle (US), where a regulation to add green infrastructure to the cityscape was introduced. New building constructions are only approved if they obtain a defined vegetation score. This score evaluates the vegetation on the building site and the visibility of this vegetation is integrated as a major factor for the weighing (Stenning, 2008). These sorts of concepts increase a positive socio-cultural pressure, which might be more powerful than general recommendations.

3.4.1 Social relations

This chapter describes the possibilities private gardens, to contribute to social relations. The effects of private gardens on social relationships of their owners is not yet fully understood. The level of knowledge of this discipline compared to other urban green areas is rather low. The reason is probably the private character of the home garden in contrast to the communal aspect of parks, squat gardens and community gardens.

Apart from health benefits, green spaces in the closer vicinity of the citizens combat their feeling of loneliness and shortage of social support (Maas et al., 2009). Green spaces can have a vital contribution to the social cohesion, interaction, support and empowerment of individuals, communities and even nations (Sandifer et al., 2015), which implements a serious potential for all urban greens including private gardens. Still, the empirical basis for such contributions is very thin (de Vries et al., 2009). Pursuing the aim of enhanced superficial conversations, attractive, green front gardens seem to be the best basis as they improve the 'walkability' of the street.

Some people experience their garden to some degree as a burden. The visibility and publicness of (front) gardens obligates owners to keep it clean and tidy (Coolen & Meesters, 2012). They often mirror personal and social ideals and standards (Cook et al., 2012). Yet, most of the publications report positive relationships between garden(ing) and social interactions (for example Cilliers et al., 2013). In a survey by Gross and Lane (2007), all respondents were eager to share their knowledge and memories about their gardens. For them, gardens were characterized by shared interests and social context.

Specifically, the interaction with the direct neighbours can be promoted by gardening (Balder, 2008). (Cook et al., 2012) reported positive interactions between social cohesion and the factors irrigation, fertilization, ground and canopy cover. Possible underlying causes are, that gardeners exchange experiences through best-practice sharing, including successful fertilizing and irrigating methods. Gardeners who put a lot of effort in the maintenance also stay in contact with their neighbourhood. These forms of communications can easily be used to encourage more natural and sustainable gardening methods (Lin et al., 2015). In a first step, the prioritization of expedient knowledge and communication channels have to be formulated.

Besides, gardens are often a place of retreat (Bhatti & Church, 2004) which potentially conflicts with social obligations (de Vries et al., 2009). Neighbours must find a balanced relationship between mutual support and the respect of everybody's privacy.

These results indicate that the provision of social cohesion is a sensitive topic, which needs further investigations. Community gardens and allotments can be valuable models for socially flourishing concepts (Guitart et al., 2013). Alternatively or additionally, memberships in gardening associations and clubs can furthermore enhance the social cohesion of citizens.

Implications for authorities
Private gardens hold a large potential to encourage all kinds of social interactions. However, this must be approached with some awareness for the interests of the owners.

Implications for garden owners
Using of the private garden can easily encourage social relations. Active gardeners are happy to help with advice and experiences as well as tools and plants. Vegetated (front) gardens increase the general appearance of the street and neighbourhood, resulting in higher social cohesions of the community.

3.4.2 Education

The educational contribution of gardens can be roughly divided into the education of children and the learning effects on adults. Nevertheless, many insights are presumably applicable for both groups. As a consequence, no separation is made between them in the following review.
A garden can be of invaluable importance during the childhood. Particularly children who grow up in urbanized environments benefit from gardens, since they provide nature on the doorstep. In 2015, 92% of the respondents of a German survey agreed that giving children an understanding of nature is an important element of the education (Küchler-Krischun et al., 2016). Gardens are places of safety and pleasure and support the development of relationships with nature, friends and family (Gross & Lane, 2007). Citizens who grew up with a garden have a higher awareness of the need of nature protection and individual actions in the direct and indirect environment (Freitag, 2002; Kowarik, 2011). Also, experiencing environmental changes in the urban ecosystems can give an understanding of the alarming processes in more pristine ecosystems nearby and far away (Shwartz et al., 2013; Yli-Pelkonen & Niemelä, 2005). The intensifying climate change and loss of nature frighten many people. The possibility to take actions oneself can give people the desired power over their personal impact on the environmental (Dewaelheyns et al., 2016).
For many citizens, gardens are vital sites of personal developments and experiences. They are visited for sensual impressions of the environment and the understanding of nature (Bhatti & Church, 2004). In another publication, the author added that thoughtfully designed and maintained gardens can illustrate the plight of the planet (Bhatti, 1999). With the term 'extinction of experience', Goddard et al. (2010) emphasized the present dilemma of a disconnection between citizens and natural environments due to the relatively poor species richness in the urban surrounding. Artificial resource provision such as nest boxes and ponds demonstrate the public passion to support urban wildlife, irrespective of their eventual effectiveness. Bates et al. (2015) described a similar willingness to participate during a bug counting citizen science project.
Gardening is a continuous process of experimenting and learning about the natural response (Langemeyer, 2014). Thereby, ecological knowledge about safeguarding biodiversity, food supply and urban resilience can be gained and (re)stored. If taken too seriously, gardening can become more stressful than educating (Coolen & Meesters, 2012). Specifically unexperienced gardeners should not be discouraged by unsuccessful projects and cultivation efforts. To prevent disappointments, gardeners should set up a plan, including what they want to have and do in their garden and execute it one step at a time (Roo, 2016).

Implications for authorities
There are various possibilities for authorities to encourage educational ES of private gardens. First of all children are probably learning more in a natural garden than in one that only consists of sealed surfaces. Though, adults benefit from green gardens either. Studies show a high enthusiasm to participate in citizen science projects and to support local biodiversity. Authorities can respond to that by promoting nature friendly activities.

Further reading

- Educational resources of the Let it Grow Campaign (EAZA): http://www.letitgrow.eu/resources/shared-resources-draft/ [English]

Implications for garden owners
Nature-friendly gardens can provide various educational services for their owners. They support childhood education and all kinds of (re) connections between citizens and nature. Engaging in nature conservation by providing resources and participating in (local) organisations can increase someone's education as well as satisfaction.

3.4.3 Aesthetics

Figure 7 Foxgloves (Digitalis spp.) in a private garden

The aesthetic value of a site is very subjective so ES provision mainly depends on the individual preferences. This implies huge potentials for domestic gardens as they are private property with restricted possibilities for external regulations. As a result, there are hardly any limitations for preferences and designs. Gardens in the US are correspondingly maintained to meet primarily aesthetic and recreational demands (Clayton, 2007; Cook et al., 2012; Kiesling & Manning, 2010). Clayton (2007) blamed the homogenous cultural norm of neat and tidy gardens, transferred by the mass media, for the loss of pristine natures.

Valuation of aesthetic services is very complex. One possibility is to compare house prices in greener and more urbanized environments. Compared to similar buildings, properties next to greenways and urban parks were shown to have higher market values (Savard et al., 2000). Russell et al. (2013) developed a method of valuation by determining the number of viewable trees and water features from the house. The assessment included that the property costs rose by 1% per large tree. In a similar study, a city block with ten more trees was on average comparable to being seven years younger, higher personal or median incomes (Kardan et al., 2015). More applications of this valuation system are given in chapter 4.2 Monetary valuation.

Based on a survey and experiment, Zhang et al. (2014) found evidence for enhanced prosocial tendencies in participants who perceived subjectively beautiful nature. In four tests, elevated levels of empathic concern, perspective taking, generosity in resource allocation tasks and helping behaviour could be measured. These results support the **biophilia hypothesis that humans have an intuitive connection and affinity with nature**. Conversely, paved front gardens can compromise the proportions and appearance of a streetscape. The lack of vegetation increases the wind speeds, dust and noise pollution (Verbeeck et al., 2011). **In a study about multifunctional ES, Garbuzov & Ratnieks (2014) detected a variety of ornamental garden plants which were inexpensive and attractive for pollinators**. Streets without front gardens, provide fewer opportunities for streetscape vegetation. Therefore, many municipalities promote facade and vertical greening (Meyer-Rebentisch, 2013).

Implications for authorities

Many species are attracted by a certain degree of wilderness, which might not always be regarded as ‘beautiful’ in the public perception. Initiatives that promote wildlife-friendly gardens should inform gardeners that naturalness not necessarily excludes the aesthetic appeal. Findings such as the biophilia hypothesis and the range of affordable ornamental plants can be used to convince garden owners. For some owners, the monetary benefits of greener gardens can be an effective incentive.

Implications for garden owners

All in all, natural gardens can benefit nature as well as human aesthetic demands. They often increase the value of the property, connect people with nature and enable self-expression. Gardens should reflect the own personality and not the homogenous norm of a neat and tidy nature.

3.4.4 Spiritual and Sense of Place

For the scope of this review sense of place and spirituality are combined. Both deal with the individual bond between people and the private site. Spirituality relates to a religious or metaphysical level, whereas sense of place is more connected to the (ecological) environment. The values connected to them cannot be reduced to one type of understanding but rather embrace a whole range of ecosystem associated experience (Chan et al., 2012). Valuation of these services might therefore be exceptionally complex.

Dearborn and Kark (2010) suggested that, by conserving urban green spaces, people can fulfil their moral and religious obligations to be a good steward of the planet. Spiritual values might be less prevailing in urban environments because of their often connected with natural landmarks and extensive areas (Gómez-Baggethun & Barton, 2013). Developing a sense of place can be a vital contribution to individual development and well-being (Dennis & James, 2016). Access is a crucial factor for the provision of a sense of place, which confers private gardens with an advantage over public green spaces. Moreover, gardens can be designed according to the preferences of the owner, allowing the creation of a spiritual and religious site. Standish et al. (2013) assumed that some people intentionally design their outdoor environment in response to the homogenized composition of urban nature. Another purpose can be as hide or retreat, where residents often create a place as a compensation of their stressful urban lifestyle (Bhatti & Church, 2004; Horstra, 2016). Gardens can also connect people to their geographic place of origin (Cook et al., 2012). They are repositories for ethnobotanical and cultural knowledge of families and communities (Galluzzi et al., 2010). Many immigrants and foreigners use this chance to design their gardens like the ones in their home regions (Meyer-Rebentisch, 2013).

Gardening likewise inspires and encourages to creational activity and development (Bhatti, 1999). Interacting with the environment can combat alienation from nature (Freitag, 2002; Gómez-Baggethun & Barton, 2013). In the UK, about one quarter of the population has a very strong attachment to the private garden and is regularly engaged in gardening (Bhatti & Church, 2004). On the other hand, one quarter experiences the activity as a chore and unrewarded work.

Even one bird species can have the potential to evoke a sense of place for the residents (Standish et al., 2013). Those findings can be added to the cultural heritage ES, which is otherwise presumably underrepresented in private gardens. It furthermore shows the connection between Sense of Place and biodiversity (described in chapter 4.4.1).

Implications for authorities
The awareness of gardens for this purpose can be encouraged by authorities. Many people possibly use their garden as a place of spirituality without being aware of it. Authorities can encourage this service in combination with others. Promising multifunctional combinations for this are aesthetic and social services.

Implications for garden owners
Garden owners who design and maintain their gardens based on thoughtful personal preferences can benefit from it as a unique place. This does not necessarily have anything to do with religious belief. Citizens can rather create a haven to find and preserve the inner balance in their life.

3.4.5 Recreation

In times of growing urbanization high-quality recreational areas in the close vicinity become more important. The domestic garden can provide such an undisturbed outdoor room. In a survey by Beumer (2014) among Dutch citizens, relaxation was an important reason to be in the garden for three-quarter of the respondents, followed by 30% for enjoying nature (multiple responses allowed). The daily routine is often stressful, so the citizens require easy to access offsets for recovering (Hoffmann, 2002). People often prefer gardens, as public green spaces cannot provide the demanded privacy (Coolen & Meesters, 2012). Specifically in cities with widely scattered parks, citizens effectively replace the services by the private gardens. The general popularity of other green spaces such as urban parks indicates that greener gardens are more recreation services than those without vegetation. Owners see the garden as a functional extension of the house and maintain it accordingly (Cook et al., 2012). The study showed that floral composition, ground and canopy cover, fertilization and irrigation had positive impacts on the leisure and recreation values. Comparable to the social cohesion performances, these factors may reflect a general higher degree of care.

Gardening activities also promote self-expression and creativity (Gross & Lane, 2007). In the earlier mentioned survey, 41% of the respondents garden to be outside, while watching things grow and having some private time was indicated by about one-fourth respectively (Beumer, 2014). At the same time, half of those surveyed, work in their garden to keep it tidy.

Implications for authorities
Authorities can utilize the demonstrated need of citizens for restful spaces. Public green spaces cannot fulfil the demands for privacy so this advantage of gardens need to be emphasized. Furthermore, gardening could be promoted as an inexpensive and permanently accessible recreational activity.

Implications for garden owners
Garden owners can easily design a recreational site in their garden. However, it is questionable if a completely sealed garden has any recreational values. The best recreation service can be delivered when the design and maintenance meet the demands of the user.

3.4.6 Health and Well-Being

The relationship between the individual health and the surrounding green in an urban environment is the subject of many recent publications. However, due to its complexity and mediating and modifying alternative explanations, the generation of profound relevant studies is comparatively low. Hereafter a selection of studies concerning the effect of greenery on the mental and physical health are presented.

A review by Sandifer et al. (2015) reports a broad range of positive physical and psychological effects connected to the use of urban green environments. In accordance with a study by Fuller et al. (2007), they found a direct relationship between a high species richness of the surrounding and positive psychological effects. More general studies indicate a connection between a green environment and the reduction of income-related health inequalities, loneliness and social isolation (Maas et al., 2009; Mitchell & Popham, 2008).

The specific contribution of the vegetation in the direct environment however is controversial. In contrast to studies that indicate clear cause-and-effect relationships (Bolund & Hunhammar, 1999; Cilliers et al., 2013), there are several publications that can only support this in parts of their results (e.g. de Vries, Verheij, et al., 2003). A research by de Vries et al. (2003) questioned the empirical support of most of the related investigations. For example, inhabitants of greener neighbourhoods tend to have a healthier lifestyle which might explain outcomes of positive studies (A. E. van den Berg & van den Berg, 2015).

Several studies deal with the topic of health benefits of urban green spaces by measuring particular responses to grey and green surroundings. The relatively recent discipline of brain research unveiled several impressive publications regarding nature perception. Thereby pictures of rural, compared to urban, sceneries were shown to participants, while brain activities and other indices were measured. Results indicated that photographs of nature compared to urban photographs

(i) were preferred by the participants (Kim et al., 2010),
(ii) reduced physiological arousal and attentional selectivity (Berto et al., 2008; de Vries et al., 2009; Laumann et al., 2003),
(iii) improved attention related abilities (Berman et al., 2005) and
(iv) improved the ‘inner perception’ as self-awareness and reflection (Kim et al., 2010).

These findings are supported by studies that investigated the influence of the view from the window on human well-being. Taylor et al. (2002) demonstrated that a green view improves concentration performances, impulse inhibition and delay of gratification of girls. However, no relationship could be found for the group of boys. Lee et al. (2015) also reported positive results when comparing the effect of micro breaks lasting for 40 seconds. Viewing a green roof city scene significantly sustained attention of 150 university students more effectively than looking at a concrete roof. In a study by Wells and Evans (2003), the greenness of the environment of children was measured. Children living in a more vegetated environment measured in terms of garden design, number of houseplants and view from window exhibited lower levels of psychological distress and higher levels of self-worth.
Several publications indicated a positive effect of indoor plants in offices on the work performance (among others Nieuwenhuis et al., 2014). With a newly developed method Honold et al. (2016) measured the cortisol levels in the hair of participants with and without a green home view. They found significantly lower cortisol levels for participants with views of diversified vegetation structures. Furthermore, the degree of vegetation in the neighbourhood, perceived from the view from the living room, was found to be the significant predictor of neighbourhood satisfaction (van Herzele & de Vries, 2012). The view even made a difference during the recovery of illnesses. Looking at natural environments was found to support the convalescence of patients (Tzoulas et al., 2007; Ulrich, 1984)

Garden

While the number of insights on the general urban green space as parks and cemeteries is predominant, there are few studies that specifically focus on gardens and the occupation of gardening. Gross and Lane (2007) stated that a private garden is, as much as public green spaces, an environmental and personal support of the psychological as well as physical health. It can be regarded as a multifunctional zone that represents an escape from the everyday stress by providing a personal, natural environment, which is often associated with positive memories and meanings. Mcphearson et al. (2014) hereby emphasized the need for locally occurring ES. If cities want to be more sustainable and health supporting, only inner ES provision can be effective.

Various locations are suitable for the promotion of health benefits, not least private gardens. Research has shown that the quality of the green along the streets can have an effect on self-perceived general, mental and acute health (van Dillen et al., 2012). In a study by de Vries et al. (2013) the quality of the vegetation was more strongly associated to perceived general health, acute health-related complaints, and mental health than the quantity alone. Thus greening the front garden not only brings benefits to the occupant but also people passing by and potentially even drivers in their cars if they frequently take this route.

The size of the garden only plays a minor role in its ability to increase the well-being. Even small gardens, when designed thoughtfully, can promote restoration and identification (Tenngart Ivarsson & Hagerhall, 2008). Moreover, green gardens decrease the level of stress measured as irritation, fatigue and stress. These results are in concordance with a study by Nielsen and Hansen (2007), showing that access to a garden or nearby public green reduces stress and the risk of obesity.

Grahn and Stigsdotter (2003) measured the experienced stress of people with a green garden and those without a garden or with one containing only little or no vegetation. The results show that green gardens engage to spend more time outdoors, as garden owners visit open green spaces more often than people without a garden. Moreover, the occupation of gardening and designing this natural environment contributes to the owner's satisfaction, stress relief and balanced lifestyle (Coolen & Meesters, 2012; Hoffmann, 2002). Other studies demonstrate the relationship between gardening and self-perceived health (Maas et al., 2008) and physical health through regular physical activity (Park et al., 2009).

It is evident that health benefits are often interlocked with other explaining factors such as physical activity or social side effects (Hartig et al., 2014). The objective of this research is not to disentangle those interrelationships, so some results of this chapter can be applied elsewhere as well.
Many conducted studies lack a consensual standard for the evidence of health benefits (A. E. van den Berg & van den Berg, 2015) and consequently the number of thorough researches is relatively low (de Vries, 2016). De Vries remarked that a found relation does not always imply a cause-effect relationship, however gardens do show a clear potential for health benefits. Especially short-term restoration (Hartig et al., 2014). This statement corresponds with this review, whereby a positive relationship between a green environment and the personal health is the prevailing outcome. The benefits range from the general self-reported health to in depth calculations of a higher life expectancy due to an increase in the number of trees in the neighbourhood (Kardan et al., 2015).

Implications for authorities

There are various studies demonstrating the benefits of green surroundings in general and green gardens in particular. Authorities can make use of them to promote green environments among citizens. The incentive of an improved health and well-being might be more powerful than other ES.

Further information

- Website with studies about influence of nature on brain: www.mieras.nl [Dutch]

Implications for garden owners

There are plenty of studies showing a positive relationship between experiencing vegetation and health and well-being. These demonstrate the services green gardens can deliver for their owner.

3.4.7 Security

The evidence base concerning the effects of different garden designs on the security is very thin. Vegetated streetscapes seem to have positive as well as negative consequences. Tree-lined streets are safer because of lower traffic speeds (Lyytimäki et al., 2008). Vegetation-free streets appear wider, inducing higher speed (Verbeeck et al., 2011). Yet, too dense vegetation might cause slippery roads due to fallen leaves and reduce the visibility for drivers, thereby increasing the potential of accidents (Lyytimäki et al., 2008).
Apart from the accident safety, vegetation can affect crime rates. Wolfe and Mennis (2012) measured vegetation of a neighbourhood by remote sensing and related it to criminal acts. While no relationship was found for theft, significant associations between vegetation abundance and lower assault, robbery and burglary rates could be detected. The authors concluded that higher public surveillance in greener areas is the responsible factor for the lower crime rates. Kuo and Sullivan 2001 compared the police crime reports of neighbourhoods with low, middle and high vegetation levels. They reported that even after ruling out possible control variables, a significant negative relationships between the vegetation level and the number of property crimes and violent crimes remained. Yet, not only the simple presence of vegetation is relevant, but also the type and volume. Densely vegetated parks are sometimes perceived as unsafe, specifically at night, which can be avoided by proper maintenance (Lyytimäki et al., 2008). Sreetheran and van den Bosch (2014) reviewed 48 studies about the relationship between urban green space and fear of crime. Concerning the vegetation of a park, no unanimous results were found. Often other factors confounded the relationship such as the past experience of the respondent and the maintenance level of the green space. Even though this review explored public greens, it reflects the general level of uncertainty about the effect of vegetation on safety and security. More research is needed to examine the appropriate equilibrium between vegetation cover and level of maintenance. Most of the investigated crimes of public spaces are hardly applicable in the garden context as they involved violent crimes. Garden specific factors and the influence of different garden designs on security are largely unexplored.

Implications for authorities
The present state of knowledge is too limited to provide any sound implication recommendations.

Implications for garden owners
The present state of knowledge is too limited to provide any sound implication recommendations.

4 Additional findings

Several additional results were obtained in addition to the ES described so far. They often covered multiple ES or complementary issues, which are also relevant in this context.

4.1 Exotic Species

The nature of urban gardens is highly affected by cultural influences. Owners cultivate and weed the plants they favour and dislike respectively. This includes the planting of exotic species, which normally would not grow in that area. In the following, several studies which examined the impact of these measures are described.
Shapiro (2002) reported in his research about Californian butterfly assemblages that the eradication of exotic weed plants leads to the disappearance of urban and suburban butterfly fauna. In a study by Fontana et al. (2011) no significantly different effect was found between the exotic and native plants on bird species richness, diversity or community composition. On the other hand, many publications demonstrated or emphasized the benefits of avoiding exotic plants. Kowarik (2011) set up a list of risks that are mentioned in connection with exotic species in urban regions. These include the displacement of native species, impacts on higher trophic levels and biotic homogenization. The latter is a recurring issue throughout this review. It reflects socio-ecological processes such as the social stratification (3.1.1 Food), the neighbourhood mimicry (3.4 Cultural services) and the focus on exotic plants due to the “ecology of prestige” (Warren et al., 2008) and an exaggerated “luxury effect” (Hope et al., 2003). All in all, these processes jeopardize the biodiversity and the genetic of an ecosystem. In addition, Niinemets and Peñuelas (2008) showed that invasive plants emit biogenetic volatile organic compounds (BVOC), which create ground-level ozone, thus increasing the photochemical smog in the city. In this situation vegetation can even cause air quality disservices.

Ignatieva et al. (2011) found that native species generally promote native biodiversity but exotic species can also occasionally play a role for ecosystems. Sometimes exotic species are so closely interconnected in the local environment that a removal would disturb or even destroy food webs with integrated native species (G. D. Daniels & Kirkpatrick, 2006). While these studies encountered a more general approach, others looked into more detail concerning individual animal classes or species. An assessment in Pennsylvania (US) by Burghardt et al. (2009) demonstrated that native plant communities held significantly more caterpillar species and individuals as well as a higher bird abundance, diversity, biomass and number of breeding pairs. Other studies generally advice to cultivate native vegetation to promote local biodiversity and ecosystems (C. Berg, 2003; Dolan et al., 2011; Goddard et al., 2010; Sperlich, 2006).

Whether they are truly responsible for decreasing native biodiversity is not yet sufficiently investigated (Kowarik, 2011). The interrelationships and underlying causes need to be examined further before any recommendations can be made. Therefore, Dearborn and Kark (2010) advised to specify the goals of the policy and include or exclude exotic species accordingly. The policy priority for SOS is the promotion of vegetation. The advocacy of a certain type of vegetation can be a subsequent step. Until then, the promotion of, but not fixation on, native species can be a good measure.

Implications for authorities
The present state of knowledge represents a general favour for native species but a certain precariousness when it comes to the role of exotic species. The policy priority for SOS is the promotion of vegetation. The advocacy of a certain type of vegetation can therefore be a subsequent step. Until then, the promotion of, but not fixation on, native species can be a good measure.

Implications for garden owners
The present state of research favours native species. It is therefore recommended to cultivate mainly native plants in the private garden. They are found to promote local biodiversity and naturally belong into the ecosystem.

4.2 Monetary valuation

It is beyond the scope of this review to calculate the monetary value of greener gardens. Yet, several publications are found with promising approaches for a monetary evaluation. The thematically fitting studies are included in the chapter about aesthetic services. As the remaining are no less notable, they are described in the following.

The most important project in this discipline is *The Economics of Ecosystems and Biodiversity* (TEEB) which is developed to assess the economic profits associated with the delivery of ES and biodiversity (Wetten et al., 2012). In a second step TEEB City is set up to emphasize monetary and social benefits of urban nature for urban planning. By means of these resources, local authorities can effectively include sustainability and nature protection in their policy and management plans. Some Dutch municipalities tested the TEEB City methodology and regard it as a worthwhile application for private garden valuations as well (for example Reitsma, 2016).

In the framework of a more general study, Yli-Pelkonen and Niemelä (2005) defined the Total Economic Value (TEV) of green areas based on three value levels: “user value (e.g. recreation and education), option value (option to use later to whatever purposes), and existence value (importance of nature because of itself)”. While the first can be extended by the garden owner, the last provides some potential for municipalities. Authorities can encourage greener neighbourhoods to enhance its reputation as a ‘green city’. The option value can also be exploited for insurance and resilience calculations (Mcphearson et al., 2014). In a first attempt, Gómez-Baggethun and Barton (2013) developed economic accounts for the air, temperature and climate regulation. **Applying these methodologies can substantially benefit on a neighbourhood scale and certainly immense at a city-wide scale.**

In addition, monetary valuation can be a more effective incentive than trying to convince people and authorities by rational justifications alone. Top-down regulations such as tax subsidies and forfeits are a popular tool to reach environmental goals. In the US, incentives are used to impose the Endangered Species Act on private land (Goddard et al., 2010), whereas several German municipalities charge for higher taxes per sealed square meter (Hofnagel, 2010). The most important factors for Dutch garden owners are time and cost expenditure (Horstra, 2016). The promotion of inexpensive and easy to maintain gardens, as positive incentives, can address a larger group of citizens (Beumer, 2016; Faber, 2016; Horstra, 2016; Reitsma, 2016). The city of Zaanstad (Netherlands) is considering to organize a competition for the best private garden according to the BIMBY (Biodiversity in my backyard) methodology and to tender a first prize of waiving all municipal fees (Beumer, 2016). Approaching the topic from an economic perspective is supported by some promising concepts. Further research herein can deliver substantial profits for municipalities and initiatives.

However, caution should be exercised when adopting this scheme. Some ES like Sense of Place probably cannot be simply expressed in monetary terms. The design furthermore implies a quantification of the value, resulting in rankings and comparisons of ES. Authorities can be induced to neglect certain ES or exclusively promote one ES. Prior to the examination, solutions must be found how to handle such difficulties.

Implications for authorities
The monetary valuation of ES in private gardens can be a highly promising approach for municipalities. It can furthermore convince social classes that mainly interested in monetary incentives. However, the method must be elaborated in detail beforehand to prevent premature judgements of less convenient ES valuations.

Further information

- TEEB General: http://www.biodiversiteit.nl/teeb [Dutch]
- TEEB for business: http://www.biodiversiteit.nl/samenwerking-voor-biodiversiteit/taskforce-biodiversiteit-natuurlijke-hulpbronnen/nieuwsarchief/bedrijven-in-de-hoofdrol-bij-behoud-biodiversiteit [Dutch]

Implications for garden owners
Garden owners can inform themselves about the possible monetary profit of their garden. There is likely to be more value in the garden than someone expects.

4.3 Multifunctional nature

Individual ES of urban green spaces are often regarded as marginal compared to those of pristine landscapes (Lovell & Taylor, 2013). This can discourage authorities and initiatives in their campaigns. As a consequence it is advisable to promote the multifunctional nature of gardens. The literature research revealed that the promotion of one type of ES often creates some synergies, which initiate the delivery of more ES. Langemeyer (2014) defined a number of ES that are often found together. They are (applied to the herein used terminology); food provision and soil quality; aesthetics, recreation and well-being; and social cohesion, spiritual and sense of place. In the case of the latter, the gardeners felt a political fulfilment when working with soil and self-grown food. However, the author found some trade-offs, where the delivery of one ES interfered or excluded another. This was the case for food provision and recreation. It might reflect the previously found statement of the garden as a burden. The cultivation of food often requires consistent commitment where the harvest might not always reflect the invested efforts. The permaculture concept provides some promising answers for these and other problems around cultivating food in the urban environment (Mollison, 2001). Similar to the monetary approach, care must be taken not to focus too much on quantitative comparisons (Hansen & Pauleit, 2014). The valuation of ES depends on many factors including the personal preferences of the garden owner so oversimplified and generalized judgements should be avoided. This corresponds with a survey by Dewaelheyns et al. (2016), where garden owners preferred combinations of various goals and incentives rather than a single motivation. A clear and comprehensible presentation of the goals is crucial in this context. Figure 8 shows the representation method for ES bundles designed by Deutsch et al. (2013). The authors provided an example for the agricultural land-use (Figure 9). This methodology can be adopted and customized to present ES of different garden designs and demanded ES. One possible application platform is the website (described in Appendix I).

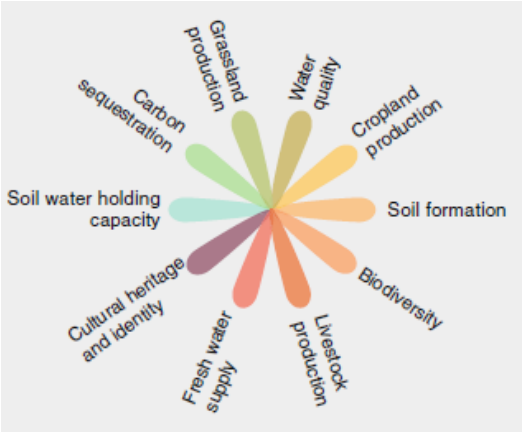

Figure 8 Ecosystem services bundle design by Deutsch et al. (2013)

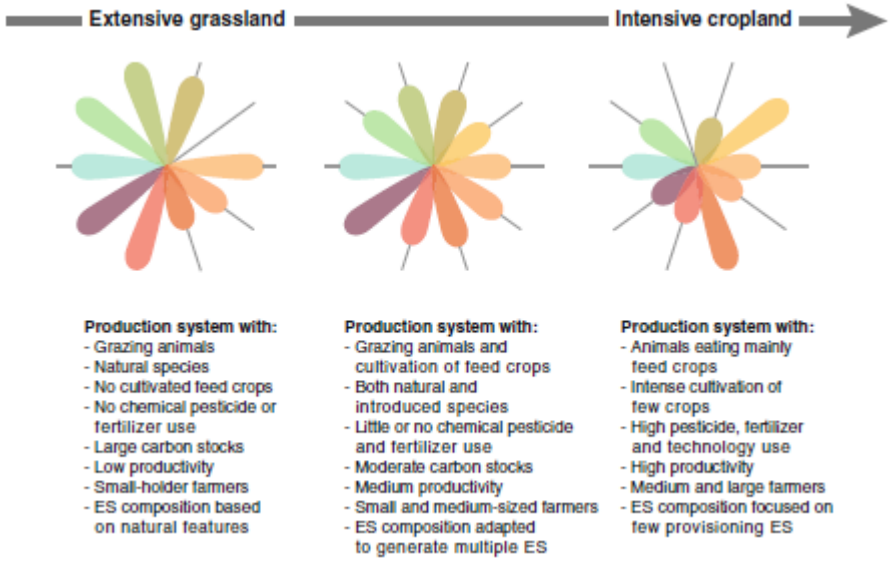

Figure 9 Example of three elaborated ecosystem bundles for agricultural landscapes (Deutsch et al., 2013)

Implications for authorities

Authorities are advised to promote multiple ES instead of focussing on a single service. Thereby, more citizens can be addressed. The fact that the facilitation of one ES can have multiple concomitant benefits of other ES, is a strong argument for the encouragement of ES in private gardens. It can also help to increase the provision of unfamiliar ES via the promotion of more popular ES. Improving soil-related services, for example can be too abstract for gardeners, whereas stimulating food production is more comprehensible. This way, promoting provisioning services might be more effective, resulting in advantageous increases for supporting services as well. Authorities should exploit this and other concepts such as urban permaculture more vigorously.

Implications for garden owners

Garden owners can easily increase the ES provision of the garden by favouring multifunctional systems. Gardens can be valued much higher when owners dissociate from the concept of considering only a single ES. The permaculture concept is one example of various approaches to support multiple ES.

Further information

- Pamphlet about Permaculture for Urban Areas & Urban-Rural Linkages: http://rucore.org.za/wp-content/uploads/2011/11/Mollison-PDC-manual_ALL.pdf [English]

4.4 Environment

Many studies about ES demonstrated a close connection of them with biodiversity and connectivity. The provision of ES is dependent on a suitable habitat for species. Appropriate levels of biodiversity and connectivity form ecosystems and thereby support various ES. While humans consciously or unconsciously demand all kinds of services from nature, they often forget to make their contribution for a sustainable supply of those. Several socio-economic developments have negative consequences for the local environment (Cook et al., 2012; Galluzzi et al., 2010). These include soil sealing and social stratification, which were found to degrade biodiversity levels. In contrast, the cultivation of native and structurally divers vegetation can increase biodiversity within the city, while urban agriculture conserves pristine areas outside the city (for example Dolan et al., 2011; Ignatieva et al., 2011; Smit et al., 2001a)

This chapter emphasizes the close relationship between biodiversity, connectivity and ES, in order to raise awareness for the necessity of a healthy equilibrium between demand and supply. It illustrates the influence of green spaces, particularly private gardens on biodiversity and connectivity levels. Furthermore, studies about the effects of sealing on biodiversity and connectivity are reviewed.

4.4.1 Biodiversity

In recent years the interest in urban ecology and biodiversity is constantly increasing. Many universities and research institutions established research departments to study the impacts of the city on the organisms living within. On the occasion of the Year of Biodiversity in 2010, Gairola and Noresah (2010) pointed out that the conservation of biodiversity is one of the crucial tasks of today's and future urban planning, specifically in the ongoing growth of the human population. Studies, looking at the development of the structural species diversity recorded worrying declines (Pauleit & Duhme, 2000). The fact that cities are often initially built at species rich locations, further worsens the situation for urban nature (Kühn et al., 2004). Thoughtful urban planning, which integrates ecological zones can provide habitats for wildlife, which often surpass biodiversity values of surrounding, overstrained agricultural fields (Schuetze et al., 2011).
One ecological assessment method of gardens and parks in Aachen (Germany) has been developed, based on the ecological quality of structural parameters (Wilke, 2014). These structural parameters, including grassland, bushes trees and sealed surfaces, are mapped per park or garden site. Subsequently, the ecological parameters 'green volume', 'abundance of flowers' and 'biodiversity' are determined. This methodology has a good cost-benefit-ratio, due to its easy and comprehensible application. This combination with data about use and maintenance of an area can eradicate most of the detected weak points. Another advantage of the method is the possible utilization by non-scientists (B. Daniels, 2016). **This methodology enables the garden owners to apply of this method in their gardens to evaluate the ecological quality of them.**

Soil sealing
Soil sealing has a severe negative effect on the environment, as it always leads to biodiversity loss and reduces the biodiversity potential (based on the Shannon-Weaver biodiversity model) of urban landscapes (Fontana et al., 2011; Radford & James, 2013; Scalenghe & Marsan, 2009). An increase of the volume of vegetation in the city is reported by several publications as a successful measure to support species abundance and diversity (Fontana et al., 2011; Savard et al., 2000). Furthermore, citizens express a high valuation of biodiversity in urban green spaces (Voigt & Wurster, 2014). There is obviously a public demand for highly biodiverse sites in the city so authorities should make use of that.

Several studies of species diversity and assemblages along an urban gradient have been conducted so far. The results are not unanimous but rather provide various factors that influence species richness such as several socio-economic variables (e.g. population and housing density, education, home ownership) (Luck et al., 2009), distance from nature areas and housing age (Loss et al., 2009).
Other researchers note that mature trees can partly provide biodiversity to support ecosystem service provision in a heavily sealed city area (Larondelle & Haase, 2013). In this respect, Gairola and Noresah (2010) suggested to prescribe the plantation of a 'multipurpose tree' for every household. **A list of motivations to conserve urban biodiversity depending of the degree to which humans or nature would benefit from it has been set up, which includes a description of common challenges and approaches to achieve conservation goals** (Dearborn & Kark, 2010). Baumgärtner (2007) additionally argued "that biodiversity acts as a form of natural insurance for risk-averse ecosystem managers against the over- or under-provision with ES"

Pesticides and Herbicides

The assessment of the application of chemical substances such as herbicides and pesticides in gardens is covered by several studies. Pesticides had significant negative effects on bird species richness (Shwartz et al., 2013), as well as insect numbers (Jaganmohan et al., 2013). Several studies advised to minimize the application of herbicides and pesticides (for example Savard et al., 2000; Setälä et al., 2014). Both substances are classified as "signs of conflicts" in the BIMBY indicator set (Beumer, 2014). These findings showed that biodiversity can be substantially jeopardized by the application of chemical substances.

Gardens

The connection between urban ES and biodiversity is probably the discipline that has been investigated in the greatest detail. Apart from the already mentioned more generally applicable studies, several researchers dedicated their work to the biodiversity in private urban gardens. They emphasized the potential of these landscapes to increase species richness and improve the life of all organisms in the city including plants and people (e.g. Pauleit et al., 2005; Rudd et al., 2002). Thereby, garden setup and practices play an important role for the provisioning of suitable conditions for a broad range of species varieties. In a comprehensive research by Cook et al. (2012), several of those conditions could be identified. The amount of ground and canopy cover as well as the surface temperature and irrigation of plants had positive effects on faunal trophic dynamics and interactions. **These in turn increased habitat and subsistence provision and beneficial predation of pest species. However, many gardens facilitate synanthropic species, which can cope better in an anthropocentric environment and consequently outcompete less adapted species (Cook et al., 2012). The urban organism community thereby homogenizes and biodiversity levels decrease**. They are furthermore threatened by exotic plants (Niinemets & Peñuelas, 2008). A detailed review of the influence of exotic species is given in chapter 4.1 Exotic species. In the following, the results are organized into floral and faunal diversity.

Plant diversity

While the theoretical potential of gardens to support plant diversity is undisputed, the scale of the potential remains controversial. Some studies attribute high levels of floral variety to domestic gardens (Kühn et al., 2004; Maurer et al., 2000). Gardens show furthermore no saturation of species accumulation curves, which indicates a high diversity between gardens (Thompson et al., 2003). A study conducted in the framework of a larger survey of biodiversity in gardens in Sheffield (UK), also reported a major influence of the local climate on lawn species compositions (Thompson et al., 2004). Yet, Burkhard et al. (2009) only reported a medium relevant capacity of urban green spaces to support plant diversity.
Care must be taken when evaluating garden biodiversity, as a study in South Africa showed (Lubbe et al., 2010). High rates of species richness in individually garden plots showed a large homogeneity across gardens and actually consisted of mainly alien plant communities.

Animal biodiversity

Most of the publications concerning animal biodiversity in private gardens dealt with invertebrate, avian and mammal orders. In the following paragraphs they are examined separately. Studies about invertebrate biodiversity are also potentially relevant for the ecosystem service pollination. To avoid double entries, the pollination chapter only covers studies that explicitly mention this service, every other study is described in this chapter.

Invertebrates

Similar to the findings about plant diversity, the design of a garden can influence the present invertebrate diversity. The microhabitat availability is found to be a significant factor for invertebrate assemblages, leading to the presumption that urban environments can be purposefully designed to attract a specific (range of) species (Bates et al., 2015). The same study reported no changes in broad assemblages along a rural-urban gradient, however, at species level changes were detected. The authors assumed that general taxonomic structures remain preserved in the city, while individual species become extinct or thrive due the altered conditions. Thereby, ES provided by invertebrates are likely to be constant, though (local) extinction can be a threat to the overall functioning of the ecosystem (Bates et al., 2015).

Jaganmohan et al. (2013) reported a direct relationship between the number insect of orders and the present number of tree, herb and shrub species. A study by Goddard et al. (2010) specified this further by including the importance of complementary gardens on the neighbourhood scale. The complexity, rather than size, of a garden can be used as a predictor of the existing vertebrate and invertebrate species diversity and abundance. Moreover, their results suggested that garden design should follow the design of the surrounding landscape to maximize the effects of gardens on urban ecosystems. Comparable suggestions are made by Smith, Warren, et al. (2006) who recommended to **consider the distribution of other green spaces throughout the city in order to increase garden effectiveness.**

Other studies provided further arguments for the hypothesis to **rank the factor vegetation structure above the total surface of the garden**, although relationships were not consistent across taxa (Lin et al., 2015; R. M. Smith, Gaston, et al., 2006; R. M. Smith, Warren, et al., 2006). Therefore, researchers suggest to **study a range of taxa across various locations to gain more reliable assessments of garden biodiversity** (Shwartz et al., 2013). Most studies agree that there is no patent remedy, but different approaches to measure and monitor biodiversity are available, which have been tested and described (among others Bates et al., 2015; Niemelä, 2000).

The total vegetated area of a garden seems to be a meaningful predictor for bee species richness (Matteson & Langellotto, 2010). Additionally, significant factors were canopy cover, the presence of unmanaged corners and the vegetation of the neighbourhood. Bee and butterfly species required a minimum of 10-30% green spaces within a 500 m radius**, which further stresses the importance of combined actions towards a greener urban environment** (Matteson & Langellotto, 2010). The positive effect of unmanaged corners or wilderness is supported by similar publications that included the factors wilderness (Berg, 2003; Ignatieva et al., 2011; Jaganmohan et al., 2013; Sperlich, 2006) as well as intact litter layers under trees (Herrmann et al., 2012).

The number of studies about the effect of providing food, shelter or nesting facilities for invertebrates is limited. In a study by Pellkofer (2011), the number of nesting sites (natural and artificial) had no influence on the abundance, richness or evenness of solitary-nesting Hymenoptera species. Other efforts to support local invertebrate taxa with artificial nests, ponds, dead wood and nettle plantations revealed mixed results (Gaston et al., 2005). The efficiency of these wildlife garden measures does not seem to be as straightforward as expected, so the authors recommend not to create excessive expectations when those measures are used for awareness and participation activities.

Birds

Birds are conspicuous and easy to identify for citizens. Therefore, they are a popular research subject of urban ecology (Chamberlain et al., 2004; Loss et al., 2009). A detailed description of the present state of research would exceed the scope of this review. Research indicates that birds, just as invertebrates, respond variously to the urban environment, with some species thriving better and some worse (see for example R. B. Blair, 1996; Melles et al., 2003). Moreover, domestic gardens can be designed to attract specific species especially when native trees and dense shrubs are planted (G. D. Daniels & Kirkpatrick, 2006; Lin et al., 2015).

Figure 10 Artificial (box) and natural (tree hole) bird nest sites

Mammals

The number of different mammal species in the urban environment is rather limited. A survey among British garden owners recorded in total 22 species or species groups occurring in residential gardens (Baker & Harris, 2007). Only six of them (bats, red fox *Vulpes vulpes*, grey squirrel *Sciurus carolinensis*, hedgehog *Erinaceus europaeus*, mice, voles) were mentioned by more than 20% of the respondents. Increased fragmentation and distance to natural habitats as well as decreased garden size and structural diversity were the most detrimental factors for mammal occurrence. Gaston et al. (2007) found that residential mammal feeding was positively correlated with housing density. Even though this trend provides some form of mitigation for the inhospitality of dense urban environments, this measure alone is hardly sufficient to facilitate viable population sizes. Small mammals are furthermore vulnerable to predation by domestic cats (Cooper et al., 2007). In a study by Angold et al. (2006), the presence of green corridors in the city seemed to have a limited value for mammal dispersals. Nevertheless, garden hedges can offer a habitat, shelter and dispersal opportunities for hedgehogs and other mammals (Beumer, 2014).

Figure 11 Young squirrels (Sciurus vulgaris) in a private garden

Biodiversity measuring

Biodiversity is interconnected with all types of ES. However, there is no universal applicable method for measuring biodiversity and habitat quality of an area so the opinions about the extent and potential of urban biodiversity diverge. A good method for thoughtful assessments is to include several species of various taxa (Dauber et al., 2003). When time restriction only allow a rapid biological assessment, MacGregor-Fors et al. (2015) developed a list of recommendations for the execution and interpretation of the results. Sattler et al. (2014) suggested that, by assessing the status of several umbrella species, complementary data on the quality of the local biodiversity can be gained. Alternatively, a set of criteria for selecting the best indicator species has been defined by Vandewalle et al. (2010). Beumer (2014) developed two effective frameworks. Firstly, the Biodiversity Benefit framework to discuss about the values of greening practices for biodiversity conservation. And secondly, the BIMBY framework for a social-ecological assessment, which is specifically designed for garden biodiversity.

Implications for authorities

The studies underline the need to provide information and coordination for the general public about the opportunities and risks of garden management concerning biodiversity. Gardens can greatly support biodiversity and consequently various ES. Authorities can seek more public support by using flagship species or umbrella species for the whole ecosystem. Mammals are often highly suitable, although even invertebrate citizen science projects such as the BUGS study demonstrated promising participation enthusiasm.

Further information

- Urban domestic garden studies: http://www.bugs.group.shef.ac.uk/BUGS2/results.html [English]
- Catalogue of Assessments on Biodiversity and Ecosystem Services: http://catalog.ipbes.net/?attachments=f&geo_scale=&systems_assessed=Urban&ecosystem_services_functions_assessed=&tools_and_approaches=Indicators,Social%20(non-monetary)%20valuation&page=1 [English]

Implications for garden owners

Biodiversity is interconnected with all types of ecosystem services. Supporting biodiversity in the private garden can pay back with increased ES provisioning. Studies demonstrated that even small-sized gardens can offer habitats to achieve high biodiversity levels.

Further information

- Website about backyard conservation in the US: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/az/home/?cid=nrcs143_023574 [English]
- Vogelbescherming project Tuinvogelconsulenten: http://www.vogelbescherming.nl/actueel/resultaten/q/ne_id/1857 [Dutch]

4.4.2 Connectivity

Apart from the previously described provision of habitats for biodiversity, the connectivity of those habitats may not be disregarded. There is no unanimous application of terminology concerning green infrastructures so this review includes various publications with keywords such as stepping stones, urban planning, corridors, resilience, connectivity, dispersal, network, fragmentation, matrix and land use. In the following, a selection of relevant studies is described. No distinction between different species or orders have been made in this chapter, as it is a universal approach to the possibilities and benefits of connected gardens.
The fragmentation of urban green spaces is a growing research topic, which is lately boosted by new and improving technologies such as GIS. For instance, promising improvements of connectivity were obtained by **using least-cost path methods in a Chinese city (Kong et al., 2010) and the *Zonation* conservation planning tool** in the city of Melbourne (Gordon et al., 2009). Several studies dealt with the evaluation of green infrastructure and provide replicable methods to increase potential biodiversity levels (Mantle, 2010). Colding (2007) developed an '***Ecological land-use complementation concept*'** that combines all urban green areas to create suitable habitats for wildlife, without jeopardizing these areas for human uses. According to the author, it results in increased ecosystem resilience, response diversity, ecotone utilization and ES. Direct dependencies of regulating services such as seed dispersal, pollination and pest regulation, on a functional network of landscapes have been reported (Andersson et al., 2014). Humans can benefit from a closer connected green network as it provides a variety of amenity resources (Tian et al., 2013).

Similar to the requirements for habitats, the needed connectivity varies across taxa. More sessile species, for instance carabid beetles and spiders, rely on a dense network of habitats or appropriate individual sites, whereas mobile spices, such as bees and weevils, are capable of covering larger areas and finding habitats in a broader ecosystem (Angold et al., 2006; Braaker et al., 2013; Goddard et al., 2010; Kowarik, 2011). In a study by Öckinger et al. (2009), species richness of butterflies was positively related to the percentage of green areas within 1 km of the site, whereas total area size had no significant effect. Similar results are found for hymenopteran abundance and richness, in particular small green areas had elevated levels of both parameters when located in a green environment (Pellkofer, 2011). Dearborn and Kark (2010) reported that the removal of even one green area can compromise the overall functionality of the system. Other studies pointed out that the matrix between stepping stones and corridors should not be neglected (Baum et al., 2004; Dauber et al., 2003). Connectivity depends on numerous species- and landscape-related factors, so Angold et al. (2006) suggested to focus on high quality habitats rather than connectedness. All in all, Beumer (2014) came to the conclusion that the potential of cities to offer stepping stones for biodiversity is underrepresented in conservation efforts.

Gardens
The majority of publications related to garden connectivity attributed private gardens a significant potential to support wildlife populations. The research by Sperling and Lortie (2010) revealed that urban environments have a considerable species pool at their disposal. Connected green spaces are necessary to prevent fragmentation and isolation of developed areas. If nature reserves are widely spaced, small and closely distributed patches such as gardens can link and support the biodiversity of large natural areas (Goddard et al., 2010; Jim, 2013; Rudd et al., 2002) and additionally yield a higher potential for connectivity than the scattered rural gardens (Verbeek et al., 2011). The SLOSS debate discusses if a 'Single Large Or Several Small' natural reserves would be more beneficial for conservation (Diamond, 1975). This concept can be transferred to natural areas in the urban environment. In favour of a 'Several Small' concept is an analysis by Dennis and James (2016) which indicated that a network of multi-functional habitats can even exceed the species richness of larger green sites.

The design of the garden has a major contribution to the functionality as a stepping stone (Ignatieva et al., 2011). Ideally, these gardens feature a variety of ecological zones and structures to provide a suitable habitat and food source for a maximum number of species (Galluzzi et al., 2010; Rudd et al., 2002).

As a result, many scientists call for an integral planning of urban green infrastructure. Future biodiversity projects need a multidisciplinary approach involving natural and social scientists, urban planners and garden owners (among others Jim, 2013; Rudd et al., 2002).

Implications for authorities
Several tools and models have been developed to assess the connectivity of habitats in the urban environment. These can be applied to determine the condition of the city and to find areas with high priorities for improvements. A functional green infrastructure requires an integral planning concept and the improvement of the connectivity is a community task. Authorities can make a major contribution by initiating and guiding collaborations between urban planners, garden owners, natural and social scientists.

Implications for garden owners
Garden owners can essentially contribute to better connectivity levels in the city. The provision of resources for the local biodiversity can enhance the connection for various species with other urban green spaces as well as natural areas. Gardens can contain considerable species pools and function as stepping stones for wildlife populations.

5 Discussion

The applied methods of literature and qualitative research proved to be efficient for the present review. The literature gave an in-depth understanding of the subject. The possibility and extent of ES delivery in the European cultural and climatic area were collected and evaluated. Within the given time frame, the topics could be covered adequately. Based on the literature research, questions for the experts and representatives of the municipalities could be developed. Those interviews turned out to be especially valuable for underrepresented topics. The findings represent the results of the consultations and reviewed publications. This gives no guarantee for the effectiveness or ineffectiveness within a random individual garden. However, the sheer quantity of evidences in similar circumstances gives a strong likelihood that they also apply elsewhere.

Despite the demonstrated potential of gardens to support urban environments, most of the used publications studied public green spaces, mainly parks. This disproportion is the result of several aggregative conditions for research in private gardens. First, data collection is more elaborate because it depends on the willingness of each garden owner to cooperate and to permit access (for example Barratt et al., 2015; G. D. Daniels & Kirkpatrick, 2006). Second, the risk of biased results is higher as garden owners consciously or unconsciously influence their description of the own garden (G. D. Daniels & Kirkpatrick, 2006; Gaston et al., 2007; Kirkpatrick et al., 2007). These drawbacks, however, should not discourage researchers to take on this assignment. Considering the increasing pace of urbanization, the garden as a part of the urban green infrastructure will undoubtedly gain more attention. Uniting plenty of gardens can contribute dramatically to a better local and global environment. As Sperling and Lortie (2010) wrote; “Backgardens provide an opportunity for ecological restoration with cities”.

The review demonstrated that garden size can have a considerable influence on the occurrence of ES. Larger gardens often provided relatively more ES than smaller ones. This seems logically because of more spaces to contain various features (Loram et al., 2008; R. M. Smith et al., 2005). Both studies revealed that larger plots have more structurally varied vegetation and favourable elements such as compost pits and large trees. The proportion of impervious surfaces further decreased with increasing garden sizes because features such as garages, parking lots and sheds do not increase with increasing garden sizes (Loram et al., 2008; R. M. Smith et al., 2005). The complete paving of gardens is also connected to a certain threshold value. Smaller gardens are more likely to be completely sealed whereas owners of larger ones often fear high costs of sealing measures (Reitsma, 2016). Nevertheless, many studies demonstrated that small gardens can have valuable ES as well particularly where design is a more important factor than size (Goddard et al., 2010; Jarošík et al., 2011; Öckinger et al., 2009; Shwartz et al., 2013; Tenngart Ivarsson & Hagerhall, 2008).

The reviewed ES can be divided based on their scale dependencies. Throughout the review, it became apparent that ES provisioning takes place on one of three scales namely; the *individual garden* scale, the *garden and surrounding properties* scale or the *neighbourhood* scale. The scales and their respective ES are explained hereafter.

1. *The individual garden*
   In an individual garden plot, cultural and provisioning services can already be delivered in substantial amounts. In contrast to public greens, citizens can independently decide how to set up and what to cultivate in the garden. They are generally for the personal use only, so the production of food, flowers and materials is similarly for the personal consumption only. Consequently, the options to deliver providing services are manifold and the only restrictions are the size of the garden and the cultivation conditions (for example Cook et al., 2012). The same applies for most of the cultural services as they

are based on subjective preferences. The parameters education, aesthetics, spirituality and recreation are highly subjective. In back gardens these ES are primarily providing benefits for the owner. On the other hand, a front garden can produce these cultural services for a larger number of people. The better visibility for neighbours and passing cars and people increase the potential of front gardens to benefit more people. Thoughtful garden designs can easily respond to these potentials and considerably increase the quality of life for the owner as well as for those in the neighbourhood.

2. *The garden and surrounding properties*
   Social relations, security, health, well-being and soil quality seem to be not exclusively dependent on the individual garden. They are at least partially influenced by neighbouring plots and public green spaces. Social relations for example, require two or more sympathetic neighbours. Health and well-being are found to be increased by the view from the window alone (for example Honold et al., 2016) but other surrounding green spaces are likely to have some impacts as well (de Vries et al., 2003). Similar results are found for soil quality levels, where surrounding garden plots can have substantial impacts (Scalenghe & Marsan, 2009).

3. *The neighbourhood*
   On the other hand, regulating services are most efficient on the neighbourhood or city scale. Publications indicated that they often depend on a network or a minimum area to function effectively. This can be seen as a drawback but also as a community challenge where everybody can and should play its part. The resulting implications can put a social pressure on owners of sealed gardens. Initiatives such as SOS can communicate this aspect to promote the mutual control for natural gardens between neighbours and within the neighbourhood. The integration of community groups, for example, can be very suitable for such tasks. These groups are representatives of the neighbourhood and often willing to participate (Mader et al., 2011). Agreements between neighbours can supplement the efforts (Dewaelheyns et al., 2016). Besides, citizens without a garden can be involved. Possible concepts are for example sharing gardens, initiating and participating in community gardens or providing garden space for people without a garden.

ES are exceptionally intertwined, creating a network of interacting systems and processes. This has two implications for urban planning. Firstly, all these dependencies and principles are elusive for the majority of citizens. The website framework (Appendix I) can resolve this problem by offering intelligible explanations. ES are further not only dependent on the local ecology but also on man-made factors such as cultural traditions and valuations (Mcphearson et al., 2014) Secondly, advancing the provision of one ES is likely to produce multiple benefits from other ES as well. Urban ecologists and involved initiatives can take advantage hereof by selecting appropriate arguments for the different target groups. For example, elderly people are most vulnerable for the effects of the Urban Heat Island so they might be convinced by improved temperature balancing. Whereas middle-aged groups could be convinced by enhanced health benefits. Both strategies would finally lead to extended vegetation volumes thereby promoting various ES.

In combination with the findings of other studies, this review provides an promising foundation for large scale ES evaluations in urban environments. New techniques such as remote sensing are possible, thanks to the technological progress. Mappings of urban gardens and ecosystem service supply and demand have already been carried out separately (Burkhard et al., 2012; Mathieu et al., 2007). In addition, a recent thesis by Kolbe and Graça (2016) has shown promising concepts for GIS based modelling maps of green areas. Until now, no study combined structural parameters and ES of private gardens. The methodology of Wilke (2014) demonstrated the applicability of connecting structural parameters with ecological parameters. This study complemented the others by demonstrating the relationship between structural parameters and the other ES.

6 Conclusion

This report provides an integral overview of the possible ES provision in private urban gardens. Only few ES from the list of the Millennium Ecosystem Assessment were not found in private urban gardens. These are storm protection, cultural heritage values and tourism. The first of these almost exclusively includes the benefits of extended vegetation along the coast to protect shorelines and is rarely applicable for urban gardens. The latter two are also of minor importance in urban gardens. Cultural heritage values are partly covered here as a combination with other values such as sense of place. For all remaining ES direct or indirect evidence for their presence in private gardens were found.

During the literature research and the interviews with experts several indications for higher ES provision in gardens with a high proportion of vegetation compared to mainly sealed gardens were identified. The presence of a high green volume, including both the creation of vegetated areas as well as the enhancement of the vegetation structure, was found highly favourable for ES provisioning. This topic pervaded nearly every single ecosystem service. Enhanced vegetation volumes deliver direct or indirect improvements in temperature regulation, water regulation, pollination, soil quality, health and well-being as well as supporting biodiversity and connectivity levels. Further increases in other ES are likely, based on the interconnectivity interactivity of ES.

The conditions under which private urban gardens provide ES are reviewed and discussed in this report. In general, almost all ES can be promoted by private gardens. Several favouring conditions for effective ES provision were detected. The first and most definite of all is the minimization of impervious surfaces. Many ES such as pollination depend on the presence of plants. Sealed surfaces, however, suppress any form of plant growth, most of the soil-related services and a natural water balance. Completely sealed gardens can hardly be called a natural site so ES provisioning is actually absent. Apart from that, even the proportion of impervious area was found significant for several ES. Secondly, establishing large and various vegetation structures was found to be a consistent factor. Structural diversity of vegetation provides multifarious habitats for flora and fauna. It also seem to be a sensible strategy for those ES where the subject is so far not sufficiently investigated. For instance, no final result for air quality could be described beside the recommendation to extend and structurally divert vegetation. Additionally, health studies indicate that the quantity as well as the variety of the perceived vegetation are significant factors.

This review provides an important step towards a better understanding of the influences of gardens on ES. Herewith authorities, urban planners and initiatives can develop strategies and guidelines to increase public awareness. The review shows that there is a growing number of publications on this intriguing topic. Still, private gardens are likely to be the most underrepresented subject of urban ecology, despite their large areal proportion of cities. There is an urgent need for more research in this matter to gain in depths insights into involved ecological processes and potentials of the urban biosphere.
The report at hand offers a multidisciplinary presentation of the effects of private gardens on ecosystem services. Hereby the focus lays on the possibilities of the individual garden design to support ES. The characteristics and potentials of ES provision in private gardens is comprehensively evaluated. It is shown that gardens have a serious potential. Provisioning and cultural services can efficiently be generated in every single garden. Regulating services can be efficiently generated in collaborative processes on the neighbourhood scale.

Recommendations for authorities

The red boxes below every paragraph in the chapters 3 and 4 provide a good starting point for every interested authority. Several broadly applicable recommendations emerged from this review. These are:

(1) Authorities should raise the awareness about ES in private gardens. Many people demand services from nature without considering what they can do themselves to promote these services. Authorities should encourage a more healthy interaction with nature. Citizens need to be informed that they can and should take action to increase the ES of private gardens.

(2) Authorities should combat the negative effects of socio-economic processes. Many citizens might not be aware of the developments and their consequences so there is a need for information. Authorities can provide information about preferable alternatives such as inexpensive and low-maintenance vegetation.

(3) Positive incentives are more effective and preferred by gardeners and authorities. Authorities should respond to that by advocating the benefits of green gardens and the need for corporative actions.

(4) Front gardens are useful to raise the public awareness of the efforts of authorities. They can be used to reverse socio-economic processes by showing that there are alternatives to homogenous streetscapes. Green front gardens can trigger the mimicry-effect and cause a broader change for the better.

(5) Authorities can address private persons by emphasizing the ES that perform best on the individual garden and match the demands of the target group. By this, gardeners can benefit from the direct effects of their measures. As a result they are encouraged to take further steps on a larger scale.

(6) Authorities can address communities and neighbourhoods by emphasizing the possible ES on a neighbourhood scale. They can also increase the mutual control among neighbours, as the efforts of green gardens can be jeopardized or even neutralized by surrounding sealed gardens. Pollination, for example, perform best when a certain network of suitable areas is present. Neighbourhoods can contribute substantially to local pollination services, when sustainable networks are created. Authorities can support neighbourhoods by offering advice and coordination. They can engage and integrate various stakeholder and professionals to set up and support integral greening projects.

Recommendations for garden owners

The green boxes below every paragraph in the chapters 3 and 4 provide a good basis for everyone who is eager to support ES in the private garden. Several broadly applicable recommendations for garden owners emerged from the review. These are:

(1) Gardens can provide ES very efficiently. Garden owners can start with the ES which depend solely on the garden plot and the preferences of the owner. They can be designed to meet the aesthetic, recreational, spiritual and food providing demands of the owner. The most important aspect here, is the condition that the owner enjoys to be in the garden and appreciates its services. If that is the case, the provision of several ES will follow naturally due to synergetic ES.

(2) Sealed gardens are not necessarily cheaper or easier to maintain than vegetated gardens. Consequently, vegetated gardens should be favoured, as they have the advantage of ES provisioning.

(3) Nowadays, plenty of information is available about plants for every type of garden and gardener's preference. It is recommended to use native plants with open and single flowers. Furthermore, a large vegetation with a high structural diversity support various ES.

The given recommendations in the boxes are indeed not exclusively for the respective group. Individuals can, for example, use the implications for authorities to convince neighbours or set up a community association. On the other hand, authorities can adopt the individual implications for the promotion activities in the framework of their efforts.

During the execution of the research, several subjects for future research became apparent. They are promising subsequent steps to increase the efficiency of the future work of Stichting Operatie Steenbreek and other initiatives.

(1) The examination of the economic aspect of ES in urban garden can yield unexpected savings and profits for the urban society. When approached thoughtfully, projects such as TEEB City can offer a valuable framework and basis. More people can be convinced by responding to the demands for low expenditures.
(2) This research forms a basis for more specific investigations about the applicability and general validity of the benefits. This review can furthermore provide a collection of promising fields of investigations. In a subsequent project, the applicability for one specific municipality as a case study can be tested. The case can be adopted by other cities and customized for the local situation. It complement the present study with a practical component, which can help unexperienced authorities to get started.
(3) Further research about the possibilities to implement the given results is essential. The presented review offers a broad range of arguments and incentives for unsealed gardens. The following step is now, to differentiate between the target groups of an initiative such as SOS. Different arguments and incentives are required for families with children than for pensioners. Purposeful, individual guidelines for every target group can multiply the efficiency of SOS. In addition, there is a need to assess how these insights can be effectively communicated to the local citizens and authorities.
(4) A very complex but potentially worthwhile field of research is the determination of threshold values for the number of required green gardens in order to effectively support ecological systems. In the case of biodiversity minimum viable population estimations are an applicable concept. Another concept would be to integrate private gardens in the ecological infrastructure of a city and its surroundings. Concepts like these can provide estimations for required efforts for SOS in a specific neighbourhood.
(5) Similar to the previous issue, threshold values for particular regulating and supporting services are equally important. The influence of the total area as well as the fragmentation of the delivering gardens might be decisive for the potential of ES provision. Again, SOS and other initiatives can make use of the insights for the detection of high and low priority areas.

The technological and digital revolution pushed gardens to the back of our minds and gave them an outdated image. Nowadays however, gardens can benefit from the upcoming trends of urban gardening and the growing environmental awareness. As a result, gardens need to become the focus of urban greening efforts in order to exploit their full potential. Integrating private gardens in the social movements will promote the awareness and willingness to participate. Following the African saying in the beginning, many small steps in many places can bring about a change for the better.

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Pictures: Nora Hausen

Appendix I Website Framework

Method and material

Based on the literature research and the consultations of experts, the project included the development of a first framework of the web page for ecosystem services in private urban gardens. The lay-out and content has been chosen based on the demands of the target group of users. These are non-professionals on the field of ecosystem services. The website therefore needed to be comprehensible and user-friendly. Interested parties, including initiatives such as neighbourhood associations as well as private individuals, can learn about present and potential ecosystem services of urban gardens. The user can identify the ecosystem services of his or her own garden and compare the varying effects of different garden elements and practices. The scope lays on the universal effects so that for example neighbourhood initiatives, civil servants or private persons can directly examine the effects of different measures.

Structure

The literature review provided a comprehensive elaboration of the present state of knowledge on ES in private gardens. It can be used by initiative, authorities and experts to promote more environmental-friendly garden designs. In order to be able to reach the target group of garden owners directly, an informative website framework has been developed. The need for accessible information and a central database of relevant publications became apparent. In a survey in Leeuwarden (NL), 60% of the responding garden owners stated to be interested in more relevant information by means of folders, newsletter or a website (Peters et al., 2016). This was also a prevalent topic during the interviews and the SOS symposium in Leiden (NL). Another questionnaire revealed a lack of knowledge about the consequences of soil sealing (Polwijk et al., 2015). In addition, a demand for the explaining and defining ecology-specific terms such as ‘biodiversity’ was identified (Bendegem et al., 2015). This corresponds with a recent German survey. More than half of the respondents did not know what biodiversity is or even never heard of it (Küchler-Krischun et al., 2016). In their ‘toolbox for garden governance’, Dewaelheyns et al. (2016) emphasized that “the modest private garden owner needs simple, correct, orderly and accessible information to overcome the barriers of pre-mature responsibility and conflicting interests”.

SOS provides a website for associated and interested municipalities where information, guidelines and manuals for the authorities are offered. Yet, a website for the private person is lacking. Several interviewees and attendees expressed a request for a national website for garden owners. During the interviews and the second symposium in Leiden a demand for this website became apparent (Beumer, 2016; Faber, 2016; Poelgeest, 2016; Reitsma, 2016; Veldhuis, 2016; Veldstra, 2016). The citizens of Leeuwarden responded positively towards a comparable application for mobile devices (‘Huisje Boompje Beter’) (Anrooij et al., 2015; Polwijk et al., 2015). Conversely, the opinion about the more complex BIMBY-method was not that positive. Beumer (2014) developed the BIMBY method as a framework for understandable tools for garden owners to examine, discuss and compare their gardens. However, it seem to be too complicated and vague for the garden owners (Leeuwen et al., 2015). The authors therefore suggested to simplify and adjust the scores. These options were accordingly discussed with Carijn Beumer (2016). She saw viable possibilities to adopt the BIMBY framework for a website by reducing and simplifying the scoring method.

Content

The content of the web page consists of four areas.
The first provides information about the problem and topicality around sealed surfaces and the consequences for the direct and indirect environment. Many citizens are probably unaware of the effects of their sealed gardens. The website gives a brief overview about SOS and interesting and inspiring projects of SOS and associated initiatives including the links to the respective websites and reports.
The second part contains definitions and explanations of relevant terms. Hereunder is a possible list for the menu. It is based on the demands of the target group for information and supplemented by other scientific terms (Bendegem et al., 2015; Küchler-Krischun et al., 2016). The user can click on a term and get the relevant information about it. The given information should be to the point, exhaustive and easy to understand. Furthermore, links to websites where more information can be found can be offered.

What is actually…?

- biodiversity
- resilience
- ecosystem
- ecosystem service
- green infrastructure
- connectivity
- air pollution
- noise pollution
- light pollution

The third area provides information about the effects of the garden elements and practices on ES. A first draft of this is given in at the end of this appendix in the form of a table. It displays benefitting ES and helpful gardening tips for more sustainability per element of the garden and gardening measure. The table can be constantly supplemented, whenever new insights are gained. The user of the website gets an understanding of the impacts of garden elements and (re)development plans. He or she can click on the intended gardening action to learn more about affected ES and tips for more sustainability. In a future expansion, user possibly get to define his situation so more customized recommendations can be made. The selection can for example include:

- life and family situation: pensioners/elderly people, family with young children, family with older children, single, couples, communes,
- characteristics of the garden: large/small, shadowy/sunny, courtyard, balcony,
- preferences of the owner: high/low maintenance needed, type of preferred ES (i.e. food production, aesthetics, educational)
- the type of garden owner: by means of a simple questionnaire of the trade association the type of garden consumer (red, yellow, blue, blue-green, yellow-green or green) can be determined (Productschap Tuinbouw, 2011)
- location of the garden: climatological location, amount and frequency of precipitation, nearby natural areas and ecological structures

The information for the table derives in general from the present review and in particular from similar indices (C. Berg, 2003; Brussels Instituut voor Milieubeheer, 2010; Goddard et al., 2010; Russell et al., 2013)
As mentioned previously, the scoring system is not yet fully developed. The goal is to enable a simple form of

citizen science, where owners can evaluate their gardens and subsequently compare the results among each other. Apart from the BIMBY method, complementing approaches such as the permaculture index by Guitart et al. (2013), the measurement strategies by Lovell and Taylor (2013) the biodiversity quantification by Radford and James (2013)or the methodology of structural and ecological parameters by Wilke(2014) can improve the applicability.

This website will illustrate the ES in private urban gardens and provide information about effects of garden designs and practices on the performance of ES. These four parts can be supplemented and new elements can be added. This report shows the demand and usefulness of the website and offers a basis of relevant information.

Recommendation

The following step is to complete the website and put it online. In the end, this website should inspire and inform people, so an attractive design and information transfer is vital for its success. It is therefore recommended to have some experience in the field of communication and media design. Based on the high interest among the experts and representatives of the municipalities, it will certainly improve the service of SOS and increase the level of awareness among municipalities and citizens. The following sites can be used as a basis and for inspiration for the development of the website:

- Website about urban gardening in Antwerpen (BE): http://plantwerpen.be/ [Dutch]
- Tuinreservaten project from Jaarrond Tuintelling: http://tuintelling.nl/tuinreservaten [Dutch]
- Information about Tuinambassadeurs from KNNV (Koninklijke Nederlandse Natuurhistorische Vereniging): https://www.knnv.nl/tuinambassadeurs [Dutch]
- Vitale Groene Stad: http://www.vitalegroenestad.nl/Home [Dutch]
- Initiative for more green gardens: http://delevendetuin.nl/ [Dutch]
- Huisje Boompje Beter: http://huisjeboompjebeter.nl/ [Dutch]
- Initiative from Amsterdam to reduce flooding and other water related problems: https://www.rainproof.nl/ [Dutch]

Website content per garden element (Dutch)

Wat heb je / Wat wil je doen		Direct profiterende ED	Let op	Tips voor natuurvriendelijkheid	Afbeelding
Elementen	Moestuin	Voedsel, Bodemkwaliteit, Genetische bronnen, Sociale cohesie	Geen herbiciden	Inheemse soorten, ook een of ander onkruid laten staan, niet te netjes houden	1), 2)
	Bloemenbed	Bestuiving, Esthetisch, Bodemkwaliteit, Gezondheid en Welzijn, Sense of place, Sociale cohesie	Geen pesticiden, inheemse niet gevulde soorten	Vaste planten zijn onderhoudsvriendelijker, kijk bijvoorbeeld hier [link bijenhelpdesk]	
	Terras	Geen	Vang afvoerwater op om planten te wateren	Gebruik geen regenwoudhout	3)
	Garage	Geen	Het verzegelen van de grond i.v.m. het aanleg van de garage verbeterd de situatie nooit	Leg een groen dak [link groen dak] op de garage en biedt dieren broedmogelijkheden aan [link vogelhuisjes en insectenhotels]	
	Groen dak	Afhankelijk van beplanting, o.a. Bestuiving, Habitat, Welzijn, Waterhuishoud, Bodemkwaliteit	Het dak moet het gewicht van de planten en aarde moeten kunnen dragen	Een gevarieerde beplanting (qua soorten, hoogte en structuur) biedt de hoogste waarde voor ES	
	Compost	GHG, Afval management, Bodemkwaliteit		Een compost biedt veel dieren een leefruimte	4)
	Regenwater-opvangsysteem	Waterhuishoud	Een stokje in de regenton voorkomt dat dieren erin verdrinken		5)
	Struiken	Habitat, GHG, Voedsel, Waterhuishoud	Plant inheemse soorten, snoei niet in de broedperiode	Veel vogels vinden een plekje voor hun nest in struiken	6)
	Heggen	Habitat, Climate regulation, Water huishouding	Plant inheemse soorten, snoei niet in de broedperiode	Veel vogels vinden een plekje voor hun nest in hagen	7)

	Bomen	Habitat, GHG, Voedsel, Waterhuishoud, Temperatuur, Bodemkwaliteit	Plant inheemse soorten	Veel vogels en zelfs eekhoorntjes vinden een plekje voor hun nest in bomen, biedt een nestkastje aan	8)
	Geveltuin	Habitat, Groenvolume, Voedsel, Temperatuur (huis), Bodemkwaliteit, Waterhuishoud	Plant inheemse soorten	Veel vogels en zelfs eekhoorntjes vinden een plekje voor hun nest in een geveltuin	9)
	Vijver	Habitat, Waterhuishoud, Esthetisch, Educatie		Vijvers zijn ideaal voor de educatie van kinderen	
Maatregelen	Bemesten	GHG, Productiediensten, Bodemkwaliteit	Geen kunstmest gebruiken	Leg een compost aan [link naar compost] en gebruik die aarde daarvan i.p.v. turf Vraag bij de lokale boeren of zij paarden- of koemest hebben	
	Maaien		Een uniform gazon levert weinig ES op, beter is een	Hergebruik het gemaaide gras voor de composthoop of om de tuinbedden te mulchen	
	Gieten	GHG, voedsel en bloemen	Giet de grond onder de plant en als mogelijk niet zozeer de plant zelf, giet niet te vaak	Gebruik regenwater van een regenwateropvangsysteem	

Appendix II Agenda of the consulted experts

Consulted Expert	Position	Method of consultation	Date of consultation
Benjamin Daniels	Expert of the work group at RWTH Aachen University	Personal interview	29.02.2016 11.05.2016
Sven Kolbe	Student Van Hall Larenstein with final thesis about bumblebee abundance in Leeuwarden (NL)	Personal interview	19.04.2016
Wout Veldstra	Chairman of SOS and client	Personal interview	18.05.2016
Christa van der Weyde	Expert of SOS and representative of OS Leeuwarden	Personal interview	24.05.2016
Geert van Poelgeest	Project leader for Duurzaam Den Haag initiative and representative of OS Den Haag	Interview conducted by fellow student from workgroup	27.05.2016
Carijn Beumer	Expert of SOS and representative of OS Maastricht	Personal interview	30.05.2016
Gjalt Faber en Irene Reitsma	representatives of OS for municipality of Leeuwarden	Interview conducted by fellow student from workgroup	01.06.2016