Bridging stormwater management and ecosystem services using raingardens – Examples from Gothenburg, Sweden

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Abstract

Climate change and urban densification are leading to increasing surface runoff in urban areas in Sweden, potentially leading to flooding and water pollution. Green infrastructures, such as raingardens, are increasingly used for the management of stormwater in urban areas. Raingardens are planted beds that are designed to capture stormwater and remove pollutants before the stormwater enters the sewer network or reaches waterways. Examples of raingardens in Gothenburg, Sweden are provided. These examples show that raingardens provide a number of additional benefits compared with conventional piped stormwater solutions in the local context. These include provisioning, regulating and cultural ecosystems services, as well as supporting ecosystems services. The raingardens contribute to the control of the quantity, flow and quality of stormwater water. The raingardens also provide important cultural ecosystems services in the form of improved health, improved social cohesion and interactions in neighborhoods, and increased property value for property owners, as well as education and recognition of ecosystems services. Supporting ecosystems services include biodiversity and habitats. The benefits depend however on the location of the raingarden, which affect the volume and quality of stormwater to be treated, and on the design of the facility.

This report was prepared as part of the VINNOVA-funded project 'testbeds for the detention and treatment of stormwater' (Testbädd för fördröjning och rening av dagvatten, project nr. 2016-02518).

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Introduction

Stormwater originates from precipitation and ice or snow melt. Under natural conditions (i.e. with a natural ground cover), most of the stormwater infiltrates into the ground or returns into the atmosphere through evapotranspiration. A relatively small fraction of precipitation remains on the ground surface as runoff and reaches waterways. In contrast to natural areas, urban areas with significant impervious surfaces (e.g. paved or asphalt ground cover, roofs) are characterised by lower infiltration and evapotranspiration. Therefore, more water stays on the ground surface, directly reaching watercourses or entering the sewer network.

Climate change and urbanisation are the factors exacerbating stormwater management challenges, due to increases in precipitation and impervious surfaces (Zhou, 2014). Average precipitation in Sweden is projected to increase in the entire country, mainly during winter and spring until the end of the century. In addition, there will be an increase in the number of short-term extreme precipitation event, mainly in the form of heavy showers, in the entire country (Eklund et al., 2015). This expected increase of precipitation due to climate change together with the increase of impervious surfaces in cities due to urbanisation and densification, raise concern over the potential consequences of these changes for urban stormwater management.

Potential risks associated with stormwater in our cities include flooding, overload of the sewer network, and contamination of waterways. It is essential to avoid flooding in urban areas, as water on roads and in public spaces may compromise critical societal functions, such as transport and access to emergency services. To transport stormwater away from populated areas, Swedish and European cities generally use a mix of combined and separate sewer systems. The combined sewer systems are an older design (carrying in one pipe both wastewater and stormwater to the wastewater treatment plant) and are therefore generally more concentrated to central districts (Hvitved-Jacobsen et al., 2010). In Swedish cities (including Gothenburg, Stockholm and Malmö) central areas are becoming increasingly attractive and are favoured politically for densification to reduce automobile use and provide an increasing reliance on public transport. The downside of this positive development is that densification may increase impervious surfaces and thus stormwater volumes entering the sewer network. As stormwater flows over urban surfaces including roads, parking spaces and roofs, it collects metals, organic contaminants, oils, salt, nutrients and pathogens (Hvitved-Jacobsen et al., 2010; Payne et al., 2015). High stormwater flows into the sewer network may lead to emergency discharges, in case of combined sewers – combined sewer overflows, into water bodies, to avoid overload of the sewer system. This means that pollutants in stormwater and wastewater are discharged into the water environment (Hvitved-Jacobsen et al., 2010). Moreover, high stormwater flows disrupt the treatment processes at the wastewater treatment plant, also leading to negative impacts on water quality.

Conventional pipe solutions designed to remove stormwater from the built environment are increasingly replaced by stormwater management options aimed at providing retention detention and pollutant removal. Retention prevents flooding by removing stormwater, e.g. by infiltration into the ground. Detention slows the stormwater flow, thereby reducing peak flows, limiting erosion and flooding in accumulation areas. Both retention and detention reduce the overloading of the sewer systems and the stormwater volumes reaching wastewater treatment plants (Hvitved-Jacobsen et al., 2010). Pollutant removal is the trapping of contaminants to avoid them reaching watercourses and the sewer network, thus reducing pollutant loads into water environment (Hvitved-Jacobsen et al., 2010; Scholes et al., 2008). A green infrastructure, in contrast to conventional pipe solutions, is typically designed to manage stormwater at or near its source, while providing environmental, social, and economic benefits (Gómez-Baggethun et al., 2013; Demuzere et al., 2015; Prudencio and Null, 2018). The green infrastructure ranges from small-scale elements integrated into specific site to larger elements covering entire watersheds. Raingardens are elements of the green infrastructure that have become increasingly popular as a consequence of ecosystems services benefits, including the regulation of water flows and the improvement of water quality, as well as a range of socio-economic benefits (Prudencio and Null, 2018).

This report aims at providing an overview of stormwater management using raingardens and at providing examples of how raingardens can contribute to ecosystem services in urban areas. The examples are taken from the city of Göteborg, where raingardens have been used to support the local management of stormwater, thereby reducing potential risks associated with climate change. The report is also part of a VINNOVA-funded project 'testbeds for the detention and treatment of stormwater' (Testbädd för fördröjning och rening av dagvatten, project nr. 2016-02518).

Raingardens

Raingardens or bioretention facilities are planted beds that are designed to capture stormwater and remove pollutants before the stormwater enters the sewer network or reaches waterways (Payne et al., 2015).

Raingarden principles and design

Raingardens are versatile green infrastructure elements that can be installed in almost any urban spaces to contribute to stormwater management, typically only covering a small area in relation to the catchment area (Payne et al., 2015). Raingardens are typically designed as a shallow depression in the landscape with a vegetation cover and an absorbent soil substrate. The concept mimics the natural hydrological cycle by supporting infiltration into soil and evapotranspiration, i.e. the stormwater which is led to the raingarden evaporates into the atmosphere, is taken up by plants or infiltrates into the soil material. Pollutants presents in the stormwater in are retained in the soil or taken up by the plants. In addition, planter boxes can be considered as raingarden. A planter box is a walled container with a closed or open bottom, which is placed above ground and can be used to collect, store and filter stormwater. Planter boxes are suitable solutions when available space is limited, for instance in dense urban areas where they can be used to collect stormwater from diverted roof downpipes. Raingardens can either be designed to enable the infiltration of stormwater into underlying soil or to discharge the stormwater through a drainage pipe placed at the bottom (Payne et al., 2015).

The raingardens generally consist of a soil material that acts a substrate for a vegetation cover. The soil and the vegetation cover are the key elements of raingardens. The soil represents the filter material in the raingarden, as well as the substrate for the vegetation cover. The selection of the soil material depends on the purpose of the raingarden, i.e. coarser material should be used if stormwater retention or detention are prioritized, while a finer material will allow the stormwater to slowly percolate if treatment is prioritized (Robinson et al., 2019). A mix of standard soil and sand, with the addition of clay, is often used in raingardens. Other materials, such as pine bark and olivine are also suitable and can efficiently remove contaminants (Statens Vegvesen, 2017). The vegetation cover takes up and evaporates water, metabolizes nutrients, and keeps the soil permeable. In addition, the plants are aesthetics features of the landscape. The raingarden vegetation needs to be able to tolerate periods of flood and dry conditions, as well as tolerate relatively high levels of contaminants from the stormwater. In region where salt is used as a de-icing agent on roads, plants should especially be able to tolerate high salt concentrations (Robinson et al., 2019). Other elements of a raingarden might include an inflow, a pretreatment, transition and drainage layers, and an outflow (Payne et al., 2015).

Construction cost and maintenance

The costs for constructing a raingarden have been estimated to be similar to the cost of any other planted bed. Raingarden may decrease the need for conventional stormwater system and the final cost of implementing a raingarden is estimated to be similar to that of a conventional system (Robinson et al., 2019). Therefore, private or public landowners might also be more willing to invest in a raingarden if they can lower the costs of maintenance compared to a conventional system (Meng and Hsu, 2019). The raingardens also require regular inspections and maintenance to ensure continued functionality amd performance, as well as extend the useable life of the facility and maintain its aesthetic value (Erickson et al. 2013; Hunt et al. 2015). Lack of maintenance can lead to failure of the system (Blecken, 2017).

Examples of raingardens in Gothenburg, Sweden

Gothenburg is Sweden's second largest city with a population of ca. 580,000 inhabitants. Located on the Swedish Westcoast it has a temperate climate with precipitation spread across the year. Gothenburg is especially vulnerable to flooding. In the future, the risk of flooding is expected to increase due to rising sea levels, increased rainfall and increased flows in watercourses. Rainfall is projected to increase in coming decades, especially in the form of extreme precipitation events. The negative consequences of a rainfall with a 100-year return period include damage costs of approximately 4 billion SEK, as well as 350 million SEK for delays or waiting times (Ramboll, 2015). Smaller rains also need to be addressed, as it can create local damage, affect mobility, and affect the environment through the direct discharge of contaminants into water courses and through combine sewer overflows. Several localised floods have occurred in recent years, including a flood in Kålered, South of Gothenburg, that stopped traffic and damaged properties in 2019.

The Municipality of Gothenburg has developed guidelines to mitigate the risks associated with stormwater (Göteborgs Stad, 2010). These guidelines support local management of stormwater and recommend that when planning new areas:

1. Stormwater should be managed locally and close to the source to minimize stormwater flows and pollution;
2. Stormwater from impervious surfaces must be delayed and, if necessary, treated locally;
3. Stormwater can ultimately be directly diverted to the pipe network.

Raingarden are relevant solutions for the management of stormwater according to these guidelines, and several raingardens have already been established in Gothenburg. A raingarden was for instance implemented to manage the runoff of a parking lot for 600 cars at the Kviberg sport facility (Sörelius et al., 2017). Examples of raingardens in the Gothenburg area are provided below. The location of these examples are provided in Figure 1.

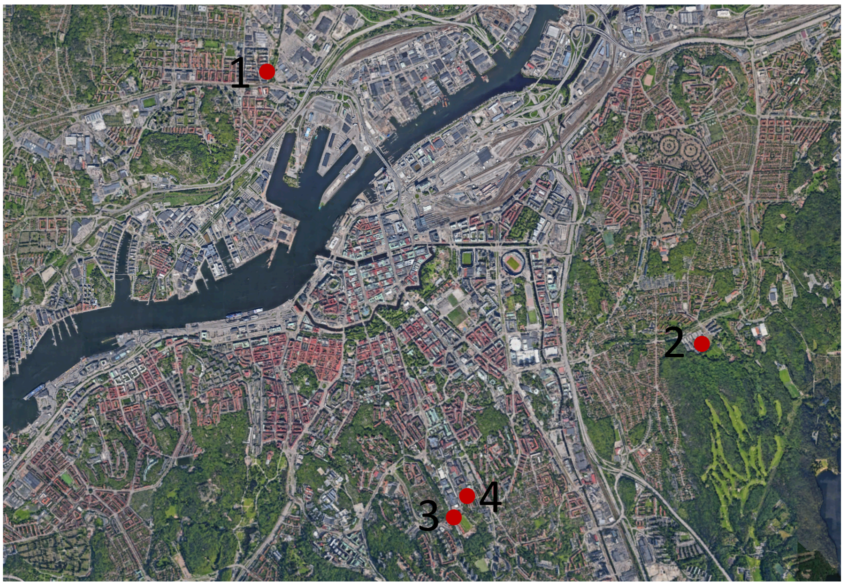

Figure 1. Satellite map of Gothenburg with the location of selected raingarden examples. 1. BRF Umbra; 2. Stora Torp; 3. Johanneberg Science park; 4. HSB Living Lab.

BRF Umbra (HSB)

BRF Umbra is located centrally on Hisingen, to the east from Backaplan and near the watercourse Kvillebäcken. The area was recently transformed from an industrial area into a lively city district with attractive housing, shopping and office spaces. Prior to transformation of the area, due to mainly impermeable surfaces in the area, large volumes of water could quickly reach the combined wastewater and stormwater pipe network and Kvillebäcken during strong rains. During the transformation, greenery was given a special attention, with green inner yards, trees along the streets, and the park area along Kvillebäcken. The combined pipe network means that flooding and overflows can occur during strong rains. To mitigate this problem, the goal was to incorporate as many green spaces as possible, in order to increase infiltration of stormwater on site and reduce the volumes reaching the pipe network. Stormwater management in the area reduces environmental impact because the pollution load on Kvillebäcken is reduced. Kvillebäcken has a high biological value and hosts a rare red listed aquatic plant – hairlike pondweed *(Potamogeton trichoides)*. Kvillebäcken then reaches Frihamnen, a new development area which could potentially offer the possibility for bathing areas in the future, before reach the Göta River and the sea.

BRF Umbra is a good example of the use of green spaces in a dense urban setting with limited available space for stormwater management (Figure 2). This residential block with 68 apartments has been planned with raingardens and a green roof area (Figure 3). The inner yard between the buildings, which is elevated and covers a parking garage, include raingardens and multi-functional spaces for recreation. This inner area also includes a green roof section covered with sedum plant species. Raingardens are also found on the outers sides of the buildings at the street level, where downspout disconnections take water from the higher parts of the building into the raingardens.

Figure 2. BRF Umbra, Gothenburg.

Figure 3. Raingarden at BRF Umbra in Kville, Gothenburg.

Stora Torp

Stora Torp is a new housing area located in Örgryte, approximately 3 km from the centre of Gothenburg. This housing area was constructed on the space occupied earlier by TV and Radio building Synvillan. The area is located in direct vicinity of a nature reserve to the South. Slopes lead to the Stora Torp area with natural streams transporting runoff from the nature area; this water is carried through the housing area in a culvert. In the northern part of the area, there are three stormwater pipes under the road Delsjövägen. The stormwater from the culverted streams is diverted in this system.

In addition to the culverted streams, the stormwater that flows on the surface needs to be managed. During construction of the housing area, the goal was to manage stormwater on site as much as possible to delay stormwater and reduce pollution load downstreams. Thus, to allow for stormwater infiltration, large green areas were created between the buildings, as well as solutions for stormwater detention (Figures 4, 5). The green areas were designed as a continuation of the park, representing a set of fingers between the buildings. The green spaces are composed of grass areas and planted areas. A concrete path with footbridges enables access to the buildings and wooden decks used as common outdoor spaces for instance for playgrounds. Stormwater is led to ditches filled with gravel along the concrete path. The ditches then lead the stormwater to reservoirs where stormwater can accumulate in a planted area encased in a granite wall. The stormwater solutions at Stora Torp allows to slow down the water flow through the use of grass and planted areas, as well as gravel in the ditches, and to store stormwater before it reaches areas downhill and the municipal sewer network.

Figure 4. The Stora Torp area, Gothenburg.

Figure 5. Raingardens at Stora Torp, Gothenburg.

Johanneberg Science Park

Johanneberg Science Park is a collaborative arena for sustainable urban development located at Sven Hultins Plats on the South side of the Chalmers Johanneberg Campus. The buildings mainly include office and meeting spaces, and restaurants. Sven Hultins Plats is a low-lying point in the area with a high risk for flooding. The water comes from several directions and there is no natural diversion possibility, which means that the area is expected to be flooded during extreme rain events. Although the finished floors of the building around Sven Hultins Plats are 4-9 cm above the highest flood level in the event of a downpour, flooding would affect accessibility to the buildings. A number of solutions have been proposed to remediate the flooding issues, including road design, and open diversion of surface water to ditches and a neighboring football field.

A raingarden has been constructed on the southern side of Johanneberg Science Park, next to a sport facility (Figure 6). The area includes areas covered with wetland-type vegetation, as well as areas covered with stones to direct water flows and facilitate infiltration. A wooden deck and footbridges allows people to use this area for recreation, including as an outdoor space popular for office workers at Johanneberg Science Park. An insect hotel has been placed at the raingarden to support pollination and biodiversity. The raingarden is complemented with planters around the buildings and green areas at a parking (Figure 7).

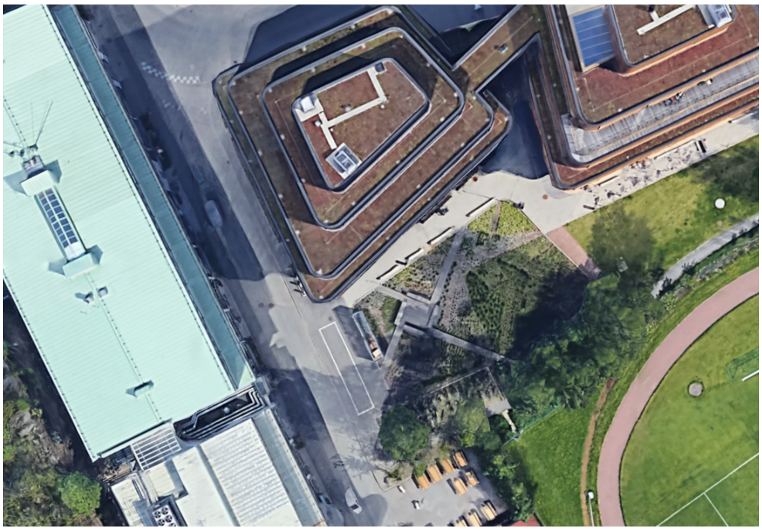

Figure 6. Raingarden at Johanneberg Science Park, Chalmers, Gothenburg.

Figure 7. Raingarden at Johanneberg Science Park, Chalmers, Gothenburg

HSB Living Lab

The HSB Living Lab is an innovation and demonstration arena located on the Chalmers Johanneberg Campus. The four-story building includes homes for students and researchers, and provides a venue for sustainability-related projects performed under real-life conditions. One of these projects aims at designing a testbed for the evaluation of techniques for purification and delay of stormwater. The HSB Living Lab is located on a hill and flooding risks are therefore very limited. The testbed has the purpose to treat stormwater originating from the 230 m^3 impervious building roof before it reaches the municipal combined wastewater network, as well as to reduce risks of flooding in lower areas on the Chalmers Campus.

The testbed consists two planters consist of rectangular basins with a volume of 8 m^3 each and filled with different soil materials. The stormwater enters the basins into a distribution gutter placed longitudinally in the middle of the basin. The distributed stormwater then reaches the soil surface and percolates into the soil. The soil media act as a filter to remove contaminants from the stormwater. A drainage pipe at the bottom of the basins takes the filtered stormwater into a stormwater well, before it is discharges into the combined wastewater network (Katzin, 2017).

Figure 8. HSB living with the two rectangular bioretention planters in front of the building.

Figure 9. Bioretention planter at Johanneberg Science Park, Chalmers, Gothenburg.

Ecosystem services

Ecosystems services have substantial impacts on quality of life and resilience of urban areas (Gomez-Baggethun et al., 2013) and there is therefore a growing interest in assessing ecosystems services in urban areas.
Ecosystems services are broadly defined as "the benefits people obtain from ecosystems" (Millenium Ecosystems Assessment, 2005). Ecosystems services can be divided into four categories, i.e. supporting, provisioning, regulating and cultural (Millenium Ecosystems Assessment, 2005). Supporting services are basic functions of ecosystems (e.g. nutrient cycling, water cycling, and provision of habitat) that enable the ecosystems to provide further ecosystems services. Provisioning services provide resources such as raw materials, water, food and energy. Regulating services are all benefits obtained from the regulation by ecological processes, including climate regulation and water regulation. The cultural services provide values, such as education, spiritual enrichment, aesthetic experience, spiritual enrichment and their role in supporting education, knowledge and social relations (Gomez-Baggethun et al., 2013).

Ecosystems services provided by raingardens

Raingarden provide a number of ecosystems services, including provisioning, regulating, cultural and supporting services (Prudencio and Null, 2018) (Table 1).

Provisioning services: Green infrastructure, including raingardens, contribute to the continued provision of water by controlling the availability and maintaining the quality of water resources (Prudencio and Null, 2018). Raingardens with unsealed bottoms allow water to infiltrate into the ground and recharge groundwater resources.

Regulating services: Raingardens can contribute to the regulation of the flow and quality of stormwater in urban areas by mimicking the natural hydrological cycle. As stormwater infiltrates into the ground or is returned to the atmosphere by evapotranspiration surface runoff is reduced compared with impervious urban areas. In addition, stormwater is delayed and the peak flow is reduced. Vegetation intercepts precipitation and surface water, and reduces the velocity of surface runoff. This reduces the risk of flooding, as well as the overloading of the sewer network. Water quality is improved by filtering and adsorption of contaminants in soil, as well as the uptake of nutrients by plants. Additional regulating service include carbon sequestration by plants, the improvement of urban air quality and the regulation of the local climate (Prudencio and Null, 2018).

Cultural services: Raingardens provide cognitive values, social values, economic values, and recreation opportunities by providing access to green areas in urban settings (Gomez-Baggethun et al., 2013). They are an opportunity for education on the environment and for increased recognition of ecosystems services. Common spaces and green areas are also known to foster interpersonal relationships and to foster social cohesion. Access to green areas is also known to increase the attractiveness and economic value of properties. Although raingardens do not cover extensive areas that can be directly used for recreation, the presence of green spaces favors outdoor activities. The amount of greenspace one can access also improves overall heath (Coutts and Hahn, 2015). Studies have demonstrated a link between health, well-being and access to green spaces by reducing stress and by favoring physical activity (de Vries et al., 2003).

Supporting services: Urban green spaces, such as raingardens, have the potential to contribute to local biodiversity by providing physical habitats and, depending on the location, connectivity (Tzoulas et al., 2007). A species-rich ecosystem is usually considered to be more resilient and more productive than simpler ecosystems. Healthy ecosystems are expected to support biotic, bio-chemical and abiotic processes that result in a range of ecosystems services (Costanza et al 1997).

Table 1. Description of ecosystems services from raingardens (adapted from Prudencio and Null, 2018).

Ecosystems services categories	**Ecosystems services**	**Description**	**Main benefits**
Provisioning	Water supply	Reduced pollution of water sources	More water available
	Water storage	Infiltration into the ground	More water available through groundwater recharge
Regulating	Water cycle regulation and flood protection	Surface runoff is reduced by infiltration and evapotranspiration; peak flow is reduced	Reduced flooding risks and related costs, reduced risks of pollution of waterways by combined sewer overflow
	Water purification	Pollutants are remove by filtering and adsorption in soil (e.g. particles and metals) and taken up by plants (e.g. nutrients)	Reduced pollution of waterways
	Air quality	Airborne pollutants are removed by vegetation	Improved air quality and reduced negative health effects
	Climate regulation	Vegetation buffer microclimate conditions in urban areas	Reduced need for heating or cooling
	Carbon sequestration	Carbon dioxide is captured and stored by vegetation	Reduced climate impacts
Cultural	Cognitive value	Green spaces are opportunities for educationt	Increased recognition of ecosystems services
	Social value	Green spaces improve spatial quality of meeting places	Improved social cohesion and interactions in neighborhoods
	Economic value	The proximity of green areas is affecting the attractiveness and value of urban properties	Increased property value
	Recreation	Green spaces favor outdoor activities	Heath benefits from physical activities and reduced stress
Supporting	Biodiversity and habitat	Green spaces increase habitats for insects, birds and mammals	Increase in biodiversity and mitigation of biodiversity loss in urban areas

Ecosystems services provided at the case study sites

All four urban raingardens included in this study provide a range of ecosystems services. This report provides a qualitative assessment of ecosystems services by these urban raingardens.

In all cases, the raingardens provide **provisioning** and **regulating** services related to the quantity, flow and quality of water. Differences in the extent of the contributions are however expected. The locations of the raingardens affect the quantity and quality of inflowing stormwater. The raingarden at BRF Umbra and at HSB Living Lab handle stormwater from relatively small areas, whereas the raingarden at Stora Torp receives water from the natural area on the neighboring hill. The raingarden at the Johanneberg Science Park receives stormwater from impervious surfaces in the urban area with higher pollution loads. Therefore, the importance of the stormwater quality improvements is expected to be important. In addition, it is located in an area with high risk for flooding and can contribute to flood control.

The studied raingardens also provide **cultural** ecosystems services. Three of the raingardens, i.e. BRF Umbra, Stora Torp and HSB Living Lab, are located in residential areas. BRF Umbra and Stora Torp include multi-functional areas for recreation. The raingarden provide greenspaces in the recreational areas, thereby supporting social cohesion in the neighborhood, as well as providing health benefits through outdoor physical activity and reducing stress. The green spaces are also expected to provide economic value to residents or housing organizations by increasing the attractiveness of the residence. The planters at HSB Living Lab are located in the entrance of the building and increase the attractiveness of building. For both BRF Umbra and HSB Living Lab, the contribution to attractiveness is illustrated by signs indicating the presence of raingardens. These signs also support knowledge and education. The raingarden at HSB Living Lab is located at a workplace. The raingarden includes outdoor sitting places supporting social interactions. Health benefits are supported by encouraging workers to be outdoors and by the reduction of stress resulting from the presence of green areas.

Supporting ecosystems services in the form of biodiversity and habitat are expected to depend on the location and design of the raingardens. Stora Torp is located near at the edge of a nature reserve and the raingarden is expected to support biodiversity by provide additional habitat space. Johanneberg Science Park is located in an urban corridor in the urban area, which is the habitat of a protected woodpecker species, and the raingarden is also expected to provide additional habitat space. BRF Umbra is located in a densely urbanized area and the habitat function of the raingarden is therefore expected to be more limited, although the contribution to the neighborhood is expected to be important. In contrast, the planters at HSB Living Lab provide more limited habitat spaces. All raingardens contribute to habitats for insects and therefore to pollination. Insects hotels have been placed at both BRF Umbra and Johanneberg Science Park to support this function. In addition, all the raingardens support to some extent biodiversity by mitigating surface runoff and reducing the pollution of water courses.

Potential ecosystems disservices

In addition to the benefits of ecosystems services, green infrastructure, including raingardens, might also have negative effects and causes disservices. The vegetation in raingarden can lead to allergies, for instance owing to increased pollen depending on the type of vegetation. The presence of animals, such as rodents, might cause the need for pest control. In addition, the increase in property can be a benefit for residents but might also result in gentrification and segregation of urban areas.

Conclusions

Raingardens are increasing implemented as a stormwater management option in urban areas. Examples of raingardens in Gothenburg shows that the raingardens provide a number of additional benefits compared with conventional piped stormwater solutions in the local context. These include provisioning, regulating and cultural ecosystems services, as well as supporting ecosystems services. The raingardens contribute to the control of the quantity, flow and quality of stormwater water. The raingardens also provide important cultural ecosystems services in the form of improved health, improved social cohesion and interactions in neighborhoods and increase property value for property owners, as well as education and recognition of ecosystems services. Supporting ecosystems services include biodiversity and habitats. The benefits depend however on the location of the raingardens, which affect the volume and quality of stormwater to be treated, and the design of the facility.

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