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A valuation of ecosystem services from blue-green infrastructure for stormwater management

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ABSTRACT

A valuation of ecosystem services from blue-green infrastructure for stormwater management

Sofia Anderzon

The ongoing urbanization leads to densification and growth of cities, which replaces natural areas with hard surfaces. Precipitation is then more likely to runoff as stormwater than to be detained locally. Also, precipitation is predicted to be increasing as an effect of climate change. Traditionally, stormwater has been handled by draining it in underground pipes. As a complement, blue-green infrastructure (BGI) can be used to take care of the increased amount of stormwater. BGI is vegetation and water-based systems that intend to restore the natural flows of water. It does, however, not only provide services for stormwater management but also other services that contribute to human welfare. These are provided for free by nature and are called ecosystem services. By illustrating the value of ecosystem services, the motivation of implementing more BGI can increase. The aim of this project was to provide guidance on how to value ecosystem services that BGI can provide at a district level. The valuation was to be semi-quantitative with the grades 1-5. To do so, ecosystem services were identified and given indicators that could illustrate the extent of the ecosystem services' presence.

Seven different BGI for stormwater management were studied, to determine which added values they can bring into urban settings. The BGI were green roofs, trees, rain gardens, swales, detention basin, detention ponds and attenuation storage tanks. Nine ecosystem services provided by these BGI were then identified. These were flood protection, water treatment, local climate regulation, air quality control, environmental noise control, erosion prevention, recreation, social relations and biodiversity.

Indicators were identified for each ecosystem service through a literature study. It was noted that to value the ecosystem service, it was not enough to only value the presence of the indicators but also necessary to estimate the demand or need for the ecosystem service. Therefore, questions were formed that could help determine the demand for the ecosystem service. The valuation was then based on how well the presence of the ecosystem service corresponded to the demand of it.

After using this valuation method on a case study, it was concluded that this type of valuation is useful for reconstruction projects in an early stage, to illustrate what functions and demands that need to be considered to obtain more ecosystem services. It can then be used for comparison of different proposals, to see which one provides the most ecosystem services. The valuation is conceptual rather than specific. It is useful as it can include any type of ecosystem service but lacks the perspective of costs.

Keywords: Stormwater, blue-green infrastructure, (urban) ecosystem services, indicators, semi-quantitative valuation

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REFERAT

Värdering av ekosystemtjänster från blågrön infrastruktur för dagvattenhantering

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Den pågående urbaniseringen leder till en ökad utbredning och förtätning av städer, vilket innebär att grönytor byts ut mot hårdgjorda. Detta leder till att nederbörd inte omhändertas lokalt utan avrinner istället på de hårdgjorda ytorna som dagvatten. Dessutom förutsägs nederbörden att öka i och med klimatförändringar, vilket ökar mängden dagvatten ytterligare. Traditionellt har dagvatten hanterats genom att avledas i ledningar under mark. Som ett möjligt komplement till denna infrastruktur finns blågrön infrastruktur (BGI). BGI är vegetations- och vattenbaserade system som avser att efterlikna det naturliga flödet av vatten för att minska översvämningsrisken men ger fler nyttor än så. Dessa nyttor benämns ekosystemtjänster. De ökar människors välbefinnande och förses av naturen gratis. Genom att synliggöra värdet av ekosystemtjänster kan motivation till att implementera BGI öka. Syftet med detta projekt var att sammanställa ett beslutsstöd för hur en värdering av ekosystemtjänster från BGI på stadsdelnivå kan gå till. Värderingen skulle vara semi-kvantitativ med en skala 1-5. För att möjliggöra detta identifierades först ekosystemtjänster som sedan tilldelades indikatorer som belyser i vilken utsträckning respektive ekosystemtjänst förekommer.

Sju olika blågröna dagvattenlösningar studerades för att avgöra vilka mervärden i form av ekosystemtjänster dessa kan tillföra urbana miljöer. Dessa dagvattensystem var gröna tak, träd, växtbäddar, svackdiken, översvämningsytor, dagvattendammar och fördröjningsmagasin. Nio ekosystemtjänster identifierades kunna uppkomma av dessa blågröna lösningar. Dessa var översvämningsskydd, vattenrening, lokalklimatsreglering, luftrening, bullerreducering, erosionskontroll, rekreation, sociala relationer och biologisk mångfald.

För att värdera i vilken utsträckning funktionerna hos ekosystemtjänsterna fanns närvarande togs indikationer fram genom en litteraturstudie. Det ansågs däremot att det inte räckte att enbart värdera förekomsten av ekosystemtjänsten för att bestämma dess värde, utan det var även nödvändigt att studera behovet av dem. Därmed inkluderades frågor som skulle besvara behovet av ekosystemtjänsterna. Värderingen av ekosystemtjänsten baserades då på hur väl förekomsten av ekosystemtjänsten svarade mot behovet.

Efter att denna värdering använts på en fallstudie kunde det konstateras att denna typ av värdering är användbar i ett tidigare skede av ombyggnadsprojekt, för att belysa vilka funktioner och behov som behöver tas i beaktande för att erhålla olika ekosystemtjänster. Den kan även användas vid jämförelse av olika förslag, för att visa på vilket förslag som bidrar med mest ekosystemtjänster. Värderingen är konceptuell snarare än specifik och har fördelen att alla ekosystemtjänster kan värderas men belyser enbart nyttor och inte kostnader.

Nyckelord: Dagvatten, dagvattenhantering, blågrön infrastruktur, (urbana) ekosystemtjänster, indikatorer, semi-kvantitativ värdering

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FOREWORD

This project is a 30 credits master thesis that marks the end of the Master Programme in Environmental and Water Engineering at Uppsala University and the Swedish University of Agricultural Sciences. The project was conducted through Ramboll. Supervisors at Ramboll were Mikaela Rudling at Water and Waste Water Engineering in Gothenburg and Ingrid Boklund-Nilsén at Environment in Uppsala. The academic subject reviewer was Jan Bengtsson, Professor at the Department of Ecology at the Swedish University of Agricultural Sciences. I greatly appreciate all the help and support that these people have given me throughout this process. I would not have been able to do this project without them.

Special thanks go to Petter Berglund, my partial project collaborator. As he was also doing a project about ecosystem services provided by blue-green infrastructure for Ramboll, we decided to do parts of the background together. 2.1-2.3 was written together with Petter. I am the main author of the sections 2.2.1-2.2.3 and 2.3, while Petter is the main author of the sections 2.1, 2.1.1, 2.2, 2.2.4-2.2.7. So, thank you for easing the work load and for all the support throughout the project.

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POPULÄRVETENSKAPLIG SAMMANFATTNING

Värdering av ekosystemtjänster från blågrön infrastruktur för dagvattenhantering

Sofia Anderzon

Hälften av jordens befolkning bor idag i städer, och det är en andel som förväntas att öka. Uppskattningsvis var 60 % av den yta som förväntas vara urban år 2030 inte bebyggd år 2000. Detta innebär att det pågår en drastiskt ökande utbredning och förtätning av dagens städer. Hur en hållbar stadsutveckling, på det ekonomiska, ekologiska och sociala planet, ska uppnås beror därmed till stor del på hur dessa ytor planeras. Ett problem som dyker upp i och med tillväxten av städer är omhändertagande av dagvatten. Nederbörden, som förväntas att öka i framtiden till följd av klimatförändringar, kan inte längre omhändertas naturligt, utan avrinner på de hårdgjorda ytorna. Vanligtvis har vatten avletts i underjordiska ledningar till närmaste recipient eller reningsverk. Alternativa och mer hållbara lösningar som undviker att de konventionella systemen måste byggas ut och som istället tillvaratar nederbörden som en resurs finns däremot tillgängliga. Dessa går under namnet blågrön infrastruktur (BGI) och är vatten- och vegetationsbaserade system som återskapar det naturliga flödet av vatten inne i städer. BGI kan både fördröja och rena stora vattenmängder, men ger fler nyttor än så. De blågröna ytorna bidrar till både psykiskt och fysiskt välmående genom att bland annat erbjuda rekreationsmöjligheter, luftrening och klimatreglering. Dessa nyttor går under namnet ekosystemtjänster, som naturen förser människan med gratis. Syftet med detta projekt har varit att synliggöra värdet av de ekosystemtjänster som kan erhållas av BGI, för att på så vis öka motivationen att implementera mer BGI i dagens städer. Värderingen av ekosystemtjänsterna gjordes semi-kvantitativ på en skala 1-5.

Till att börja med valdes sju olika BGI ut som ansågs passa i en tät, urban miljö, för att studeras närmare. Dessa var gröna tak, träd, växtbäddar, svackdiken, översvämningsytor, dagvattendammar och fördröjningsmagasin. Ett större antal ekosystemtjänster identifierades som skulle kunna erhållas från dessa system, varav nio stycken valdes ut för att avgränsa arbetet. Dessa tjänster var översvämningsskydd, vattenrening, lokalklimatsreglering, luftrening, bullerreducering, erosionskontroll, rekreation, sociala relationer och biologisk mångfald. De studerades djupare genom en litteraturstudie, för att identifiera vilka mätbara variabler inom ekosystemen som indikerar att dessa tjänster skapas. Dessa indikatorer kan således antas påvisa förekomsten av ekosystemtjänsten. Många av indikatorerna visades vara gemensamma, såsom andel infiltrerbar yta, andel area täckt av trädkronor, typ av vegetation och placering av BGI. Generellt var det att föredra att ha en variation av växter, inklusive vintergröna växter, och att de blågröna lösningarna placerades nära källan till de problem som skulle reduceras. För de kulturella tjänsterna rekreation och sociala relationer var det viktigt med närhet till blågröna områden, att det inte var för mycket folk på dessa områden och att ytorna erbjöd vad som uppskattades av lokalbefolkningen. Att många av indikatorerna sammanföll för olika ekosystemtjänster tyder på att det inte krävs att många nya strukturer införs i den urbana miljön för att flera viktiga tjänster ska erhållas.

För att kunna bestämma värdet av ekosystemtjänsterna behövde indikatorerna kompletteras med behovet av eller efterfrågan på tjänsten. Ett antal frågor sammanställdes för varje ekosystemtjänst, vars svar var avsedda att belysa behovet. Värdet av ekosystemtjänsten blev således hur väl förekomsten av indikatorn svarade mot behovet av tjänsten. Om ekosystemtjänsten förekom i lägsta acceptabel mängd erhölls en trea i värdering; om den förekom i större grad erhölls ett högre värde och om den förekom i en lägre grad erhölls ett lägre värde.

Denna semi-kvantitativa värderingsmetod kan anpassas till alla typer av ekosystemtjänster, inklusive tjänster som inte kan värderas i pengar. Det är här denna typ av värdering har sin styrka. Den kan då användas i ett planeringsstadium, för att visa hur väl olika förslag bidrar med ekosystemtjänster. I övrigt blir resultatet lätt att förstå och hantera. Vad denna typ av värdering saknar är en koppling till kostnader för BGI, så en kompletterande utredning för detta kan behövas.

TABLE OF CONTENTS

1. INTRODUCTION

Since the beginning of the industrial revolution in the late 18th century, humans have had a considerable effect on the climate system. Effects of elevated levels of greenhouse gases in the atmosphere show impacts globally, with temperatures and precipitation increasing on average. Precipitation patterns have been seen to intensify, leading to more droughts as well as floods (IPCC, 2014). Another effect of the industrial revolution is an increasing urbanization, due to more efficient agriculture which has enabled people to move into the cities. Today, more than half of the world's population lives in urban areas, and the amount is expected to rise (UNFPA, 2016). The Cities and Biodiversity Outlook (CBO, 2013) estimated that more than 60 % of areas projected to be urban by 2030 were to be built in 2000-2030. Therefore, how the world will be able to transform to sustainability[1] is intimately linked to the growth of urban areas.

When cities are growing and densifying, hard surfaces replace natural surfaces. Consequently, less precipitation can be detained locally through infiltration into the ground or through evapotranspiration. It will instead create more runoff water, or so-called stormwater (Dagvattenguiden, n.d.). An increased attention has also been brought to the increase of pollutions in stormwater, like heavy metals and nutrients (Blecken, 2016). Traditionally, stormwater management has been solved by draining stormwater in storm sewers to underground pipes, using so-called gray infrastructure. The stormwater is thereafter either brought to local treatment plants, or released in the closest recipient (Woods Ballard et al., 2015). With impending climate changes and urbanization, stormwater management systems need to increase their capacity to avoid risks of floods and dispersion of contaminants. Stakeholders like planners and engineers are now looking at how complementary stormwater systems can be made, not only to deal with the issues stormwater can bring, but also to help reach sustainability goals set in the United Nation's (UN) Agenda 2030 as well as the national environmental objectives.

One sustainable approach is to use blue-green infrastructure (BGI), which is vegetation and water-based infrastructure for stormwater management, such as green roofs and ponds. Instead of seeing stormwater as a waste that needs to be disposed, these systems use the water as a resource. For instance, the stormwater works as irrigation for vegetation and can create habitats for a variety of species. BGI intends to restore the natural flows of water and provide more benefits than just flood protection and water treatment, such as recreational values, better air quality and biodiversity. These are examples of services provided for free by nature and go under the name *ecosystem services* (Woods Ballard et al., 2015). By providing more benefits than gray stormwater systems, the motivation to invest in blue-green systems is increased.

The concept of ecosystem services was first used in the 1980's but got its breakthrough in the late 1990's. It is defined as the "*ecological characteristics, functions, or processes that directly or indirectly contribute to human wellbeing*" (Costanza et al., 2017, p.3). Ecosystem services are the foundation of welfare in most societies, but are often taken for granted (Costanza et al.,

[1] Sustainability is to assure economic, environmental and social well-being without depleting resources for future generations (UN, 2015)

2017). By raising awareness of ecosystem services and how to value them, their importance will be made more explicit and can help guide decision-making. This could lead to a greater utilization and development of ecosystem services in urban environments.

To contribute to a more sustainable future, the private consulting company Ramboll uses the expression *Liveability*, which describes "*the frame conditions of a decent life for all inhabitants of cities, regions and communities including their physical and mental wellbeing*" (Ramboll, n.d.). To be able to illustrate the liveability that comes with BGI, there is a need of indicators to value the ecosystem services that the BGI provides.

1.1 AIM

In this thesis, it was aimed to identify and value ecosystem services provided by BGI for stormwater management to illustrate liveability. By making visible the added benefits that BGI provides, the incentive to implement more BGI in urban areas is hoped to increase.

Indicators meant to illustrate to what extent the ecosystem services are present were to be identified and then valued semi-quantitatively on a five-graded scale. The valuation would be applicable at a district level in a Swedish, urban environment before and after a planned reconstruction of the district. The intention is that the valuation can be used as a complement to more traditional technical descriptions when implementing a new stormwater solution.

1.2 OBJECTIVES

In this thesis, I sought to answer the following questions:

(i) Which ecosystem services can be provided by BGI for stormwater management?

(ii) Which indicators can be used to value these ecosystem services?

(iii) How can these indicators be valued on a scale 1-5 before and after a planned reconstruction?

2. BACKGROUND

This section of the report summarizes what was gathered in an initial literature study about stormwater management and ecosystem services. In section 2.1, stormwater management is defined and regulatory guidelines are presented. Section 2.2 explains sustainable stormwater management and presents the seven different BGI that this projected has focused on. In section 2.3, ecosystem services are introduced. Section 2.4 finally presents how ecosystem services can be valued.

2.1 STORMWATER MANAGEMENT

The main method for stormwater drainage has traditionally been to construct storm sewers in which stormwater can be directed to adjacent recipients. Growing urban areas have resulted in an increase in impervious surfaces (Stahre, 2006), which has shifted the hydrological fluxes in urban areas towards increased runoff and decreased evapotranspiration and soil infiltration (Svenskt Vatten, 2016). Changing precipitation patterns due to climate change with more intense rainfall are to be expected, also contributing to an increase of urban stormwater. Existing sewer system will be more prone to overload and urban flooding will likely increase (Stahre, 2006). Swedish insurance companies have recorded a steady increase in flood damages for residential properties the past decades (Grahn & Nyberg, 2017). The urban environment also causes many pollutants which can be collected and transported during intense rainfalls, worsening water quality in recipients. The main sources of pollutants in stormwater are traffic, land use changes and areas under construction. Common pollutants are metals, nutrients and particles (Naturvårdsverket, 2017a).

2.1.1 Regulatory standards and guidelines for stormwater in Sweden

The foundation regarding administration of water within Sweden and the European Union (EU) is the Water Directive, 2000/60/EC, which was accepted in 2000 by the EU. The aim was to ensure the protection of water as a natural resource, decrease pollutant loads and contribute to lessen the effects of extreme weather events (Directive 2000/60/EC). The framework for water administration serves the purpose of unifying countries within the EU by establishing common goals regarding water quality but allowing national measures to be taken in reaching those goals (Naturvårdsverket, 2005). By implementing the Water Directive into Swedish law in 2004, environmental quality standards for water were introduced. The quality standards serve as a measure for achieving "good water quality" status for a specific water body (Naturvårdsverket, 2005).

There are no current national guidelines concerning the release of polluted stormwater. Initiatives in regulating the release of pollutants to downstream recipients have however been taken by the cities of Stockholm and Gothenburg (Göteborgs Stad, 2017a; Andersson, Stråe & Svensson, 2016). The environmental administration of Gothenburg has directed a guide for local treatment of stormwater. The kind of treatment suggested is dependent on the pollutant load of the site, which indirectly takes land-use into consideration, and the ecological status of the downstream recipient. The aim of the guide is to facilitate selection of treatment where needed to better allocate resources (Göteborgs Stad, 2017a).

2.2 SUSTAINABLE STORMWATER MANAGEMENT

BGI is a way to locally treat stormwater and attenuate flow peaks in a sustainable way. BGI is denoted by many different names in the literature; Sustainable urban Drainage Systems (SuDS), nature-based solutions (NBS), and Low Impact Developments (LID) are all considering the implementation of sustainable stormwater management. BGI is implemented as a way of simulating the natural flow of water by using blue and green spaces in urban areas to detain water and thus regulating water flows (Figure 1). The aim with BGI is to generate additional environmental and social values, contributing to a more sustainable future (Svenskt Vatten, 2016).

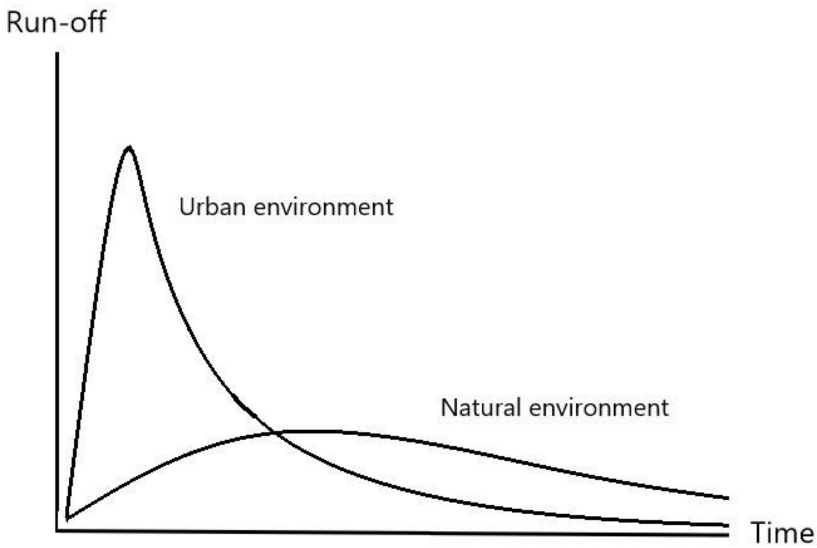

Figure 1. During an intense rain event, stormwater runs off differently in urban and natural environments. In urban environments, where hard surfaces dominate, a lot of runoff water can be generated during a short time period, risking floods and contaminant dispersion as consequences (Stahre, 2006). Inspired by a figure in Stahre (2006).

Depending on the extent of water pollution and its characteristics, various infrastructural solutions are more or less appropriate for treating the water. Local issues concerning either inadequate water quality or areas prone to floods are influencing the type of treatment that is needed (Svenskt Vatten, 2016).

This project is primarily focusing on urban BGI at a district level. That means that available land is limited. Wetlands are today one of the most common methods for detention and treatment of stormwater and are usually included in BGI discussions. They, however, need much space and are usually placed in the outskirt of urban areas and not in dense districts (Stahre, 2006). Therefore, wetlands will not be considered further in this thesis. Below follows the BGI features selected for discussion in this thesis: green roofs, trees, rain gardens, swales, detention basin, detention ponds, and attenuation storage tanks.

2.2.1 Green roofs

Green roofs are vegetation systems placed on roofs. Green roofs are used for retaining and reducing flow rates of stormwater, and do not necessarily intend to treat the water, as the precipitation that is collected on the roof is not considered very contaminated. They consist of multiple layers: outermost, there is a vegetation layer, anchored to an inner soil layer, then a drainage layer and at the bottom a sealing layer, preventing the roof to get damaged by the water. The vegetation and soil layer can retain precipitation, while the drainage layer can either store or drain out excessive water (Blecken, 2016). The vegetation can be in need of irrigation when precipitation is not sufficient. Maintenance, like controlling downpipes and gutters, is recommended to be carried out at least twice a year (Blecken, 2016).

As concerns stormwater management, green roofs can reduce runoff by 25-75 % (Alfredo, Montalto & Goldstein, 2010), and with about 50 % over a year. To maximize the effect, it is important that the slope of the roof is not too steep (Stahre, 2006). The reduced runoff is a result of a delay in initial runoff, reduced amount of total runoff and slower runoff over a longer period of time (Blecken, 2016). If precipitation is intense and the system gets saturated with water, the effect of the system decreases greatly (Stahre, 2006). However, it is still argued that with a saturated system, flow peaks of runoff water would be delayed which reduces the risk of flooding the stormwater drainage system (Blecken, 2016).

2.2.2 Trees

Planting trees along roads as a complement to a conventional underground pipe system yields both detention and treatment of stormwater. Trees can take up water through interception and hold it either in the canopy or in the roots after the water infiltrates the soil. Some of the water leaves the tree through transpiration. Altogether, trees can reduce runoff with 40-80 % depending on tree species. Regarding treatment of the stormwater, trees and its soil can reduce pollutants efficiently if the soil is designed properly. For instance, soil suitable for trees growth has shown to reduce heavy metal loadings by 70-85 % (Woods Ballard et al., 2015).

For the tree to be able to thrive in urban environments, and to avoid risk of damaging the pipes, careful city planning is needed. Trees surrounded by hard surfaces need soil with special qualities to be able to grow. Structural soils are used for this purpose and are a mix of macadam, which can hold up the hard surfaces, and plant soil, which fills the pores in between the macadam. The soil can hold nutrients and humidity and give plant roots the room needed to grow. Typically, about 2/3 of the structural soil are macadam and 1/3 is plant soil. For good conditions for the trees, there also needs to be a drainage to supply the tree with enough water, and drainage underneath to remove excess water (Svenskt Vatten, 2011).

2.2.3 Rain gardens

The shaping of rain gardens, also called biofilters, is flexible and can therefore be implemented in varying environments, like parking lots or city centers. Rain gardens are often dimensioned to be able to treat rainfalls with 0.5-2 years recurrence. More intense rainfalls will overflow to the conventional pipeline system. When water percolates through the filter, the filter adsorbs, mechanically traps and biologically treats the water. In the top layer of the rain garden, a biofilm that biologically treats the water typically forms. The vegetation plays a central role and serves many purposes, like maintaining the infiltration capacity, enabling microbial water treatment processes and offer esthetical values. Prioritizing the aesthetics of a rain garden, that may need an addition of nutrients to the soil, can on the other hand be on the expense of water quality (Blecken, 2016).

Rain gardens can reduce total concentrations of metals and total suspended solids (TSS) by 80-90 % (Blecken, 2016). A large fraction of particulate metals, i.e. metals attached to particles, and TSS are separated through mechanical filtering (Hatt, Fletcher & Deletic, 2008). The extent of separation of dissolved metals depends on the interactions between the specific metal and the filter, but is executed through adsorption, surface deposition and fixation to clay minerals (Alloway, 1995). Conditions like extent of rainy/dry periods, temperatures, concentration of the contaminants, type of filter and plants affect the water treatment of dissolved metals in rain gardens. Rain gardens are still considered to generally have more potential to treat the water of dissolved metals than other stormwater facilities like ponds. It is of greater importance to treat the water of dissolved rather than particulate metals, as dissolved metals are bioavailable (Blecken, 2016).

2.2.4 Swales

A swale is designed as a vegetated trench without permanent water surface. Swales are among the most common facilities within BGI and are useful for the collection and drainage of stormwater. Swales are mostly used in the vicinity of roads and streets where important design criteria are submerged edges in the connection between road and swale. This prevents road inundation due to damming (Blecken, 2016).

The main aim of implementing swales is to regulate high water flows. It is important in the process of implementation to allow infiltration and thus avoiding longer periods of stationary water. Swales alone do not in general serve as sufficient treatment to reach a good water quality. Sedimentation can act as a process for treatment before reaching finer filtering systems for enhanced treatment. This process improves the efficiency for further treatment downstream (Svenskt Vatten, 2016).

If swales are designed with an underlying macadam structure, a better infiltration capacity can be achieved. Vegetated swales give further resistance and regulate flow. It also contributes to enhanced treatment due to increased retention time (VINNOVA, 2014). To further enhance removal and treatment of nutrients, special consideration could be made regarding the type of vegetation implemented; generally, plants are more efficient than grass (Svenskt Vatten, 2016; Winston et al., 2012).

2.2.5 Detention basins

Detention basins are designated surfaces with the ability to store and attenuate water. They can be vegetated and thus allow treatment of polluted stormwater (Woods Ballard et al., 2015) and erosion prevention. Since detention basins do not need to carry water continuously, the green surface can be used for other purposes, such as recreational activities. In order to effectively be using the area, the basin should be connected to a drainage system, quickly draining and enabling the use of the green area (Svenskt Vatten, 2011).

Detention basins mainly provide treatment by removing sediment and coarse particles. Enhanced treatment and water quality can be achieved by extended detention time for intense rain events. Through interception in soil, nutrients, heavy metals, toxic waste and oxygen-demanding materials can be reduced within vegetated detention basins (Woods Ballard et al., 2015).

2.2.6 Detention ponds

Detention ponds are implemented in order to detain and treat large volumes of stormwater as an “end-of-the-pipe” solution. As an “end-of-the-pipe” solution, stormwater throughout the catchment is being drained in ponds where a substantial residence time enables various treatment processes. Detention ponds have been widely used globally in the past and are in Sweden among the most used treatment methods of stormwater (Blecken, 2016).

Detention ponds are efficient when it comes to separation of suspended solids and metals. The treatment process in ponds is based on sedimentation of suspended solids. Coarse sediment is deposited close to the inlet due to gravitational forces whereas finer sediment is transported further down the pond. Generally, finer sediments hold a higher concentration of metals, leading to more deposition of metals downstream within the dam. This is important when considering the percentage of suspended material being released from the dam which usually contains a greater proportion of more fine sediment and hence proportionally more metals. Nutrients such as nitrogen that are not bound to particles do not separate in the same extent as particulate nutrients like phosphorus, that is generally bound particularly and therefore more prone to settling. The degree of separation varies heavily depending on local circumstances, indicating the importance of planning and design (Svenskt Vatten, 2016).

2.2.7 Attenuation storage tanks

In areas where there is a limited amount of open space, as it often can be in highly urbanized areas, underground storage spaces could be constructed. The aim is to temporarily store water underground to decrease the risk of inundation. Tanks can be connected to green spaces with an infiltration capacity draining to the underground storage space. An alternative approach for designing temporary storage systems is to oversize pipes within the stormwater drainage system and thus enabling storage of water during intense rainfall (Woods Ballard et al., 2015).

In order to limit the need for maintenance and improve the performance of attenuation, pre-treatment should be considered in order to limit the risk for sediment accumulation (Woods Ballard et al., 2015).

2.3 ECOSYSTEMS

In 1992, the UN Convention on Biological Diversity defined an ecosystem as “a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit” (UN, 1992). Ecosystems can be studied at different scales, and can be as small as a microhabitat, or as big as the whole biosphere (Naturvårdsverket, 2012). Ecosystems support human life and contribute to human well-being. Research has been done to investigate how these benefits can be conveyed in a scientifically robust way to decision-makers. Although there is not yet a final, fundamental way of defining the impact of an ecosystem on human well-being, the cascade model is commonly used to illustrate the connection (Figure 2). As an example, primary production[2] is a crucial process for maintaining a viable fish population, which is considered as one of many functions of the ecosystem. The functions of the system can be harvested for human usage as an ecosystem service, which in this case would be providing food. Ecosystem services provide humans with benefits, in this case reducing hunger, that can be valued, for instance in monetary terms (TEEB, 2010).

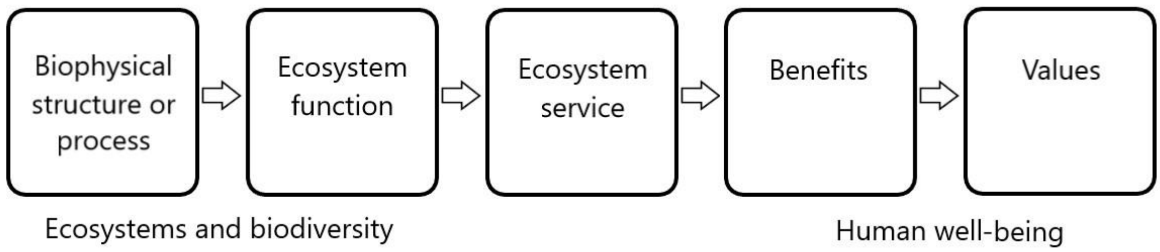

Figure 2. A simplified illustration of the cascade model presented in TEEB (2010, Ch. 1, p. 11). Feedback within the model can occur. If the value of an ecosystem is made visible, the use of the ecosystem service may be wanted to increase. This can result in management or restoration of the structures, processes and functions of the ecosystem.

2.3.1 Ecosystem services

Ecosystem services are defined as “the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life” (Daily, 1997, p.2). Ecosystem services are therefore an anthropocentric term, where the basis of the development of the concept comes from making the benefits that humans can gain from ecosystems visible (Naturvårdsverket, 2012). Ecosystem services produce ecosystem goods, such as food, fuels and fiber; support functions necessary for life, such as cleansing and renewal; and they confer many intangible cultural services like recreation (Daily, 1997). The expression ecosystem services is rather new, even though the knowledge of man’s dependence on nature is ancient. In the middle of the 20th century, natural capital was introduced in academia (Osborn, 1948, Vogt, 1948 & Leopold, 1949), and a few decades later, the expression environmental services was coined (Study of Critical Environmental Problems (SCEP), 1970). Ecosystem services got more known outside of the academic community in the early 21st century, through the UN initiative Millennium Ecosystem Assessment (MA) (Naturvårds-verket, 2012). The MA was intended to assess the ecosystems’ contribution to human well-being, as well as consequences of ecosystem changes for human well-being and what actions that would be needed to conserve and to be able to sustainably use these systems (MA, 2005).

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[2] Primary production is the synthesis of organic compounds from inorganic elements through photosynthesis or chemosynthesis in living organisms (Nationalencyklopedin, n.d.a).

There are now three international systems for classification of ecosystem services, where the MA is one of them. The other two are The Economics of Ecosystems and Biodiversity (TEEB) and Common International Classification of Ecosystem Services (CICES). These three vary in the sense that they have different perspectives and purposes. However, they are still developing, so which system that will become the standard of ecosystem services valuation is still to be determined (Naturvårdsverket, 2012).

Ecosystem services are divided into four categories based on what type of service they provide: provisioning, regulating, cultural, and supporting ecosystem services (MA, 2005). Definition of and examples to the different categories of ecosystem services are presented in Table 1. A gross list of ecosystem services is presented in Appendix 1.

Table 1. Definitions of the four categories of ecosystem services with examples (MA, 2005 & TEEB, 2010).

Category	Definition	Examples of ecosystem services
Provisioning services	Physical services like material and energy outputs	Food Fresh water Raw materials
Regulating services	Services provided when ecosystems act as regulators to necessary processes	Flood protection Water treatment Regulation of climate, air quality and environmental noise Erosion prevention
Cultural services	All the intangible services that ecosystems provide humans with	Recreation Education Social relations
Supporting services	Provides all other ecosystem services with the necessary conditions for their operation	Biodiversity Photosynthesis Soil formation

Research in the field of ecosystem services is still very active, but policies have already been set in place (Naturvårdsverket, 2012). The EU strategy for biodiversity implemented in 2011 has the headline target to halt the loss of biodiversity and the degradation of ecosystem services by 2020. It is argued that although actions against loss of biodiversity will be costly, it would be even more expensive to not do anything as nature provides many services for free (EU, 2011). In Sweden, there is a milestone goal set to 2018 that the importance of biodiversity and ecosystem services should be publicly known and integrated in decision making if relevant and reasonable (Naturvårdsverket, 2012).

2.4 VALUATION OF ECOSYSTEM SERVICES

Defining the values of services that ecosystems provide is a way of building an understanding of human dependence on nature and biodiversity. In a valuation, ecosystem services are made visible and can therefore more easily influence decision-making, for instance in community planning. This is important for the transition towards a more sustainable development. Valuation of ecosystem services can be done in multiple ways. Naturvårdsverket (2015) presents four common methods for an ecosystem service valuation:

- Qualitative valuation: Values are expressed in words
- Semi-quantitative valuation: Values are expressed in points
- Quantitative valuation: Values are expressed in a physical unit, e.g. kg/m^3
- Monetary valuation: Values are expressed in monetary terms

These all value the benefits the ecosystem services provide to humans. The choice of valuation method can depend on the purpose of the valuation, data availability and if there are available indicators of that valuation method (Naturvårdsverket, 2015). For instance, an indicator could be *proportion of natural areas* when valuing biodiversity as an ecosystem service (CBI, 2014). Putting an appropriate monetary value on how the natural areas contribute to biodiversity could be useful but difficult. Therefore, another type of valuation may be more suitable when valuing biodiversity (Naturvårdsverket, 2015).

2.4.1 Semi-quantitative valuation

A semi-quantitative valuation is often made through a desk study but can also involve dialogue with stakeholders like experts or residents in the given area. It can also involve field studies. The scale is set by the user and could for instance be from -3 to +3 to illustrate if there is a negative or a positive effect of a project on the ecosystem service. The valuation could also be used to illustrate to what extent different ecosystem services provide benefits for humans, which would give an order of importance. A semi-quantitative valuation is useful as long as the grade is based on a framework; that is, it should be clear what the numbers on the scale represent (Naturvårdsverket, 2015).

An advantage of using semi-quantitative valuation is that all ecosystem services can be expressed in a point system, whether it is its presence or perceived value that is graded. For a monetary valuation, the value of the service is often based on real or imaginary markets. However, not all ecosystem services can be made visible on these markets; this includes, for example, emotional and ethical values. Monetary valuation can therefore only be used on a fraction of the ecosystem services within an area (Naturvårdsverket, 2015).

Another advantage is that it is easy to take an average of the semi-quantitative values, which makes the result of the valuation easy to manage and convey. A disadvantage can on the other hand be that the grading is not very specific, as quite a range can fit into one grade. To summarize, the semi-quantitative value does not go into depth, but give an easily mediated value. A shortcoming with semi-quantitative valuation is that it will only tell the importance or the presence of the ecosystem service, and not the cost of implementing or maintaining it. If a valuation that contrasts the benefits and costs is desired, a monetary valuation would be preferable (Naturvårdsverket, 2015).

2.4.2 Setting the indicators

A vital part in a valuation is to identify suitable indicators. It takes both scientific rigor and creative thinking as there is no consensus on indicators for ecosystem services. The indicators should preferably fulfill several qualities. They should be:

- relevant to the users need,
- understandable – how the measure relates to the purpose,
- useable – for measuring, awareness raising, reporting etc.,
- scientifically sound – with data being reliable and verifiable,
- sensitive to change, and
- practical and affordable – to ensure its continued use over a longer time period (Brown et al., 2014)

If indicators are supposed to be used for management purposes, then it is important that the indicators show whether a proposal is resulting in the set goals, or if improvements are needed. Indicators should also be sensitive to be able to reveal trends (UNEP, 2003).

There are three types of indicators: complete, partial, and directional indicators. The complete indicators match the ecosystem service well and can solely describe the ecosystem service. Partial indicators indicate the ecosystem service to some extent, but the ecosystem service needs more indicators to be fully covered. The presence of the ecosystem service could be changed without a difference in the partial indicator. Lastly, there are directional indicators that can be used to determine whether the ecosystem service will increase or decrease. The connections between the ecosystem service and the directional indication are not proportional however, so it can be difficult to say to what extent the presence of the ecosystem service will change due to the directional indicator (Naturvårdsverket, 2015).

Once possible indicators have been identified, the next steps are to gather and review data, calculate the indicators, and communicate and interpret the indicators. Lastly, the indicators should be tested and refined together with stakeholders (Brown et al., 2014).

3. METHOD

This project was carried out in six steps:

1. A literature study about BGI
2. A literature study about ecosystem services
3. Finding indicators for the ecosystem services
4. Forming a framework for valuation of the indicators
5. Collecting support for valuation
6. Case study: Masthuggskajen, Gothenburg

Step 1. A literature study about BGI

A brief literature study was made about what BGI is and what different types of BGI there are that can be used as stormwater management solutions. Seven different BGI were chosen as a delimitation and studied in greater depth through a literature study. These were chosen as they were considered to be suitable in dense, urban areas at a district level. A discussion was held with advisors to assure that the chosen blue-green systems are commonly used in these settings.

Step 2. A literature study about ecosystem services

Ecosystem services were initially studied at a general level. A gross list of different types of ecosystem services was put together and can be found in Appendix 1. From this gross list, several ecosystem services were selected that were believed to potentially be provided from BGI used for stormwater management. These were ecosystem services that had been mentioned in previous studies focusing on ecosystem services from blue or green elements in urban settings, for instance by Lovell & Taylor (2013), Gómez-Baggethun & Barton (2013) and Bolund & Hunhammar (1999). A further literature study of these ecosystem services was made. Due to time constraints, nine ecosystem services were chosen to be included in this thesis. The demarcation was made after discussions with advisors. The selection of the nine ecosystem services was based on the initial purpose of BGI, that is to provide services needed for stormwater management, and what additional services BGI can provide that are important for the liveability within an urban district.

Step 3. Finding indicators for the ecosystem services

The literature study was continued for the chosen ecosystem services, in order to find indicators that can describe the presence of each ecosystem service. This was done in two ways. First, previous reports of ecosystem service compilations were studied to seek out indicators. For some ecosystem services indicators were found scarce. Therefore, in addition to studying previous compilation reports, the ecosystem services themselves and their functions was studied more thoroughly. This was made partly to be able to justify previously found indicators and partly to create new indicators where indicators were lacking.

At the start of this step, indicators for both the function and the benefits of the ecosystem service (Figure 2) were searched for and studied. For instance, for the ecosystem service flood protection the indicator *proportion of permeable surface* can be used to describe the presence of its function and the indicator *percentage of streets flooded during a heavy rain* to make its potential benefits visible. A demarcation had to be made to focus on indicators to estimate the functions rather than the benefits of the ecosystem services. The motivation for this was to keep the project at a reasonable work load. Also, it was found more difficult to collect data for the valuation of the benefit indicators, specifically concerning future scenarios.

It was noted during the project that it would be necessary to also value the need of the ecosystem service to determine BGI’s effect on the liveability, as the ecosystem service would only have human value if there was a demand for it. Therefore, a few questions addressing the need for the ecosystem service were put together in a list for every ecosystem to be considered during the valuation.

Step 4. Forming a framework for valuation of the indicators

To match the current valuation method for Liveability, indicators were intended to be valued on a scale 1-5, where the scale would go from very bad to very good (Table 2, column 1-2). It was then considered whether the value of an ecosystem service as a whole could correspond to the mean value of its indicators. However, it would not be correct to solely take the mean of the different indicators’ values, as not all indicators are of the same importance for the ecosystem service. For that, weighting of the indicators would be needed. This was however outside the scope of this project. An alternative valuation method had to be formed, that would also tie in the fact that the need for the ecosystem service would affect the liveability value. The rating method was then based on how well the presence of the ecosystem service corresponded to the need for the service. New descriptions to the grades 1-5 were set (Table 2, column 3).

Table 2. Grading framework for valuation of the ecosystem services.

Grades	Liveability framework	Does the ecosystem service occur in the district?
1	Very bad	No, or to a very small extent
2	Bad	Yes, but to an unfulfilling extent
3	Ok	Yes, to an acceptable extent
4	Good	Yes, to a wider extent
5	Very good	Yes, to a more than sufficient extent

Grade 1 corresponds to no or a neglectable presence of the ecosystem service. Grade 2 corresponds to a certain presence of the ecosystem service which does not fulfill laws or recommendations. Grade 3 corresponds to what is just required or believed to be acceptable. Grade 4 corresponds to what is wanted, meaning that goals are fulfilled. Grade 5 should represent that the ecosystem service is abundant and more than fulfills the needs and goals for the ecosystem service.

The proposed way to execute the valuation was to begin by determining the need for the ecosystem service and then value each indicator separately to get an idea of how well the need is met. Laws, requirements and recommendations for the indicators should be used as guidance for the valuation. The determination of the value of the ecosystem service as a whole was intended to be solved through discussion between professionals within the fields that the ecosystem services affect. With professionals it is meant people who knows the laws and goals that exist for the fields studied and who knows which indicators are more important. The results in this report are intended to provide guidance to these discussions.

Step 5. Collecting support for valuation

Guidance on how to value the indicators was collected. Focus was set on the function of the ecosystem service and to what extent the service could be available in an urban environment. Previous semi-quantitative valuation methods for similar indicators set in *Step 3* were studied, like the Cities Biodiversity Index (CBI, 2014) and Comprehensive Assessment System for Built Environment Efficiency (CASBEE, 2014), but previous valuations were found to be scarce. Certification systems for urban environments were also studied, like Citylab (2016), and BREEAM.SE (2017). C/O City (2014a, 2014b & 2015), a research and development project for ecosystem services in urban environments, was also used as a source. Guidance on valuing the need of the ecosystem service was also collected, which meant studying laws, recommend-ations, directions and goals from municipal to global level. They included the Swedish environmental quality standards (EQS) and environmental goals, nationally and internationally recommended levels, directions at a municipal level and local to global goals.

Step 6. Case study: Masthuggskajen

A case study of the valuation method was done on the district Masthuggskajen, Gothenburg through a workshop held the 12th of December 2017. The workshop was performed together with advisors from Ramboll: Mikaela Rudling, Ingrid Boklund-Nilsen, and Sofia Eckersten. Participating was also fellow student Petter Berglund, who made a master thesis on ecosystem services from BGI in Masthuggskajen as well. The aim of the workshop was to test how well the valuation worked on a real project.

Masthuggskajen is an 18 ha district in central Gothenburg and characterized by hard surfaces, mainly parking lots and roads (Göteborgs Stad, 2017b). A reconstruction of the whole district is expected to start in 2018 to densify the area, resulting in 4500 new workspaces and 1000 new housings (Göteborgs Stad, 2017c). It has been suggested that more BGI should be brought into the district, including green roofs, detention basins, rain gardens, trees, and infiltration surfaces to deal with stormwater issues (Ramboll, 2017). The reconstruction is a part of Citylab Action to ensure a planning process that works for sustainable city development (Göteborgs Stad, 2017b).

The reconstruction of Masthuggskajen is a large project and several investigations have been made. At the time of the workshop there were about 12 official documents and 24 investigations available that were used for data acquisition. These included two stormwater investigations by Ramboll (2015 & 2017), a noise investigation by Akustikforum (2015) and an ecological inventory report by COWI (2015). A visit was also made to Masthuggskajen on the 27th of October to get a better understanding of the current state of the area.

Figure 3 & 4 show blueprints before and after the reconstruction, illustrating how the district will change. Table 3 presents the changes in surface area usage in numbers.

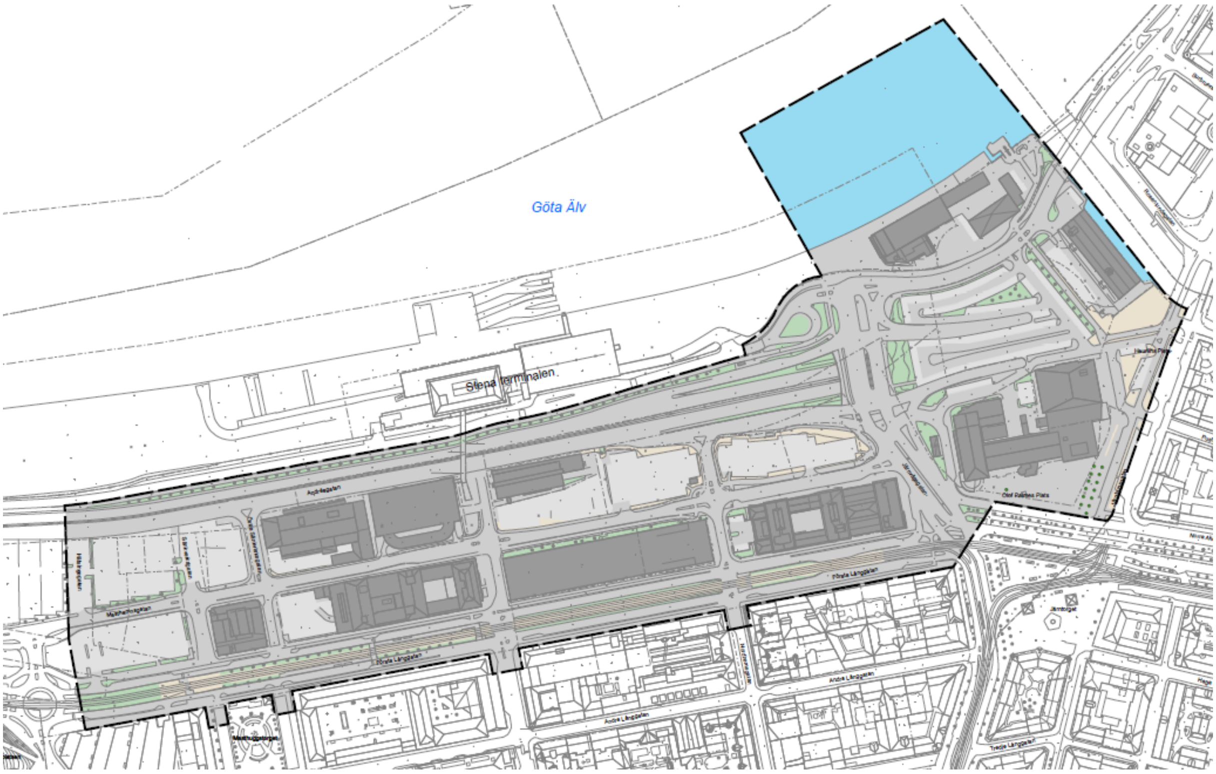

Figure 3. Illustration of what Masthuggskajen looks like today (Ramboll, 2015). The local plan area consists of gray, hard surfaces, with the exception of a few small green surfaces and a part of Göta Älv (in blue).

Figure 4. Illustration of what Masthuggskajen will look like after planned reconstruction (Göteborgs Stad, 2017b). More green areas will be implemented in Masthuggskajen and a new peninsula will be created in Göta Älv.

Table 3. Proportion of different types of surfaces in m^2 before and after reconstruction. Total area of the zone plan is 179 000 m^2 (Ramboll, 2015).

Surface	Present area [m^2]	Future area [m^2]
Roofs	30 000	55 200
Green roofs	0	3 300
Roads and parking lots	113 700	91 400
Green surfaces	8 600	19 900
Blue surfaces	19 300	4 000
Gravel/macadam	7 400	5 100

At the workshop, the ecosystem services were discussed on its own in two cases: before and after reconstruction. As a first step, it was determined whether the ecosystem service was of importance in the district. If so, the questions set in step 3 were answered to determine the need for the ecosystem service. To determine the value of the ecosystem service, its occurrence in the district also had to be estimated to see how well it corresponded to the need. To do this, the indicators set in step 3 were estimated. What had been collected as guidance for the valuation in step 5 was used for support. Ideas for how the valuation could be improved were noted and indicators and questions were revised accordingly.

4. RESULTS

4.1 INDICATORS AND VALUATION SUPPORT

Nine ecosystem services that can be provided by the BGI presented in sections 2.2.1 – 2.2.7 were selected in this project. These ecosystem services were flood protection, water treatment, local climate regulation, air quality regulation, environmental noise control, erosion prevention, recreation, social relations, and biodiversity. Indicators of the function of the nine ecosystem services were chosen and are presented in blue textboxes (section 4.1.1-4.1.9). If indicators have been found proposed as indicators in other reports, it will be stated. The indicators are intended to guide the valuation of the ecosystem services. Accompanying the indicators are a few questions, meant to indicate the need for the ecosystem services in a wider perspective. There are a few questions that are applicable to all ecosystem services that aim at indicating the need for the ecosystem service. These indicating questions are presented here instead of in each of the following sections:

- What environmental laws, recommendations, or goals could this ecosystem service help fulfill? Are these met today in the area of the valuation?
- What conventional mitigation measures are there in the district to provide the same type of service as the ecosystem service? How well do these conventional systems work?
- Is the ecosystem service threatened in the district? Could this make it harder to meet the requirements of laws, recommendations, and goals in the future?
- Are there any areas of specific importance for this ecosystem service today? Would these areas be preserved if there were to be a reconstruction in the district?
- Who will benefit from the ecosystem service? Is it for the public or a specific group of people? Is the ecosystem service present in a way that corresponds to these needs?
- Given there is a need for the ecosystem service, is it reasonable, or even possible, to implement more BGI that could increase the occurrence of this ecosystem service in the district?

4.1.1 Flood protection

There are two main reasons for implementing BGI in urban settings: to detain water and to treat water. When detaining water, flood protection follows. Flood protection is a regulating ecosystem service that is provided when implementing more vegetated or water surfaces that increase the surface roughness and infiltration capacity, which reduces the flow rate of water. It is an ecosystem service whose value is expected to rise as climate change is likely to lead to more intense rainfalls (TEEB, 2010). Indicators that were chosen to value the function of flood protection as an ecosystem service are:

- Proportion of permeable surfaces
- Amount of water detained in BGI
- Type of vegetation
- Placement of BGI

Proportion of permeable surfaces is the most prominent and straightforward indicator when examining the function of this ecosystem service, as it is within the permeable surfaces that water can be detained. This indicator is proposed for flood protection in CBI (2014) and C/O City (2014a) to mention a couple of sources. CBI (2014) does also provide a five-graded scale on how to value this indicator at a city level.

The next indicator is the *amount of water detained* in the permeable surfaces. This indicator is proposed in Lovell & Taylor (2013) and Gómez-Baggethun & Barton (2013). The amount of water detained is dependent on the permeability of the soil for vegetated systems, which depends on what type of soil that is used. Generally, soils with smaller soil particles, like clays, have a smaller permeability, and soils with bigger particles, like sandy soils, have a bigger permeability (FAO, n.d.). For water systems, the capacity of water they can detain is dependent on their dimensions and detention time.

The *type of vegetation* being used in BGI can also affect the amount of water that the systems can hold. One aspect that is important to consider is if the plants are evergreen, as evergreen vegetation can intercept and evapotranspirate more water in total per year than deciduous vegetation (Hisada et al., 2012 & Woods Ballard et al., 2015). Also, growing plants has been seen to evapotranspirate more than fully grown plants, so the developing stage of the vegetation is another aspect to consider (Stan et al., 2014).

Lastly, it is also worth studying the *placement of the BGI*. If a BGI system would be placed on top of a hill, it would clearly not be able to provide as much detention of water as if it was placed in a lower laying area, where water runs off to. Another aspect is how densly vegetation is planted, as a single standing tree can evaporate about three times more than a tree surrounded by other trees (Ögren, 2000).

To determine the need for the ecosystem service of flood protection, there are a few aspects to consider, listed as questions below. These are meant to provide a guide to the valuation. The questions are:

- Is there a risk of floods in the district, now or in the near future?
  - Could it be solved in the district? Or is inflow of stormwater from surrounding districts the bigger problem?
  - Could inflow from surrounding areas increase in the future? For instance, if trees upstream would be cut down, there would be a greater inflow of water into the district.
  - What does the terrain look like? Are there any enclosed low point areas?
  - Is there a plan against floods from cloudbursts?
  - Is important infrastructure, such as hospitals, dense residential areas, industries and main roads protected from floods?
- Is the groundwater level low enough to allow any infiltration or percolation in the soil?
- Is there contaminated soil anywhere in the district? Do the contaminants risk spreading due to flow of stormwater?

4.1.2 Water treatment

The second main purpose of BGI mentioned in section 4.1.1 was treatment of stormwater. Water treatment is a regulating ecosystem service that includes both mechanical treatment, like filtering and sedimentation, and biological treatment, like decomposition of organic waste, nitrification and denitrification. This ecosystem service cleans the water of nutrients, metals, particles and pathogens which makes the water more useable in many ways (TEEB, 2010). Indicators that were chosen to value the function of water treatment as an ecosystem service are:

- Proportion of permeable surfaces
- Extent of treatment in BGI
- Type of vegetation
- Placement of BGI

Just as for flood protection, *proportion of permeable surfaces* is an important indicator to take into account, as it is within the permeable surfaces that treatment can take place (SCB, 2013). To determine the *extent of treatment* within the permeable surfaces, there are two questions that should be asked. These are: how much and how well can the BGI treat water? The answers relate to the permeability of soil and the retention time in BGI, just as for flood protection. A longer detention time generally means more treatment but the connection between permeability and water treated is not as straight forward. Soils with greater permeability can take more water but will generally provide a lower degree of treatment. So, when doing the valuation of the ecosystem service, it is easier if the properties *amount of water that can be treated* and *extent of treatment* are combined, to provide an idea of the amount of water in the district that gets treated sufficiently. For instance, Stockholm has the requirement that every square metre should be able to withstand 20 mm water, which would mean detention and treatment of about 90 % of the yearly precipitation (Stockholm Stad, 2016). Another common unit when describing the amount of stormwater is rain events with a specific return period. For instance, a two year rain is the maximum amount of rain that is expected to return every second year. When planning urban areas, it is important to account that a two year rain likely will mean more precipiation in the future than today, as climate change is believed to increase the frequency of heavy rains (SMHI, 2017). This can be adjusted by using a climate factor (Larm, 2013).

Regarding *type of vegetation*, it is preferable that there is mix of species, as different species take upp different pollutants more efficiently (Blecken, 2016). Using several species also makes vegetated areas more resilient to extreme events, as species have different phenologies and are more adapted to different disturbances (Ponge, 2013). It is also preferred to use some evergreen vegetation, as evergreen vegetation can intercept more water per year and therefore treat more water (Capiella, Schueler & Wright, 2005).

Placement of BGI matters in the sense that BGI solutions need to be implemented where the incoming stormwater is polluted, i.e. in connection to bigger roads and parking lots. Another preferred placement is at low points to which flow is concentrated (Blecken, 2016).

To determine the need for the ecosystem service of water treatment, there are a few aspects to consider, listed as questions below. These are meant to provide a guide to the valuation. The questions are:

- Are there a lot of hard surfaces that can act as sources of pollutions in the district?
- What is the ecological status in the recipient? Are requirements for the EQS for water quality met?
- How much water reaches the recipient without being treated today?
- Is it common with dry periods and then heavy rains, giving first flush problems?
    - First flush is the first portion of stormwater to runoff from hard surfaces that have been dry for a while. During dry periods, hard surfaces will have had time to accumulate a higher concentration of pollutions (Trafikverket, 2011).
- Is there a drinking water source nearby? Or any Natura 2000 areas? Any other protected areas?
- Is the conventional pipe system mainly duplicate or combined? Duplicate systems lead the stormwater to the closest recipient, and not to a wastewater treatment plant. Therefore, if the conventional system is mainly duplicate, the stormwater needs to be treated locally before reaching the recipient, if polluted.
- Is the groundwater level low enough to allow percolation, with a safety distance down to not pollute the groundwater?
- How is maintenance of the BGI handled? For instance, are falling leaves from trees taken care of?
    - Who is responsible for the maintenance?
    - How often will the BGI be maintained? Does this correspond to what is needed for the BGI to be used at full effect?
    - What happens if the maintenance is not working like it should?
- Is there contaminated soil anywhere in the district? Could this affect the need for stormwater treatment?

4.1.3 Local climate regulation

For a city to be an attractive place to live and spend time in, regulation of the local climate is crucial. This ecosystem service is associated with regulation of four different local entities: temperature, wind, solar insolation, and relative humidity (Lovell & Taylor, 2013). Indicators that were chosen to value the function of local climate regulation are presented in the box below. Although there are four different entities collaborating to this ecosystem, the indicators are presented together as several of them are in common.

- Tree canopy cover
- Proportion of blue-green surfaces
- Placement of vegetation
- Type of vegetation

Urban areas generally have surface materials with a lower albedo than rural areas, which leads to more of the solar energy being absorbed resulting in a temperature increase. This phenomenon is known as urban heat island (UHI) (US EPA, 2008). In big cities, UHI can give rise to more than a 10 ºC increase but even cities with less than 1000 inhabitants can experience an UHI of about 2 ºC (Thorsson, 2012). When it comes to reducing the urban heat island effect, *tree canopy cover* is the most important indicator, as trees provide both shading and evapotranspiration (Jiao et al., 2017). This indicator is proposed in CBI (2014), CASBEE (2014) and SCB (2013) to mention a few. CBI (2014) and CASBEE (2014) provide valuation support for the proportion of tree canopy cover in a city on a five-graded scale. Because of the shading provided by trees, they will also serve as a provider of the regulation of solar insolation (US EPA, 2008).

Permeable surfaces in the form of blue-green surfaces help reduce UHI by lowering the city's albedo, absorb heat and evapotranspirate water (CBO, 2013). Therefore, the indicator *proportion of blue-green surfaces* can be used, which is also proposed in SCB (2013). The provided evapotranspiration also increases the relative humidity to a more pleasant level, as urban areas usually have a lower relative humidity than rural areas (Hage, 1975). A desired relative humidity in urban areas is about 20-80 % (CEC Design, 2015). Vegetation can also create a "city breeze" during windless evenings, when the urban heat island would usually reach its maximum, and during nights. Blue-green areas, either outside of the city or in parks within the city, generally have a lower temperature than hardscape areas. The thermal differences would give rise to a pressure gradient that results in the breezes (Thorsson, 2012).

Placement of vegetation is also important. When placed on buildings, either on the roof or the walls, it does not only reduce the energy usage within the building as it provides insulation all year around but also protects the building from wearing down from UV-radiation. It therefore gives a reduction in UHI and provides solar radiation protection (US EPA, 2008). CASBEE (2014) provides support on how to value the amount of vegetation on rooftops and walls on a five-graded scale.

Placement of trees specifically matters as well. When placed in windy areas, trees can reduce wind speeds by up to 80 % (Thorsson, 2012). Generally, an addition of 10 % tree cover in residential areas reduces wind speeds by 10-20 % (US EPA, 1992). The wind reduction of trees does not only depend on the placement, but also on total coverage and what type of trees being used. Species, shape and density matters, as well as if they are evergreen or not (Thorsson, 2012). Therefore, the indicator *type of vegetation* is proposed. It is also suggested as an indicator in SCB (2013).

To determine the need for the ecosystem service of local climate regulation, there are a few aspects to consider, listed as questions below. These are meant to provide a guide to the valuation. The questions are:

- Is there a problem with urban heat island in the city? All year around or only in the summer?
- Is there a desire to cut energy usage in buildings or to protect buildings from UV-radiation?

- Is the wind climate pleasant in the district?
- Do public spaces contain any shaded areas?
- Is the humidity at a pleasant level in the district?

4.1.4 Air quality regulation

Bad air quality is a common environmental problem that many cities must battle (Janhäll, 2015). BGI can work as a mitigating measure, as air quality regulation is an ecosystem service that is provided when vegetation filters and absorbs air pollutions, like nitrogen dioxide, ozone and particulate matter smaller than 10 µm (CBO, 2013). Indicators that were chosen to value the function of air quality control as an ecosystem service are:

- Proportion of blue-green surfaces
- Tree canopy cover
- Type of vegetation
- Placement of vegetation

Blue and green surfaces can act as air quality regulators, as harmful particles can deposit on them through dry deposition. Leaves and grass on vegetated surfaces can also absorb harmful gases through their stomata (CBO, 2013). *Proportion of blue-green surfaces* can therefore be used as an indicator and is also proposed by SCB (2013). Trees have been shown to be the type of blue-green systems to reduce air pollution the most, as the leaf area index is generally higher for trees than for any other type of plant (TEEB, 2010). Therefore, the indicator *tree canopy cover* is included and is for instance used in CBI (2014) and CASBEE (2014). CBI (2014) and CASBEE (2014) provide further support for valuing the proportion of tree canopy cover in a city.

Type of vegetation is another indicator to consider. Different species of trees have shown to absorb different types of pollutants, and therefore it is important to have a variety of species (CBO, 2013). SCB (2013) also points out that this indicator needs to be studied. Conifers have been shown to have a higher deposition velocity than deciduous trees (Janhäll, 2015). However, due to seasonal differences of conifers and deciduous trees, a mix of the two is preferred (C/O City, 2014a).

As mentioned in section 4.1.3, vegetation can create breezes in the city. This is important for good air quality as well, since ventilation of the air helps dilute the air pollutions (Boverket, 2010). On the other hand, trees could have a negative effect on the air quality in street canyons if placed improperly. Trees could form a lid over pollutants emitted from traffic when placed densely in street canyons. It is therefore of importance to consider the indicator *placement of vegetation*, as it could turn into a disservice if trees would block ventilation of the streets. When placed close to the source, vegetation can serve as a protecting barrier between the pollution source and the receiver (Janhäll, 2015). SCB (2013) and C/O City (2014a) also proposes this indicator.

To determine the need for the ecosystem service of air quality control, there are a few aspects to consider, listed as questions below. These are meant to provide a guide to the valuation. The questions are:

- Are EQS limits for air quality fulfilled? If not everywhere, how many people are exposed to air not fulfilling EQS close to their place of residence?
    - In Sweden, there are EQS for 12 substances, see Naturvårdsverket (2014).
- If EQS limits are not fulfilled at certain areas, are there many people that could be adversely affected in these areas? Could mitigation measures be implemented here?
- What are the sources of the air pollutants?
    - Are they within the district?
    - Are mitigation measures implemented close to the sources?
- What does the wind climate look like? Does wind help to ventilate the air?
- What is the air quality around more sensitive areas? These areas include schools, retirement homes and hospitals.
    - Are there any mitigation measures implemented here?

4.1.5 Environmental noise control

Environmental noise is defined as unwanted or harmful outdoor sound, either from human or industrial activity (Directive 2002/49/EC). Noise is an inevitable problem in cities today and is increasing with urbanization (Eriksson, Nilsson & Pershagen, 2013). Environmental noise control is a regulating ecosystem service that is provided when implementing vegetation. Vegetation can reduce environmental noise levels in urban surroundings in two ways: either through absorption or by redirecting the sound waves that can be done through reflection, diffraction or scattering (Nilsson et al., 2013). Indicators that were chosen to value the function of environmental noise control as an ecosystem service are:

- Proportion of soft surfaces
- Placement of vegetation
- Type of vegetation
- Elements for acoustic design

To begin with, the *proportion of soft surfaces* is important when valuing this ecosystem service. Acoustically soft surfaces, like vegetated or soil surfaces, absorb noise while hard surfaces, like concrete and water, reflect sound (King & Murphy, 2014). This indicator is proposed in SCB (2013). It is argued in C/O City (2015) that only the proportion of vegetated surfaces in *noisy areas* should be considered when looking at this ecosystem service. Therefore, it is important to consider the *placement of vegetation*, whether it is placed close to noise sources or not. Preferably, it should be placed close to the noise source to redirect the sound from the receiver more efficiently. If trees are placed close to the sources, blocking the sight to the receiver, a visual shield has been formed. Visual shields have been shown to make noise seem less disturbing (Bolund & Hunhammar, 1999). Both SCB (2013) and C/O City (2014a) proposes the number of roads lined with green areas as a unit for this indicator.

The *type of vegetation* being used is another indicator to study, for instance suggested by SCB (2013), as different vegetation species mitigate sounds differently. Increased leaf area density, leaf size and leaf weight all contribute to more noise reductions (Nilsson et al., 2013). Table 4 shows how much different types of vegetation can reduce noise levels. It is also noteworthy that it is beneficial to use evergreen vegetation to maintain its acoustic properties year-round (Bolund & Hunhammar, 1999).

Table 4. Noise reduction from different types of vegetation (Nilsson et al., 2013).

Type of vegetation	**Possible noise reduction (dB)**
Green roofs	2-8
Vegetation in courtyards	4
Trees along street canyons	2
15 m wide strip of trees	5-6
Hedges	1-3
45 m wide strip of grass/large-leaf crop	5-9/9-13

Previously mentioned mitigation measures have focused on reducing the noise. Another way to mitigate noise is to incorporate more pleasant sounds in the urban soundscape that can mask the noise. This is called *acoustic design*. It is important, however, to consider that if more pleasant sounds would be added, the total sound level should still not exceed recommended limits and should therefore be combined with mitigating measures. Examples of components that could result in positive sounds are environments for birds that will give birdsong, vegetation for rustling leaves or water installments that provide sounds of rippling water (Göteborgs Stad, 2014).

To determine the need for the ecosystem service of environmental noise control, there are a few aspects to consider, listed as questions below. These are meant to provide a guide to the valuation. The questions are:

- Are the Swedish Environmental Protection Agency's (EPA) recommended limits for environmental noise met? If not everywhere, how many people are exposed to noise levels above recommended limits close to their residence?
    - The Swedish EPA has recommended noise limits for residential areas, parks and bigger recreational parks. See Naturvårdsverket (2007) and Naturvårdsverket (2017b).
- What are the sources of environmental noise? Are they within the district? If so, are there mitigating measures around these sources?
- Are there quiet outdoor areas available at a reasonable distance?
    - Quiet areas are defined as areas with noise levels below 45 dBA (van der Berg, n.d.).

- As noise can impair cognitive development, it is important to look specifically at learning centers (Nilsson et al., 2013). Are these exposed to noise above limits?
    - The Swedish EPA has recommended noise limits for school yards, see Naturvårdsverket (2017c).

4.1.6 Erosion prevention

Erosion is natural abrasion of bedrock and soil by wind, flowing water or ice (National-encyklopedin, n.d.b). In Sweden, erosion is mainly a problem along shores, watercourses and lakes (SGI, 2017). Vegetation provides the regulating ecosystem service of erosion prevention in multiples ways. It works as a protecting layer between the air and the soil. Its roots hold the soil in place and make the soil more permeable, which reduces runoff. This goes for terrestrial and coastal ecosystems (CICES, 2013). By reducing erosion, dispersal of nutrients will also be reduced, as erosion is a big source of phosphorus (Blecken, 2016). Indicators that were chosen to value the function of erosion prevention as an ecosystem service are:

- Proportion of vegetation cover
- Water flow control
- Soil retention

Proportion of vegetation cover on non-hard surfaces is the most prominent indicator for erosion prevention and is proposed as an indicator by Silvacom (2015). Erosion is more prominent on slopes and around flowing water. Therefore, it is important to study these areas in detail when doing the valuation. What kind of species the vegetation cover is composed of is of no greater significance. However, forests may be more able to withstand intense runoff events rather than grasslands or herb-dominated areas (TEEB, 2010). It has been noted that natural habitats tend to have more erosion control than anthropogenic habitats, as well as a greater capacity of absorbing nutrients and pollutants (CBO, 2013).

Faster flowing water increases the risk of erosion. By reducing flows, some erosion can be prevented. *Water flow control*, i.e. how water can be detained instead of running off, was explained in section 4.1.1. This means that results from the valuation of flood protection will affect the value of erosion prevention.

Erosion leads to an increased risk of mass movements such as landslides, as weathering decreases the resistance in the soil bed (Yalcin, 2007). Vegetation can however also prevent these bigger processes, not only by holding the soil in place but also by controlling the soil moisture (TEEB, 2010). Risk of mass movements can therefore be valued not only by looking at vegetation cover, but also at the *soil retention* of the present soils in the area. Soil retention is the potential amount of water that soil can hold and is proposed as an indicator by Silvacom (2015). Mass movements happen when the water content is high and the binding forces within the soil are low. Soils of small particles, like clay, have higher soil retention, and therefore have a higher risk of mass movements (Yalcin, 2007).

To determine the need for the ecosystem service of erosion prevention, there are a few aspects to consider, listed as questions below. These are meant to provide a guide to the valuation. The questions are:

- Is there a problem with erosion in the district, such as loss of land to water?
    - Is land adjacent to water protected from erosion?
- Is there a risk of mudflows and landslides in the district or surrounding areas? How many people could get affected? Could important infrastructure be damaged?

4.1.7 Recreation

Living in a city can be stressful, and that is why recreational services of urban ecosystems are among the highest valued in cities (CBO, 2013). It is defined as revitalizing power in mind and body by being in a relaxing environment and includes both active and non-active activities (Nationalencyklopedin, n.d.c). Urban features as parks, forests, lakes and rivers enable recreational activities that can help reduce stress levels and improve human well-being (CBO, 2013). For instance, trees have shown to have an antihypertensive effect, meaning that it treats high blood pressure (Naturvårdsverket, 2012). The recreational value of blue and green areas is however not fully dependent on the surrounding natural or man-made ecosystems, as built infrastructure like benches and sport facilities affect as well (CBO, 2013). It can also be noted that people generally want access to both blue and green environments, so a separation of the two environments could be used in the valuation. Indicators that were chosen to value the function of recreation as an ecosystem service are:

- Accessibility to natural, recreational areas
- Quantity of recreational areas
- Quality of recreational areas

Recreation is a cultural ecosystem service. When valuing cultural ecosystem services, it is not enough to only look at physical elements as in previous ecosystem services described. For cultural services, it is also necessary to have a dialogue with the inhabitants of the district, to learn how they value recreational services (Pedersen, Johansson & Weisner, 2017). Which urban elements that can contribute to cultural services is an individual question, so to be able to quantify a cultural service different types of qualitative surveys are usually required (SCB, 2013). Following results is an attempt to unify physical indicators for recreation opportunities, but it is important to conduct a dialogue with the public as well for a more complete valuation.

When valuing *accessibility to natural, recreational areas*, both proximity and mobility within the natural area need to be examined. Research show that proximity to nature has positive health benefits, both mentally and physically. People living close to nature have proven to have lower stress levels and less risk of cardiovascular diseases (Ottosson & Ottosson, 2013). Boverket (2007) has a recommended distance of no more than 300 m from residential area or school to closest green area to assure proximity to nature. SCB (2013) therefore proposes this to be a viable indicator. Proximity is also mentioned as an indicator in Staub et al. (2011) and C/O City

(2014a). There is also a recommended limit of no more than 1 km to bigger recreational areas from residential areas made by C/O City (2015). Proximity to nature from retirement homes and hospitals could also be considered. A study by Ulrich (1984) showed that patients recovered faster after surgery and needed less strong painkillers when having a view over a park than patients with a view of a wall. The accessibility to and within the recreational area also needs to be recognized and valued, as proposed by C/O City (2014a). For instance, is there public transport or bike routes going to these recreational areas? Is parking available? What does the mobility within the recreational area look like? Are there paths accessible for disabled, children and elder?

The next indicator is *quantity of recreational areas* provided by BGI. This is an indicator proposed in Gómez-Baggethun & Barton (2013) and Staub et al. (2011). This could be answered by looking at how many people that share the available blue-green areas. WHO recommends at least 9 m^2 of green space per person (UN-Habitat, 2014a). CBI (2014) has created a five-graded valuation that can be used as guidance. The unit used in CBI is the amount of natural area in the city per 1000 people. Another way of identifying the quantity of recreational areas is to look at the proportion of available green surfaces. Ståhle et al. (2016) recommend that at least 10 % of the city's surface area shall consist of public green areas.

To finally measure the *quality of recreational areas* within the district, a citizen dialogue is necessary to determine whether people are happy with the amount and types of recreational areas in the district (Pedersen, Johansson & Weisner, 2017). For instance, are there enough running trails or parks for walking the dog? Do the inhabitants feel safe in the available recreational areas? And can they find privacy and comfort in these areas? (CBO, 2013) Also, if there are data available on proportion of people using recreational areas and possibly for how long, this could indicate the appreciation of these areas (Naturvårdsverket, 2015). The proportion of green areas with a specific frequency of humans visiting per day is also suggested as an indicator for recreation in Staub et al. (2011).

Another way of looking at the quality of the recreational areas is whether the area provides multifunctionality or not. For instance, can green roofs be entered and used for recreational purposes? Can designated flooding areas be used for sports when there is no precipitation? Can a variety of recreational activities be performed in the district, or is it limited to a few? Note that not all blue-green areas necessarily are public. Private areas can have a greater value to the people able to use it, but no or little recreational value to the rest of the inhabitants.

To determine the need for the ecosystem service recreation, there are a few additional aspects to consider, listed as questions below. These are meant to provide a guide to the valuation. The questions are:

- Are the inhabitants in the district suffering from health issues, like obesity or stress, that recreation could help mitigate?
- Is there a lack of opportunities for recreational activities in this district? How are the opportunities for recreation in neighboring districts?
- Is there easily accessible information for the public about available recreational areas in their district?

- Are there additional non-natural services provided in recreational, green areas that will increase the comfortability of the area? Like toilets, cafés, benches and so on?

4.1.8 Social relations

Social relations is a cultural ecosystem service which refers to nature's ability to create places for social activities and interaction (C/O City, 2014a). It includes social cohesion, mutual respect and ability to help others (MA, 2005). It has been shown that people with more social interaction have a greater understanding of people's differences, which counteracts polarization in the society, and in addition are less likely to develop mental illnesses (Boverket, 2017). Indicators that were chosen to value the function of social relations as an ecosystem service are:

- Proximity to public open spaces
- Quantity of public open spaces
- Quality of public open spaces

The indicators and valuation of social relations were chosen quite similar to the ones in section 4.1.7, as both of these are cultural ecosystem services. A full valuation cannot be done without a dialogue with the public.

To enable social relations in urban environments, public open spaces are a necessity (Ståhle et al., 2016). As not necessarily all public open spaces will contain BGI, it is necessary to separate public open spaces with blue-green elements from areas without blue-green elements for the valuation of the ecosystem service. An example of an urban, blue-green element with specifically high social values is community gardens (Lovell & Taylor, 2013).

Regarding *proximity to public open spaces*, same recommendations could be used as in section 4.1.7; that is, Boverket (2007) recommends no more than 300 m to natural areas from one's home.

To create pleasant environments, it is important that they are not too crowded. The *quantity of public open spaces* can therefore be studied, as proposed by C/O City (2014a). UN-Habitat (2014b), the UN's Human Settlements Programme, recommends at least 15-20 % public spaces in a city to cater for the need for squares, parks and natural areas. Ståhle et al. (2016) recommend at least 2/3 of the public spaces to be green and 1/3 to be parks to reach a high quality of public open spaces. It is also important to study the spaciousness within the public open spaces. This can be measured in square meter of public open space per person, counting inhabitants and workers. Stockholm recommends about 5-10 m^2 of public open space per person and New York about 10 m^2 (Ståhle et al., 2016).

To value the *quality of public open spaces*, a dialogue with the public is necessary. Is the public satisfied with the amount of public spaces for social meetings? Is there any type of social environment that they are missing? It can also be important to study the variety of people using the blue-green areas. If a diverse mix of people, meaning different gender, ages, ethnicity etc., is using these areas, it can be seen as a successful example of areas where social relations can grow. Another physical parameter is whether there are natural meeting places within the larger green areas, like cafes or playgrounds (C/O City, 2014a)

To determine the need for the ecosystem services related to social relations, there are a few aspects to consider, listed as questions below. These are meant to provide a guide to the valuation. The questions are:

- Is there a variety of inhabitants in and in connection to the district?
    - Is there segregation within or in connection to the district?
- Is there a lack of places for social interaction?
- Are BGI present in the district's most popular meeting places?

4.1.9 Biodiversity

Biodiversity is the variety of species, habitats, and ecosystems. Biodiversity of species is both the amount of species and the variety within the species (EU, 2011). Biodiversity supports all other ecosystem services and creates resilience in ecosystems. Resilience is the ecosystem's ability to withstand disturbances and changes. With more resilience, ecosystems can harbor more species, functions, and processes that give ecosystem services (C/O City, 2015). Indicators that were chosen to value the function of biodiversity as an ecosystem service are:

- Biodiversity of species
- Proportion of natural areas
- Connectivity
- Proportion of protected areas
- Governance for biodiversity

Naturally, one way to value the biodiversity in a district is to study *diversity of species*. This is proposed as an indicator by CBI (2014), Lovell & Taylor (2013) and Staub et al. (2011) to mention a few. A distinction between native and invasive, also called alien, species is important, as alien species can be a threat to natural species and therefore damage the stability of the present ecosystems (CBI, 2014). CBI (2014) provides guidance on how to value the presence of both natural and invasive species at a five-graded scale.

Natural areas usually hold a higher number of species than disturbed or man-made areas. Therefore, the *proportion of natural areas* in the district is proposed as an indicator by CBI (2014). Natural areas do typically not include environments that are man-made or very influenced by man such as parks, golf courses or roadside plantings; however, natural ecosystem within these environments where native species are dominant can be included. Also, restored and naturalized areas can be included in this indicator (CBI, 2014). CBI (2014) provides guidance for valuation of proportion of natural areas. To go into greater depth, the variability in the natural area can also be studied (C/O City, 2015). For instance, is there accessible permanent water all year around? Or unique habitats like dead wood of various tree species? Are shrubs with berries or flowers with nectar available?

Another important indicator for biodiversity proposed by CBI (2014) is *connectivity*, or avoidance of fragmentation of green areas, as fragmentation is one of the biggest threats to biodiversity. However, it difficult to measure connectivity. Different species are affected differently by fragmentation. It is therefore not enough to only study the landscape, but also its relationship to the species considered. There is no commonly recommended way of calculating the connectivity. Many different methods are presented in Kindlmann & Burel (2008). CBI (2014) has considered the difficulty of measuring connectivity but does however present a pragmatic formula that could be used when valuing this indicator (1).

Connectivity: $K = \frac{1}{A_{total}}(A_1^2 + A_2^2 + A_3^2 + \cdots + A_n^2)$ (1)

A_{total} is the total area of all natural areas, n is the total number of connected, natural areas and A_1 -A_n are separated areas which are more than 100 m apart or and areas with an anthropogenic barrier of significance in between. This could be a >15 m wide road or roads with more than 5000 cars per day (CBI, 2014). CBI (2014) provides a guide for how to value the connectivity.

Protected natural areas are usually aiming to preserve biodiversity. *Proportion of protected natural areas* is an indicator proposed by CBI (2014) that shows the city's commitment to conserve biodiversity (CBI, 2014). However, C/O City (2014b) excludes this indicator at a district level, meaning that this would be an indicator better suited at a city level. If this indicator would be included in a semi-quantitative valuation, CBI (2014) can provide guidance.

Other *governance for biodiversity* indicators can also be studied, to clarify the commitment in preserving or increasing biodiversity. These indicators could be the budget allocated to biodiversity or blue-green solutions, the number of projects implemented to improve biodiversity or policies and regulations present. Guidance on how to value these indicators is presented in CBI (2014).

To determine the demand for the ecosystem service biodiversity, there are a few aspects to consider, listed as questions below. These are meant to provide a guide to the valuation. The questions are:

- Is the biodiversity at a desired level in the district?
- Are there any red-listed species within the district or in surrounding areas that may need further protection?
- Are habitats of native species being considered in reconstruction plans?
    - Are natural shores preserved?
- How are other ecosystem services working in the district?

4.2 BGI AND THEIR ECOSYSTEM SERVICES

The connections between the studied BGI and ecosystem services were based on whether the BGI was believed to be able to provide the functions that the indicators for every ecosystem service were based on (Table 5). If the BGI was considered to have the potential of providing the ecosystem service to a greater extent it was marked with an upper-case **X** and marked with a lower-case *x* if the provision of the service was considered smaller.

Table 5. A compilation of which ecosystem services each BGI can provide. Columns indicate BGI and rows indicate ecosystem services. Upper-case **X** means that the BGI can provide the ecosystem service to a greater extent, while lower-case *x* means that the BGI could provide the ecosystem service in a small extent and blank means that the BGI does not provide the given ecosystem service.

	Green roofs	Trees	Rain gardens	Swales	Detention basin	Detention ponds	Attenuation storage tanks*
Flood protection	**X**	**X**	**X**	**X**	**X**	**X**	*x*
Water treatment	*x*	*x*	**X**	*x*	*x*	**X**	*x*
Local climate regulation	**X**	**X**	*x*	*x*	*x*	*x*	*x*
Air quality regulation	*x*	**X**	*x*	*x*	*x*	*x*	*x*
Noise regulation	*x*	*x*	*x*	*x*	**X**		*x*
Erosion control	*x*	**X**	**X**	*x*	*x*		*x*
Recreation		*x*	*x*	*x*	**X**	*x*	*x*
Social relations		*x*	*x*	*x*	**X**	*x*	*x*
Biodiversity	*x*	*x*	**X**	*x*	*x*	**X**	*x*

*For attenuation storage tanks, it is assumed it is connected to a vegetated surface that is the element providing the ecosystem services.

Flood protection

All 7 BGI are designed to provide some flood protection as an ecosystem service. The stormwater can either infiltrate the soil, evaporate from the blue-green surfaces, intercept and transpire through vegetation or be temporarily stored on the surface of the BGI. In section 2.2 it was mentioned that green roofs, trees, swales, detention basins and detention ponds can detain plenty of water and were therefore given upper-case **X**. It was also mentioned that rain gardens can overflow during more rare, intensive rains (Blecken, 2016) but are still considered to be able to provide a fair amount of flood protection and therefore also given an upper-case **X**. Regarding attenuation storage tanks, it was given a lower-case *x* as the connected vegetated surface that is providing the ecosystem service is not considered to be able to provide much flood protection. Noteworthy is that the tank itself is considered to provide a good amount of flood protection but cannot be considered an ecosystem service as it is artificial.

Water treatment

With water attenuation comes treatment. However, not all BGI are primarily meant for water treatment. The BGI that show enough treatment results according to literature studies presented in section 2.2 are rain gardens and detention ponds. These were therefore given upper-case **X**. Green roofs are not considered to provide water treatment, as the stormwater is generally not polluted when it is collected on the roof (Blecken, 2016). This one was therefore given a lower-case *x*. Same goes for swales and attenuation storage tanks, as they do not provide sufficient stormwater treatment in general (Svenskt Vatten, 2016 & Woods Ballard et al., 2015). Trees and detention basins are somewhat of borderline cases, as it was stated in section 2.2 that they can provide good treatment if designed in the right way. They were however given lower-case *x* as they cannot be assumed to always provide plenty of this ecosystem service.As a final note to this ecosystem service, all vegetated systems risk nutrient leakage in case of being fertilized and the ecosystem service would then accordingly be deteriorated.

Local climate regulation

As mentioned in section 4.1.3, this ecosystem service is in regards of regulating four local entities: temperature, wind, solar insolation, and relative humidity. All BGI are considered to better the relative humidity climate in urban areas through evapotranspiration. The evapo-transpiration also helps reduce the UHI. Trees can however help reduce the UHI even more with its addition of shading (Jiao et al., 2017), which also provides solar insolation. Trees are also the only BGI that can help reduce high wind speeds (Thorsson, 2012). As trees help regulate all four entities, it was given an upper-case **X**. Green roofs helps regulate at least three of the entities, as it also provides solar insolation on buildings, and was therefore also given upper-case **X**. The rest of the BGI were given lower-case *x*, as they help regulate relative humidity and UHI but not solar insolation or wind speeds in a significant extent.

Air quality regulation

It was mentioned in section 4.1.4 that trees can filter air pollutions most efficiently as their leaf area index is in general higher for trees than for other type of vegetation (TEEB, 2010). This BGI was therefore given an upper-case **X**. It is however important to have in mind that trees can have a negative effect on the air quality if placed too densely (Janhäll, 2015) which needs to be considered when valuing the ecosystem service. The rest of the BGI were given lower-case *x* as they all provide surfaces where air pollutions can be deposited (CBO, 2013).

Environmental noise control

All vegetated surfaces provide some noise reduction, while water surfaces do not (King & Murphy, 2014). Therefore, detention ponds are considered to not provide any environmental noise control. Rain gardens, swales, and attenuation storage tanks are in general only covering a small surface with vegetation between the noise source (typically traffic on roads) and the receiver and can therefore not provide much noise reduction. These were given lower-case *x*.

Trees along street canyons, which is how trees are commonly placed in urban environments, can reduce noise by 2 dB (Nilsson et al., 2013) as mentioned in section 4.1.5. This is not considered a very significant noise reduction and was given a lower-case *x*. Worth mentioning is that trees could be of more importance if placed in wider strips, as it can reduce noise levels by 6 dB (Nilsson et al., 2013). Green roofs were said to be able to reduce noise by 2-8 dB (Nilsson et al., 2013). It was given a lower-case *x* as its minimum of 2 dB reduction is not a very significant noise reduction, but it is worth noting that it can under the right circumstances provide a more substantial noise reduction.

Detention basins do normally cover a bigger surface area with vegetation, comparable to the size of a courtyard that can provide a noise reduction of about 4 dB (Nilsson et al., 2013). These are therefore considered to be able to provide a relatively big noise reduction, and were given an upper-case **X**.

Erosion prevention

All vegetated surfaces provide erosion prevention (CICES, 2013) while blue infrastructures can cause erosion (SGI, 2017). Detention ponds was therefore considered to not be able to provide any erosion prevention. Trees and rain gardens are assumed to be the BGI with vegetation producing more and deeper roots and can therefore prevent erosion more efficiently. These were given upper-case **X**. Swales, detention basins, and attenuation storage tanks are usually covered with vegetation with more shallow roots, like grass, and were therefore given lower-case *x*. Green roofs are placed where there is no real need for erosion prevention, other than holding the soil which the vegetation grows on in place, and was thus also given a lower-case *x*.

Recreation

Bigger blue-green surfaces with public access enables recreational activities (CBO, 2013). When not flooded, detention basins are one type of BGI that can fulfill this and was therefore given an upper-case **X**. Attenuation storage tanks and swales do usually provide smaller green surfaces with a possibility to more restricted recreational services, for instance walking your dog, and were thus given lower-case *x*.

Trees, rain gardens, and detention ponds generally cannot be entered nor used for physical activities. They can however have a positive psychological effect and, for instance, treat high blood pressure (Naturvårdsverket, 2012). A public dialogue and further studies could be necessary here to determine in what extent these BGI affect people. They were given a lower-case *x* in Table 5 to illustrate that they do provide recreational services but that it cannot be determined from studied literature to what extent.

Regarding green roofs, it is a matter of whether they can be entered or seen. It is here assumed that most green roofs cannot be entered by the public and may not even be visual. Therefore, it was assumed to not be providing any recreational values.

Social relations

Similar to recreational services, bigger publicly accessible blue-green surfaces provide a natural meeting spot which enables social relations to arise (Ståhle et al., 2016). Detention basins fall into this category and was then given an upper-case **X**. Smaller vegetated surfaces like swales and attenuation storage tanks could also provide social relations to an extent, for instance between dog owners walking their dogs, but likely not as much as for detention basins that can serve as parks. These were therefore given lower-case *x*.

As it was previously mentioned, trees, rain gardens, and detention ponds cannot normally be physically entered, but can used as elements implemented in existing meeting areas to make them more pleasant. They can for instance improve the local climate as previously mentioned. As these do not make out the foundation for a meeting spot but rather elements adding to the space, they were given lower-case *x*. It was also mentioned in the previous section that green roofs are assumed to not be publicly accessible, meaning no social relation services gained from this BGI.

Biodiversity

Regular lawns are man-made and not considered to provide any significant biodiversity of species or habitats but do still provide connectivity with other blue-green areas. A lawn is the main feature of swales, detention basins, and attenuation storage tanks which were therefore given a lower-case *x*. Green roofs do generally not contribute with much biodiversity either. It does however, as previously mentioned BGI, provide connectivity and was also given a lower-case *x*. Trees in urban areas do mainly provide connectivity as well, and was also given a lower-case *x*. A side note to trees is that old or dead trees, that are generally not used for stormwater management, can provide unique and important habitats and are valued highly in regards of biodiversity (Stockholms läns landsting, 2012).

Detention ponds bring in permanent water environments in the urban area, enabling habitats for a greater variety of aquatic and terrestrial species. It was therefore given upper-case **X**. Rain gardens usually have a varied selection of species, so it can capture different types of pollutants. In other words, the biodiversity is relatively high in this BGI, so it was given an upper-case **X**.

4.3 CASE STUDY: MASTHUGGSKAJEN

Mainly due to time constraints, two of the nine chosen ecosystem services had to be excluded from the workshop. The first one was erosion control, as it was not considered very necessary in the district due to high proportion of hardscape and no natural areas adjacent to flowing water. The other one was social relations, which lacked enough data to base a valuation on.

It was neither possible to discuss and value every indicator to the ecosystem services in the workshop, mainly because of time constraints but also because a lack of data or expertise. For instance, *type of vegetation* is an indicator for five of the nine ecosystem services. However, at the time of the workshop, it had not been decided yet on what types of vegetation that will be implemented in Masthuggskajen. Another example is that when valuing environmental noise control, there was no investigation available that presented how much the vegetation could reduce future noise levels in Masthuggskajen. The value that was given to environment noise control was then an estimate made on the amount and placement of vegetation in the areas, but an expert in acoustics would have been needed to consult with at the workshop for a more confident estimation. Therefore, the results presented should not be considered complete, but rather a pilot study of the valuation method.

4.3.1 Flood Protection

It was first noted that Masthuggskajen did have problems with stormwater management at present, as flooding of low points had been observed previously on site by participants in the workshop. The district is low lying, so inflow of water from surrounding areas occurs naturally.

When deciding the presence of the ecosystem service, discussions were held about the *proportion of permeable surfaces*, *amount of water that can be detained in BGI*, *soil type* as an indicator for infiltration capacity, and *type of vegetation*. The two indicators *Amount of water detained in BGI* and *soil type* were considered closely related. Results of the workshop are presented in Table 6.

Table 6. Valuation of flood protection in Masthuggskajen.

Indicators	Before	After
Proportion of permeable surfaces	16 % (5 % green + 11 % blue)	15 % (13 % green + 2 % blue)
Amount of water detained in BGI	Can hold less than 10 mm	Can hold at least 10 mm
- *Soil type*	Mostly clay	Mostly clay, but now more macadam
Vegetation	83 trees	~ 180 trees (estimation)
VALUATION	**1**	**3**

Considering flood protection in Masthuggskajen, it was discussed that the most important indicator was the *amount of water detained in BGI*. Masthuggskajen is a dense district, so changing proportion of permeable surfaces is difficult. However, the permeable surfaces that are available can be designed to be able to take more water. Göteborgs Stad has directions that the city should be able to withstand 10 mm/m^2 of precipitation on residential ground (Göteborgs Stad, 2017a). This will be achieved after reconstruction.

Setting the value for the ecosystem service before reconstruction, it was discussed that the ecosystem service was barely present. The grade 1 was therefore given. After reconstruction, BGI had been implemented to be able to meet the requirements set for stormwater management. The grade given was then a 3. It was not given a 4 or 5, as it was argued that the proportion of permeable surfaces was not big enough.

4.3.2 Water treatment

It was stated that local water treatment is needed in Masthuggskajen, as there are and will be a high proportion of hard surfaces collecting pollutants. Also, part of the conventional stormwater pipe system is duplicate. If there would be no local treatment, polluted water would reach the adjacent Göta Älv.

For this ecosystem service, indicators discussed were quite like the ones discussed in section 4.3.1, but now with a focus on the treatment instead of the retention. These were *proportion of permeable surfaces with a detention of 10 mm* and *placement of BGI.* Results of the workshop are presented in Table 7.

Table 7. Valuation of water treatment in Masthuggskajen.

Indicators	Before	After
Proportion of permeable surfaces with a detention of 10 mm/m²	About 0 %	5 % of road surfaces will be of rain gardens
Placement of BGI	-	Along roads
VALUATION	**1**	**3**

During the discussions, it was decided to compound the two indicators of *proportion of permeable surfaces* and *extent of treatment in BGI* into *proportion of permeable surfaces with a detention of at least 10 mm/m²*. It was said that there was basically no water treatment in the district at present state, so it was given grade 1.

For the future state of Masthuggskajen, it was said at the workshop that 4800 m² of BGI, mainly rain gardens, will be implemented adjacent to 95 440 m² of road. Placement of the BGI is therefore good, as traffic is one of the main sources of stormwater pollutions. The implemented BGI is expected to be enough to meet the city's requirements regarding local water treatment. As requirements will be reached, it was given grade 3. Again, it was argued that the proportion of permeable surfaces will not be big enough for it to be valued grade 4 or 5 after reconstruction.

Rain gardens is the BGI that was considered to provide the most treatment. It was discussed that the type of BGI that is being used is important in the aspect of water treatment but was considered to be too detailed for the final valuation method. It was also said that it is important to discuss proportion of evergreen vegetation, since there is a need for water treatment all year around.

It was also mentioned during the workshop that maintenance is important for the BGI to be able to maintain its capacity to treat the water. However, how the maintenance will be organized post development could not be answered at this stage.

4.3.3 Local climate regulation

As this ecosystem service includes more than one entity (temperature, wind, solar insolation, and relative humidity), the first step was to discuss if any of these topics were a problem within the district; that is, if there was a need for the ecosystem service. Urban heat island was not considered to be a problem in Masthuggskajen, as it does not reach very high temperatures for most parts of the year. Also, urban heat island had not been mentioned in any of the investigations. The wind climate was on the other hand considered to benefit from a regulation, especially during the winter when cold winds come from northeast (CEC Design, 2015). Solar insolation was quickly discussed, while relative humidity was excluded since it was modelled to be within the comfort zone in CEC Design (2015). The adjacent river does also have a dominant effect on the humidity, and the BGI was not considered to affect it substantially.

Indicators for local climate regulation discussed in the workshop were *tree canopy cover* and *placement*. Results of the workshop are presented in Table 8.

Table 8. Valuation of local climate regulation in Masthuggskajen.

Indicators	Before	After
Tree canopy cover	Very low	An increase but still low
Placement	-	Along some roads and walkways, and in parks 6 % of roofs will be green
VALUATION	**1**	**2**

Present state was given the grade 1, as there were barely any trees or other vegetation present that could provide local climate regulation.

In CEC Design (2015), it is discussed that the wind climate will be far from comfortable enough after reconstruction. Their simulations did not include any vegetation, but states that more vegetation than what is present today is needed to reinforce wind regulation. According to plans (Göteborgs Stad, 2017b), more trees will be planted, for instance along both sides of Första Långgatan with about 50 trees in total. This is believed to improve the experienced wind climate locally. It was however hard to value to what extent the vegetation could help more specifically. An expert in micro climate studies would have been needed to consult. The ecosystem service was still given grade 2 post reconstructions as it was discussed that the trees planned to be implemented is not expected to improve the local climate enough. More trees are believed to be needed to reach grade 3.

4.3.4 Air quality regulation

There is a need to study the air quality regulation in Masthuggskajen, since the district has previously had problems to meet the requirements of EQS for air quality along its bigger roads. Indicators and results discussed during the workshop are presented in Table 9.

Table 9. Valuation of air quality regulation in Masthuggskajen.

Indicators	Before	After
Vegetation cover	Very low	An increase but still low

Placement	-	Well in regards of where more people will be
VALUATION	**1**	**2**

Before reconstruction, there was barely any of this ecosystem service present, so it was given the grade 1. BGI is not expected to fulfil the EQS after reconstruction either, as the traffic load is big. Favorably, more trees will be planted where more people are expected to walk, while there will be no additional trees where the sources of air pollutions are big. That will likely mean that the background levels of pollutions will be higher than wanted, but that people will get some pollution protection from vegetation within the district. It was, however, difficult to say in what extent the planned trees would help regarding air quality as there is no modelling available that includes the effect of blue-green elements. It was argued that the vegetation would help reduce levels of air pollutants but not reach the EQS limits, so it was given the grade 2.

4.3.5 Environmental noise control

The discussion regarding environmental noise control started like the discussion about air quality regulation, as sources and receivers are similar for air pollution and environmental noise. It was seen in the investigation made by Akustikforum (2015) that not all areas within Masthuggskajen are meeting the requirements for noise levels today. Indicators and results discussed during the workshop are presented in Table 10.

Table 10. Valuation of environmental noise control in Masthuggskajen.

Indicators	Before	After
Proportion of soft surfaces	5 %	13 %
Placement	-	Well in regards of where more people will be
Acoustic design & visual elements	-	Some more natural areas could be needed
VALUATION	**1**	**2**

The ecosystem service was argued barely present before reconstruction and was therefore given the grade 1. Akustikforum (2015) also showed that the noise levels would not meet the requirements throughout the district after reconstruction either. It is important to note, however, that the investigation did not include the effect of vegetation. Soft, green surfaces would increase from 5 % to 13 %, which is a significant increase. Placement of the soft surfaces was considered good, as they would be implemented were more people are expected to be in movement. Also, more positive sounds like birdsong and rustling of leaves are expected to be present after reconstruction.

It was very difficult to estimate the amount of noise reduction that would be provided by the planted vegetation. An expert would have been needed to consult with. The post reconstruction case was still given grade 2, as it was supposed that the new vegetation would not be quite enough for the district to meet recommended noise levels.

4.3.6 Recreation

Whether there is a need for recreational services in Masthuggskajen was never discussed, as it was assumed that recreational opportunities are always necessary. Indicators discussed were *proximity* and *quanity of recreational areas*. The indicator could not be discussed as there had been no citizen dialogue regarding recreational services. Results are presented in Table 11.

Table 11. Valuation of recreational opportunities in Masthuggskajen.

Indicators	Before	After
Proximity	<300 m to green area for all	<300 m to green area for all
Quantity	Low	Meet requirements
VALUATION	**2**	**3**

Investigations showed that both before and after reconstruction, no inhabitant would have more than 300 m to the closest green area (Göteborgs Stad, 2017c). The district also has proximity to water environments. The amount of people that would need to share the natural spaces could not be estimated, but it was noted that the district meets the requirements of at least 10 % green areas after reconstruction. The present state of Masthuggskajen was given the grade 2 as there were not a lot of green areas, but still offers a good proximity to green areas. Future state was given grade 3 as it met all requirements looked upon in this valuation.

4.3.7 Biodiversity

Biodiversity is a necessity for the other ecosystem services to arise and could therefore be argued to always be considered in valuation. It was also noted in the investigation made by COWI (2015) that there is a red-listed lichen in an adjacent district. The investigation also stated that as of today, Masthuggskajen in itself does not have any biodiversity values. Indicators and results discussed during the workshop are presented in Table 12.

Table 12. Valuation of biodiversity in Masthuggskajen.

Indicators	Before	After
Biodiversity	Very low	Low
Natural areas	5 %	13 %
VALUATION	**1**	**2**

The connectivity in the area could not be estimated with Equation (1), since it was considered too complex for the time available. It was however presented in COWI (2015) that the fragmentation was big, meaning low connectivity, before reconstruction. The report also stated that green areas in the district do not have any values for the conservation of biodiversity. Present state was therefore given grade 1.

It was noted when studying the blue prints for planned reconstruction that the connectivity is believed to be improved. It was also argued that biodiversity will increase with the implementation of more green areas with a variety of vegetation. Grade 2 was given for after reconstruction. It was not given a higher grade, as Masthuggskajen will still be considered a district with limited biodiversity.

Something that was discussed was the importance to also implement permanent waters within the district, as some species need both green and blue environments. It was also noted that it is very important to consider whether habitats along the shore are being preserved, as there are legal requirements concerning this.

4.3.8 Valuation diagram

The semi-quantitative values that were given to the seven ecosystem services before and after planned reconstruction of Masthuggskajen in sections 4.3.1 – 4.3.7 were compiled in Figure 5.

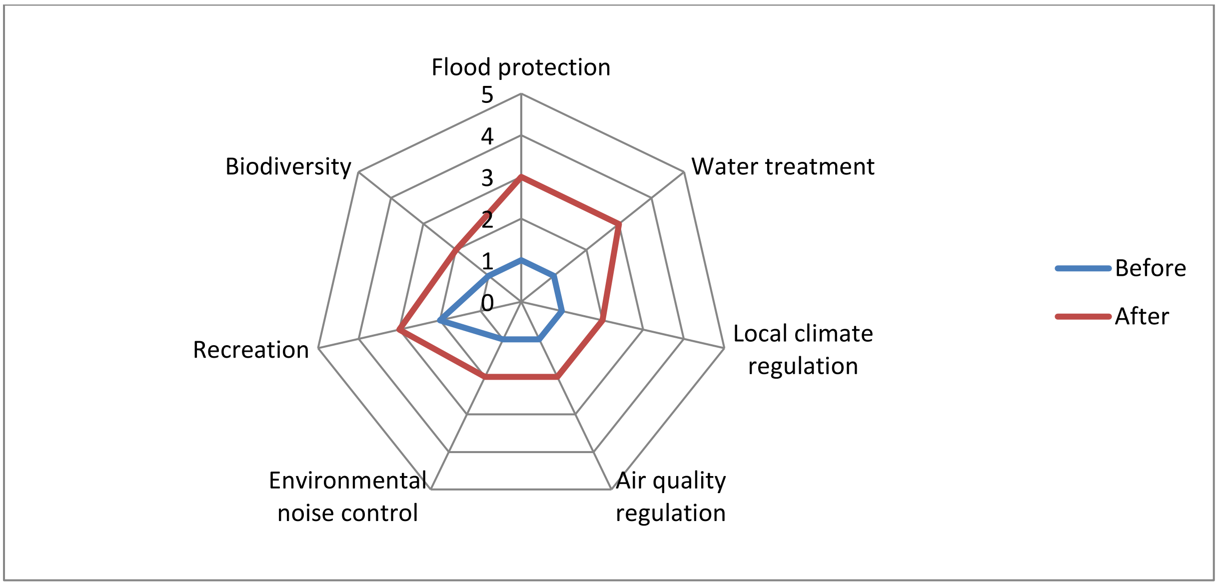

Figure 5. An illustration of what values seven out of nine ecosystem services were given during the workshop. Blue line represents the values given for present state and red line the values given for planned state of Masthuggskajen.

The BGI that are planned to be implemented in Masthuggskajen are expected to increase the presence of every ecosystem service discussed during the workshop. This is partly due to the very low presence of ecosystem services at present. Flood protection, water treatment and recreation are expected to be present in to an extent that is meeting requirements after the planned reconstruction, while the rest of the ecosystem services will not be present to an acceptable extent. This corresponds to the fact that the main purpose of the BGI being implemented was for stormwater management purposes.

5. DISCUSSION

The objectives of this thesis are discussed in separate subsections and then followed by a discussion about the workshop. This section then ends with a discussion on what is new in this report compared to present research.

5.1 WHICH ECOSYSTEM SERVICES CAN BE GAINED FROM BGI FOR STORMWATER MANAGEMENT?

Seven BGI were studied as a base for the project and nine ecosystem services were considered being provided by these BGI. The connections between the BGI and the ecosystem services were collected in Table 5, which was put together by examining the indicators for each ecosystem service, and then judging whether the different BGI had the potential to provide the right conditions for the ecosystem service to be provided. The table showed that every BGI solution could provide at least seven of the nine ecosystems to a small or greater extent (marked *x* and **X** in Table 5). This confirms that many added values can be provided when implementing any of the studied BGI. The table also showed that it is important to have a combination of BGI in the district to cover more ecosystem services better, as no BGI can provide all studied ecosystem services to a greater extent. It can also be noted that trees, rain gardens, and detention basins are the BGI that have the potential to provide a greater variety and extent of ecosystem services. A combination of these three BGI can provide all nine ecosystem services to a greater extent.

It is important to point out that even if a BGI and an ecosystem service have been matched in the table, the ecosystem service may not always be provided by that BGI. First, there needs to be a demand for the ecosystem service to exist. For instance, there is only a demand of the ecosystem service flood protection if there is a risk of floods. Secondly, maintenance of the BGI is needed for it to be able to provide the ecosystem services properly. For instance, if a rain garden were to get clogged without being treated, the rain garden would not be able to provide flood protection or water treatment. When choosing which BGI to implement in a district, it is therefore crucial to first study the needs of the district and secondly make sure that the maintenance of the BGI is performed properly.

There is also some uncertainty in how *x* and **X** were placed in Table 5. Many factors can affect to what extent the different BGI can provide the ecosystem services. The results in the table should be seen as general and theoretical and not transferable to all applied systems. The size of the BGI, its load, climate, and other interferences are factors that can affect to what extent the BGI can provide the ecosystem service.

Lastly, it is emphasized that the BGI solutions in this project can provide many more ecosystem services than the nine presented in this report but that they had to be excluded due to time constraints. For instance, educational and aesthetical values are two ecosystem services that were initially studied but had to be dropped due to time constraints. Other ecosystem services were excluded earlier in the selection process due to the district perspective. These services include water, both for drinking and non-drinking purposes, and carbon capture, which are services that were considered to suit a valuation at a city level better. Some services were excluded due to the urban perspective, as they were considered more important in rural settings, like pollination and raw material production. It can also be noted that if other BGI solutions would have been picked for this project, the selection of ecosystem services may have been a bit different.

5.2 WITH WHICH INDICATORS CAN THESE ECOSYSTEM SERVICES BE VALUED?

As explained briefly in section 3, step 3, focus was brought on indicators regarding the function of the ecosystem service rather than the potential benefits of the ecosystem service. It was still necessary to determine the demand for the ecosystem services; therefore, a list of questions was formed for each ecosystem service. These questions can also be seen as a type of indicators. However, when it came to valuing the presence of ecosystem services, it was better to solely value the indicators for the function of the ecosystem service, as there are many other factors that can affect the answer to the questions regarding the need for the ecosystem service.

Many of the indicators turned out to be similar for several services. For regulating ecosystem services, reoccurring indicators included *proportion of permeable/blue-green surfaces*, *tree canopy cover*, *type of vegetation* and *placement of BGI*. The type of vegetation preferred for the different BGI could differ, but in general, it was seen that a mixture of vegetation was preferred, and that evergreen vegetation elements were important to include to be able to obtain ecosystem services all year round. Regarding placement, it was often preferred to place the BGI close to the source of the problem that the ecosystem service could help to prevent. Indicators for the function of the cultural ecosystem services were set to *accessibility, quantity, and quality of the BGI* that provided the services. These were harder to provide valuation guidance for, especially for the indicator *quality of the BGI*, as the values must be based on personal preferences and therefore demands a dialogue with the public in intended area.

The recurrence of indicators means that synergies can be created when BGI is implemented. By implementing a few natural structures in the urban areas, many services can be obtained. This is the biggest advantage with BGI compared to gray infrastructure. For instance, if a well filter would be used instead of a rain garden, the same amount of water treatment can be achieved as for the rain garden, but many other ecosystem services would be missed out on. In some cases, however, conflicts can arise instead of synergies. For instance, placement of trees can work contradictorily for local climate regulation and air quality regulation. For local climate regulation, it was beneficial to place trees in a way that reduces wind speeds, but for air quality regulation, it was on the other hand argued that trees should not be placed so that the ventilation of air pollutions is reduced. In an applied project, it would then be necessary to discuss whether local wind regulation or air quality regulation should be prioritized in the given area.

The difficulty in selecting indicators was to know how many to choose and which to prioritize. Every ecosystem service could potentially be described with many more indicators (for instance, see Silvacom (2015)). In this project, selections were made throughout the literature study, by reading more about the functions of the ecosystem services and determining based on that which indicators that seemed more crucial. It felt more useful to have a selected few indicators, rather than to collect all possible indicators, since a valuation of all possible indicators would be too complex and time consuming. Another way of culling indicators was to study which indicators that would have data available in the investigations that are usually made for reconstruction projects. It is a necessity that data is available to be able to value the indicator properly. For this project, I did however not remove a seemingly important indicator if data were not available specifically for Masthuggskajen. I would have had to study more case studies to know what type of data is usually provided in investigations for planned constructions to know better which indicators that were more useful.

In the process of selecting indicators, there is a risk that useful indicators got culled. It could also be that some useful indicators were not even discovered. The indicators presented in the results cover a basis for a valuation of the ecosystem services, but if a user would find another suitable indicator it is encouraged for it to be added to the existing indicators. It is also important to emphasize that for valuing the cultural services a dialogue with the public is needed.

5.3 HOW CAN THESE INDICATORS BE VALUED ON A SCALE 1-5?

It was initially aimed to find general values for the grades of every indicator, making the valuation results comparable for a variety of places and projects. However, this could not be achieved in this project, as there were not enough previous research or investigations found that could be used as basis for such a valuation method. There are some valuation guides that give limits to indicators on a scale 1-5, like Cities Biodiversity Index (CBI, 2014), but all guides found were at a city level and not at a district level. Therefore, the guidance these provide could not be used in my thesis. It is also important to note that if it would have been possible to grade and value every indicator separately, a weighting of the indicators would have been needed when valuing the ecosystem service, as not all indicators are of the same importance.

Something that is lacking in general valuation guides like CBI (2014) is a connection to the conditions at a specific site. The demands for the ecosystem service and the fairness of implementing more BGI for this should in my opinion affect its value. For instance, if a district has a relatively small amount of local water treatment but still manages to fulfill the EQS for good water quality well, then there is no incentive to implement more BGI with the purpose of treating water. The ecosystem should then be valued to be present in a fair amount. By also adding the questions for the need of the ecosystem service into the valuation, the value can be more closely related to what added services that will be provided in the district, rather than just a valuation of the functions. Therefore, it is recommended to first determine the need for the ecosystem service and then value the present ecosystem functions to see to what grade the need is fulfilled or not.

It should also be discussed how reasonable it is to implement more BGI when goals for some ecosystem services are met but not for others. For instance, goals for water treatment and EQS for air quality may not be fulfilled along a major road. Say that one row of trees will be planted in between the major road and an adjacent pavement to detain and treat the stormwater running off from the road. This will be a reasonable and helpful mitigating solution also for the air quality, with regards to what BGI can provide on that street. The EQS for air quality may still not be reached after mitigating measures but the BGI is implemented where possible and needed. The problem here is rather that the sources of air pollutions are too high and cannot solely be solved with implementing more BGI. BGI is not expected to be the sole solution, but rather a multifunctional, complementary mitigating measure to conventional solutions for environmental problems. Therefore, a higher grade should be given the ecosystem service of air quality regulation when valued, as reasonable mitigating measures has been taken.

5.4 ANALYSIS OF THE WORKSHOP

The workshop that was held for the case study of Masthuggskajen gave some interesting insights. For every ecosystem service, it was discussed which indicator that was of most importance, to be able to settle its final value. It was solved in the workshop through discussions about what was important in Masthuggskajen. However, weighing of the indicators would be necessary to make this valuation guide more general, so that valuations of ecosystem services in different districts can be more comparable. Further studies of how to weight the indicators is therefore recommended. A report by Andersson-Sköld et al. (2018) was discovered at the end of this thesis that could provide support for further studies regarding weighting of indicators to ecosystem services. For instance, in the mentioned report the weighting was done by giving the different indicators *effectivity factors* on a scale 1-3.

Not all indicators could be valued easily, as clear data was not always available from investigations in the literature. For instance, investigations made on the air quality and the environmental noise in Masthuggskajen did not consider BGI at all. Only a few of the investigations made for Masthuggskajen did even mention the expression ecosystem services.

Ideally, investigations should state the effect of blue-green areas, i.e. the ecosystem services that they provide. It could be that this data is missing because there has not been made enough research in the field of ecosystem services. Since this data was missing in many of the areas, it would have been helpful with the presence of experts to be able to value all indicators more consistently. It was noted however, that with some knowledge of ecosystem services, and with the support of the guide above, it was possible to at least roughly estimate the occurrence of the ecosystem services if data on land usage was available.

This semi-quantitative valuation was considered useful for reconstruction projects at an early stage, to illustrate what functions and demands that need to be considered in order to obtain more ecosystem services and liveability. It could also be used for comparing different reconstruction proposals, to see which one provides more ecosystem services. The semi-quantitative valuation was experienced conceptual rather than specific by the participants. It was useful in the sense that it can include any type of ecosystem service but lacks the perspective of costs.

5.5 WHAT IS NEW?

In recent years, there have been several projects studying how ecosystem services can occur in urban areas. In addition, other projects have studied the advantages of introducing BGI for stormwater management in urban environments. A few known projects have to a greater extent studied which ecosystem services can arise when implementing BGI for stormwater management. What is new with this project is the broad compilation of indicators for these ecosystem services of which they can be valued; that is, to make clear which functions that are necessary for ecosystem services to occur in urban environments. The semi-quantitative valuation method in itself is not new, but the way it is proposed to work in regards of weighing the need for the ecosystem service against its occurrence is new at least to me. Another new perspective of this project is the district perspective, instead of the more typical city perspective, which makes it slightly more limited but in a sense also more manageable. To conclude, what has been studied in this project is not new in itself as it has been based on a literature study, but the broad compilation of indicators from scattered literature and the proposed valuation method is new in the purpose of promoting more sustainable stormwater management.

6. CONCLUSION

Nine ecosystem services were identified in a literature study to be able to be provided by BGI for stormwater management suitable at a district level. These were flood protection, water treatment, local climate regulation, air quality control, environmental noise control, erosion prevention, recreation, social relations and biodiversity. Indicators with a more technical point of view were collected, to showcase what functions are needed in urban environments for the ecosystem services to occur. Many indicators were similar for several ecosystem services, like *proportion of permeable surfaces*, *tree canopy cover*, *type of vegetation* and *placement of BGI*. For cultural services, indicators were *accessibility*, *quantity* and *quality of BGI* that provided the services. In addition to the function indicators, questions were presented, whose answers determine the need of the services, both at a societal and personal level. It is when the presence of the ecosystem functions matches or exceeds the need for the ecosystem services that liveability can be obtained. A simple semi-quantitative valuation method was created to illustrate how well the presence of the ecosystem service matched its demand. This method is considered useful for reconstruction projects at an early stage, to demonstrate which ecosystem services are present at a desired level, and which ecosystem services that could need more focus.

BGI for stormwater management has in this report been shown to be able to provide the studied ecosystem services and could therefore help create liveability in urban areas. It is important to point out that BGI is not meant to replace all conventional solutions, whether it comes to flood protection, water treatment or any of the other services studied in this thesis. BGI is rather intended to be a multifunctional complement to already present infrastructure to be able to cope with the challenges of more precipitation and pollutions in urban areas.

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APPENDIX 1: GROSS LIST OF ECOSYSTEM SERVICES

Different types of ecosystem services presented in MA (2005), TEEB (2010) & CICES (2013) have been put together in Table A1.

Table A1. A gross list of ecosystem services, divided by category.

Category	Ecosystem service	Source
Provisioning	Food	MA/TEEB/CICES
	Fresh water	MA/TEEB/CICES
	Raw materials (incl. fuel)	MA/TEEB/CICES
	Genetic resources	MA/TEEB/CICES
	Medicinal resources	MA/TEEB
	Ornamental resources	MA/TEEB/CICES
Regulating	Air quality regulation	MA/TEEB/CICES
	Climate regulation	MA/TEEB/CICES
	Moderation of extreme events	MA/TEEB/CICES
	Regulation of water flows	MA/TEEB/CICES
	Waste treatment	MA/TEEB/CICES
	Erosion prevention	MA/TEEB/CICES
	Maintenance of soil fertility	TEEB/CICES
	Pollination	MA/TEEB/CICES
	Seed dispersal	CICES
	Biological control	MA/TEEB/CICES
	Water treatment	MA/TEEB/CICES
	Noise regulation	CICES
Cultural	Aesthetic values	MA/TEEB/CICES
	Recreation	MA/TEEB/CICES

	Tourism	MA/TEEB
	Inspiration for culture, art & design	MA/TEEB
	Spiritual experiences	MA/TEEB/CICES
	Education	MA/TEEB/CICES
	Cultural heritage	MA/TEEB/CICES
	Social relations	MA
	Sense of place	MA/CICES
Supporting	Maintenance of biodiversity	TEEB
	Photosynthesis	MA/TEEB
	Primary production	MA/TEEB
	Soil fertility	MA/TEEB/CICES
	Nutrient cycling	MA/TEEB
	Water cycling	MA/CICES
	Maintaining nursery populations and habitats	TEEB/CICES