Master Thesis in Geographical Information Science nr 54

The Right Tree in the Right Place: Using GIS to Maximize the Net Benefits from Urban Forests

Sean Grant

2015
Department of
Physical Geography and Ecosystem Science
Centre for Geographical Information Systems
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

Sean Grant (2016). The Right Tree in the Right Place: Using GIS to Maximize the Net Benefits from Urban Forests
Master degree thesis, 30 credits in Master in Geographical Information Sciences
Department of Physical Geography and Ecosystem Science, Lund University

The Right Tree in the Right Place: Using GIS to Maximize the Net Benefits from Urban Forests

Sean Grant
Master thesis, 30 credits, in Geographical Information Sciences

Dan Metcalfe
Dept of Physical Geography and Ecosystems Science

Abstract

What is a tree worth and what benefits can it provide to the urban environment? Aside from practical monetary approaches to valuing trees there are many other factors to consider when evaluating a tree's true value. Trees provide many ecosystem services to a well functioning urban ecosystem which are easily overlooked in urban planning and decision making processes. The topic of ecosystem services is not new, and already there are tools available to aid in setting monetary values on the services provided by trees in the urban environment. In addition to the aspects which can be measured within an acceptable margin of error, such as energy savings, there are other aspects worth considering which are not as easily quantifiable. Geographic Information Systems (GIS) has the ability to combine both the spatial aspects influencing a tree's estimated value, such as conflicts with infrastructures, with non-spatial aspects, such as cultural and aesthetic values, in order to provide a realistic and usable picture of a tree's true worth. The versatility of GIS systems, in the sense that multiple analyses can be produced once the initial data has been collected, allows for the inclusion of a variety of cultural based values as a complement to the concrete values such as position and species choice. GIS can not only aid in tree choice and placement, by accounting for the trade-offs associated with the costs and benefits of trees in the urban landscape, but can also be used to plan and carry out maintenance in order to maximize the ecosystem services provided by trees.

Within the scope of this study landscape plans are assessed and analysed with respect to the potential ecosystem services provided by trees measured in Service Providing Units (SPU's). SPU's can be described as spatial units forming a grid placed over the study area, each unit being assigned an individual value of ecosystem services. In order to quantify and measure the SPU's, a tree database and ecosystem service valuation model is employed which is based on the Stockholm Royal Seaport Green Area Factor (GAF). GAF is a system of evaluating outdoor surface areas based on the characteristics which contribute to minimizing the negative effects of climate change, increasing the social value of the space while also promoting high levels of biodiversity.

Different scenarios are modelled in order to quantify the differences found within the SPU's based on tree choice and location. A key result of this study is the importance of maximizing the total values of SPU's by correct plant choice in order to fill all available space with ecosystem services while minimizing the SPU's lost due to conflicts with infrastructure.

Background information is provided on the topic of ecosystem services and more specifically the ecosystem services provided by trees based on species characteristics. How this information was used to create a species database of trees, where the service providing characteristics of these trees are expressed in GAF terms, is described. A number of questions concerning the usability and reliability of these methods are raised and discussed.

Sammanfattning

Vad är egentligen ett träds fulla värde och hur bidrar ett träds ekosystemtjänster till stadsmiljön? Det är de två huvudfrågorna som denna masteruppsats syftar till att besvara. Idag finns det olika sätt att värdera ett träds värde i stadsmiljö. Förutom det mest vanliga, till exempel kostnaden i pengar för att ersätta ett befintligt träd, finns det många andra aspekter att ta hänsyn till. Urbana träd och tätortsnära skogar bidrar med en rad viktiga ekosystemtjänster, såsom förbättrad luftkvalitet, vattenavrinning, avkylning, förbättrat mikroklimat, ökad biologisk mångfald samt många fler därtill. Trots att det finns tillgängliga verktyg på marknaden för att värdesätta många av dessa ekosystemtjänster, förbises dessa alltför ofta i stadsplanering och i beslutsprocesser. Därtill finns det ytterligare ett flertal aspekter som är svårare att kvantifiera och värdera.

Den här masteruppsatsen undersöker hur Geografiska Informations System (GIS) kan användas för att kvantifiera och maximera det fulla värdet av träd i stadsmiljö. Genom att använda olika GIS-analyser i kombination med en träddatabas som baseras på Stockholm stads verktyg och koncept ”Grönytefaktorn (GYF)” som används bland annat i stadsutvecklingsprojektet Norra Djurgårdsstaden i Stockholm, har en modell skapats som används till att analysera det totala värdet av träds potentiella ekosystemtjänster i en detaljplan. Trädens egenskaper uppskattas och kvantifieras utifrån de ekosystemtjänster de tillhandahåller, vilket presenteras i enheten ”Service Providing Units” (SPU’s). Utifrån informationen skapas olika scenarion där skillnaderna i SPU’s framgår baserat på val av trädart och dess placering i stadsmiljön. Uppsatsen ger vidare en introduktion till innebörden av ekosystemtjänster där ett specifikt fokus ligger på ekosystemtjänster från enskilda trädarter. I metodavsnittet beskrivs hur denna bakgrundsdata har används för att skapa en databas över enskilda trädarters egenskaper i förhållande till GYF samt hur dessa används i en analysmodell. Frågor kring modellens applicerbarhet, tillförlitlighet och användningsområden tas slutligen upp och diskuteras.

The Right Tree in the Right Place: Using GIS to maximize the net benefits from urban forests.

Contents

List of tables

List of figures

List of Abbreviations

BVOC - Biogenic Volatile Organic Compound
CSV - Comma Separated Values
CAD - Computer Automated Drafting
GIS - Geographic Information Systems
GAF - Green Area Factor
JAS - July, August, September (pruning period)
LAI - Leaf Area Index
MDC - Mobile Data Collection
MCA - Multi-Criteria Analysis
SPU - Service Providing Unit
UFORE - Urban Forest Effects

CO_2 - Carbon dioxide
NO_2 - Nitrogen oxide
O_3 - Ozone
PM_{10} - Particulate Matter of less than 10 millionths of a meter (10 micrometers or 10 um) in diameter
SO_2 - Sulfur dioxide

1. Introduction

Nature provides many services which people are dependent upon but often take for granted. It is rare that the value of these services is included in the economics of development. Trees, for example, offer a setting for recreation and exercise, shade on a hot day or protection from the wind on a cold one. Trees reduce and regulate ambient air temperatures through transpiration and, in the process of photosynthesis, produce oxygen and use and store carbon dioxide. Trees can be considered permanent structures in our built environment whose lifetime can span over generations. Due to this permanency the use of trees in the built landscape should be well planned in order to get the most out of the ecosystem services trees provide while at the same time minimizing the costs, or disservices, associated with them. The following pages describe the ecosystem services from trees in detail and suggest a method which can be used to account for and analyze these ecosystem services in order to make informed landscape planning decisions.

The topic of ecosystem services has been widely discussed and studied in recent years. Two noteworthy examples are the publication of The Corporate Ecosystem Services Review aiming to mainstream ecosystem services into private sector decision making (Hanson et al., 2012) as well as the decision in Sweden where a new strategy was put in place at the national level to incorporate the integration of ecosystem services in urban planning by providing guidance and support to municipalities and other authorities who influence the planning process (Keane et al., 2014). These initiatives raise the question of how ecosystem services can be valued and the different ways their value can be incorporated into the planning and decision making process.

Geographic Information Systems (GIS) is well suited to this type of challenge and by focusing on urban trees, was used in the course of this study to evaluate the potential that trees have to provide ecosystem services within proposed landscape developments. Both the placement of the tree and the species chosen is important and influences the total value of ecosystem services provided. Poor placement and species choice can affect the levels of ecosystem services provided through conflicts with infrastructures, by not allowing for maximized energy saving benefits when placed near buildings and by limiting air quality improvements or storm water interception when compared to other species or placement scenarios. In the course of this study different GIS tools and techniques were employed and the results expressed using a valuation method described in the Stockholm Royal Seaport Green Area Factor (GAF) model, which is a method used to evaluate the surfaces of planned landscapes from an ecosystem service perspective.

1.1 Objectives

The motivation for this research stems from the fact that all too often poor choices of landscape trees and placement lead to conflicts. By proper planning and analyzing different scenarios the right tree in the right place can both maximize the ecosystem services provided as well as the vitality and longevity of the tree. It will also be demonstrated that not taking proper consideration to tree choice and placement can result in measurable losses. These losses are incurred in the form of added maintenance costs and reduced levels of ecosystem services provided by the trees.

The main questions to be addressed within the context of this study are:

1. How can Geographic Information Systems (GIS) be used to evaluate the potential ecosystem services provided by urban trees and incorporate these into a Green Area Factor (GAF) assessment?

2. How can the characteristics of tree species that contribute to ecosystem services, such as water interception, air quality improvements and temperature moderation, be incorporated into the GAF model?

3. How can common GIS tools and spatial analysis methods, such as buffers and overlays, be used within the GAF analysis to provide different scenarios and models which can aid in the landscape planning process?

4. Are these methods realistic and do they have the potential to aid in the landscape planning process with respect to incorporating ES into urban planning?

The main objective of this paper is to evaluate the possibilities of using GIS technologies to estimate and maximize the ecosystem services provided by trees in the urban environment.

2. Background

Projects such as C/O city (Care of City), a research and development project dedicated to inspiring, convincing and creating new tools to aid in building cities where society and nature can exist together, are a positive force in introducing the concept of ecosystem services into modern day urban planning discussions. Their goal is to educate, inform and guide planners and decision makers, such a municipal governments and city planners, on the importance of ecosystem services by providing information about what factors should be considered and what tools are available in order to include ecosystem services in the planning process. Their document, Ecosystem Services in City planning - a Guide (Keane et al., 2014), is an excellent example of how the importance of ecosystem services can be conveyed to audiences of varied backgrounds and previous knowledge of the fundamentals behind ecosystems and ecology. By using simple and clear texts in combination with visually stimulating diagrams and pictures, the basics of ecosystem services in urban areas can not only be understood but also their importance better appreciated.

2.1 Overview of Ecosystem Services

There are many ecosystem services provided by natural systems. According to the Millennium ecosystem assessment and also outlined in the C/O City guide, ecosystem services are usually divided into four categories, supporting, regulating, cultural and provisioning (Millenium Ecosystem Assesment Board, 2005).

Supporting services provide the ground work for the other three services relevant in urban environments listed below. The following examples are not necessarily ecosystem services but are nevertheless important parts of well-functioning natural ecosystems which in turn support other vital functions:

- Biodiversity, ecological interactions, habitats and soil management.

Regulating services influence nature’s ability to regulate and mitigate undesirable effects caused by both natural and artificial processes. Examples include:

- Air quality regulation, sound dampening, water filtration, climate regulation, pollination and protection against extreme weather.

Cultural services are vital as only people benefit from them and the state of our ecosystem is most apparent when it affects our health and wellbeing. This is based on the realization that the healthier we are as a society reflects on our economic wellbeing and standard of living. Examples include:

- Health and physical activity opportunities, stimulation of our senses, social interaction, symbolic and religious associations with nature.

Provisioning services include material things that society benefits from such as food production, clean water, building materials and fuels. Services can easily overlap such as how gardening can be culturally based but also provide food. Notable examples are:

- Food production, fresh water, material and energy

After providing a description of the concept of ecosystem services as described by the Millennium Ecosystem Service Assessment, outlining those most relevant in the urban environment, the Ecosystem Services in City planning guide provides a few concrete examples of ecosystem services at work in real life which are noteworthy and inspirational. One example used in the Swedish context is the case of the Common Jay, spruce and oak forests. The proliferation of oak forests is of course desirable, as it is well known that old Oaks are a rich source of both direct and indirect ecosystem services. An old Oak can provide a habitat for 2000 different types of organisms of which a quarter would otherwise die out if it weren't for the existence of the oak species (Tell, 2008). This type of landscape exists in the Stockholm Royal Seaport region and is flagged as a landscape type to protect and encourage and for this reason Oaks score highly in the GAF point system. A Spruce, in comparison, is less desirable, at least in the urban context. Spruce is weakly rooted, doesn't tolerate pollution well and can have an understory with low levels of species diversity. The Spruce stands, however, are a preferred nesting site for the Common Jay, which in turn provides an ecosystem service to Oak propagation by transporting the oak nuts to other areas. This example is not intended to argue which type of urban forest is preferable but rather an example to illustrate the importance, and sometimes unapparent connections, between natural systems.

The C/O City guide more importantly outlines and describes a working process which can be used to incorporate ecosystem services into the planning process. According to this process first the current situation and future scenarios are identified while important questions are posed, such as which ecosystem services are currently present and which are not. Also identified are which ecosystem services are important to the area, such as Oaks in the Stockholm Royal Seaport context, keeping in mind different spaces can have different needs based on their function. The next step in the process is the assessment where the results of the identification step are analyzed. At this stage the ecosystem services which need to be protected are identified while potential conflicts with the ambitions of the project plans noted. Decisions will be needed with respect to ecosystem service creation, protection and strengthening within a project plan. In some cases it may be unviable or even impossible to protect certain ecosystem services and then the decision may be made to exclude this service entirely. The final execution stage utilizes the answers found in the identification and assessment processes in order to implement the plans in reality.

2.2 Evaluating and quantifying ecosystem services

The notion of create, protect, strengthen or skip, as suggested by C/O City (Keane et al., 2014), is closely related to a collection of other ecosystem service evaluation systems collectively known as the i-Tree suite. The suite is comprised of a group of programs developed by the US Forestry Service designed to evaluate urban forests with respect to ecosystem services. The Species Selector Beta Utility, for example, is designed to aid in the selection of an appropriate tree species to plant based on criteria entered by the user with respect to which ecosystem services are most important. The Species Selector Beta Utility user manual document describes in detail the methods used as a basis for rating trees and their potential to provide ecosystem services. The utility compiles and rates characteristics such as leaf size and tree species into a database which then allows the user to specify the types of ecosystem services desired and are subsequently supplied with a list of suitable species.

In the context of this study most of the supporting knowledge behind the concept of the ecosystem services provided by trees and more specifically which tree characteristics are important to consider when evaluating a tree species is based on the Urban Forest Effects (UFORE) model (Nowak and Crane, 1998) which is comprised research based on the collaboration of different organizations employing algorithms and sub-models which, within a reasonable margin of error, can estimate a monetary value of the ecosystem services provide by a single tree or an entire urban forest. These models, however, are limited to estimating concrete ecosystem services based on costs and climatic inputs for specific sites and specific studies. The models are less able to evaluate many of the aesthetic and cultural values provided by trees, for example, the recreation value provided by an urban forest.

To complement the theories behind the ecosystem services outlined by UFORE, this study employs a valuation system based on Stockholm Royal Seaport GAF, which takes into consideration not only the type of surface, such as pervious or impervious, but also what the surfaces are used for, such as a place for recreation or social activities. The GAF is expressed as a numeric value which provides a ratio of eco-effective surfaces (or in other words surfaces which allow water to filter through slowly, such as grass or gravel, in contrast to water tight surfaces, such as asphalt) over the entire surface area. Also incorporated in this ratio are the social and recreational aspects as well as vegetation levels. It is the combination of these aspects which makes GAF appealing to this project. As mentioned, the Stockholm Royal Seaport GAF used is originally an environmental program developed for the sustainable development of the Stockholm Royal Seaport project. The GAF concept was first introduced in Germany and has since spread to other European cities. It is the intention of the Stockholm Royal Seaport program to address the negative effects of climate change, increase the social value of the space, as well as promote a high level of biodiversity within the landscaped areas associated with a new development (Stockholms Stad, 2011). The project document describes the program in detail where, in short, surfaces are assigned a base factor and then supplementary values based on the surface’s eco-effective qualities with respect to the climate-smart effects of vegetation, that is to say how vegetation can contribute to air purification and water interception as well as natural surface run-off based on material choice or construction methods. The base factors are divided into two eco-effective categories, surface run-off and vegetation, and the supplementary values are divided into three categories representing the recreation value, biodiversity and climate-smart effects. Within this matrix an area can receive points for more than one eco-effective characteristic. The end result is a GAF value expressed as a ratio of the eco-effective area over the projects total area. In the context of this study the Stockholm Royal Seaport GAF is employed as a valuation system for comparison purposes and no real ratios or factors are calculated in the sense that they were intended for the Stockholm Royal Seaport project.

2.3 Costs and benefits associated with trees and their placement

The net ecosystem services provided by trees can be maximized by giving proper consideration to the placement with respect to infrastructures (McPherson et al., 2007). Ecosystem services can be maximized, or potentially compromised, by a trees position with respect to its surroundings. Generally speaking storm water interception, pollution uptake and energy savings are 2-4 times greater than the costs associated with tree care operations (McPherson et al., 2007). Of these benefits, yard trees, that is to say trees standing on private property, provide higher net benefits due to the lower maintenance costs compared to street trees, that is to say municipally owned trees, whose requirements for maintenance and the subsequent costs are greater (McPherson et al., 2007). Tables 1 and 2 outline the costs and benefits associated with urban trees.

Table 1 - The benefits provided by trees.

Benefits	Description
Saving Energy	Trees can modify climate and conserve building energy by shading (reduces energy absorption), evapotranspiration (the process uses solar energy which subsequently cools the air), and by reducing wind speed (mitigates infiltration and heat loss) (Akbari et al., 2001)
Reducing CO_2	Trees directly sequester CO_2 in stems and leaves while they grow. Trees near buildings reduce heating and cooling costs subsequently lowering emissions associated with power production (McHale et al., 2007)
Improving air quality	Trees absorb gaseous pollutants (e.g. O_3, NO_2 and SO_2) through leaf surfaces. Trees intercept PM_{10} (e.g. dust ash, pollen, smoke) and release oxygen through photosynthesis. Transpiration of water and shading of surfaces subsequently lowers air temperatures thereby reducing O_3 levels. Trees reduce energy use which reduces emissions of pollutants from power plants including NO_2, SO_2, PM_{10} and BVOCs. Trees reduce evaporative hydrocarbon emissions and O_3 formation by shading paved surfaces and parked cars (Nowak et al., 2006)
Reducing storm water runoff	Leaves and branch surfaces intercept and store rainfall thereby reducing runoff volumes and delaying peak flows. Roots increase the rate at which rainfall infiltrates soil as well as the soil's storage capacity. Trees reduce soil erosion by reducing the impact of the raindrops on barren surfaces. Transpiration through leaves reduces soil moisture content thereby increasing the soil's capacity to store rainfall (McPherson et al., 2007).
Aesthetics and other benefits	Urban trees improve the aesthetic aspects of urban environments (Smardon, 1988) promote physical activity (Kaczynski and Henderson, 2007) and nearness to natural settings can reduce crime rates (Kuo and Sullivan, 2001b) and aggressive behaviors (Kuo and Sullivan, 2001a)

Table 2 - The costs associated with trees.

Costs	Description
Planting and maintaining trees	Municipal and residential costs of tree care. Residential costs are not well documented and can vary but it can be said to be less than half of the municipal costs per tree (McPherson et al., 2007).
Conflicts with urban infrastructure	Trees can damage sidewalks or interfere with overhead power lines. Trees planted to close to buildings can damage facades while roots can interfere with fundaments and sewers lines. The use of street trees as a design element can result in maintenance costs due to repair and damage to physical infrastructure (Bloniarz, 2011)
Wood salvage, recycling, and disposal	Costs associated with hauling, grinding and chipping tree waste. Tree waste can be sold in the form of mulch, firewood, and milled lumber. Contractors can break even or minimize the costs to less than 1 percent of the total tree care costs (McPherson et al., 2007).
VOC emissions	Trees emit biogenic volatile organic compounds (BVOCs) such as isoprenes and monoterpenes which contribute to O_3 formation. Formation can be variable due to climatic factors. (McPherson et al., 2007) The emission amounts depend on vegetation genus, leaf dry weight biomass, air and leaf temperature and other environmental factors (Hirabayashi, 2012).

To minimize tree program costs less expensive stock can be used where appropriate as well as by training volunteers to partake in tree stewardship programs(McPherson et al., 2007). Pruning early and matching the tree to the site are two other suggestions to keep costs down (McPherson et al., 2007). Tree placement can be used to maximize the benefits from trees, for example, placing trees on the west side of buildings provides shade when energy prices are highest. The east side of buildings is the next most important with respect to tree placement when considering net energy saving effects (McPherson et al., 2007). Choosing solar friendly trees is also recommended so that shade is maximized in the summer when it is warm and minimized in the winter when solar energy from the sun can warm buildings and reduce heating costs (McPherson et al., 2007). As a rule of thumb, the optimal placement of trees within the vicinity of buildings in order to maximize energy saving ecosystem services is 3-6m on the south side and 9-15m on all other sides (McPherson et al., 2007). It is not recommended to plant within 3m of buildings due to the risk that roots will interfere with the foundation (McPherson et al., 2007). Table 3 outlines the variables considered with respect to tree placement while Table 4 outlines the characteristics specific to tree species which can be used to maximize net benefits of tree plantings.

Table 3 - Overview of the spatial relationships incorporated into the analysis.

Spatial Relation	Service/Disservice	Determining Factors	Motivation
Trees and buildings	Service	Trees placed within 3-6m on the south side, 9-15m on all sides	Trees shading buildings with a high energy consumption due to their size and age can influence the energy consumption to a greater degree (McHale et al., 2007)
Trees and buildings	Disservice	Trees not placed within 0-3m of buildings	Roots from trees placed too close to buildings can interfere with the underground infrastructure while also requiring hard pruning to avoid growing against, and potentially damaging, the face of the building (McPherson et al., 2007).
Trees and roads	Service	Locate trees along busy roads with air quality problems	Trees along busy roads can help intercept harmful particles which are then washed away to the storm water system (Forman, 2014)
Trees and roads	Disservice	Poor species choice	Little research has been done on the role of trees and traffic safety (Bratton and Wolf, 2005) however the litter from certain trees and obligatory clearance pruning can increase maintenance costs along roadways.
Trees and hard surfaces	Service	Trees with adequate gowning space growing over impermeable spaces	Trees can intercept rain water which would otherwise run-off these surfaces reducing the peak flows during precipitation events(Hirabayashi, 2013). Tree shading over these surfaces can reduce long term maintenance costs of the surfaces by reducing the heat absorption of the surface which can cause premature wear (McPherson et al., 2007).
Trees and hard surfaces	Disservice	Inadequate growing space or positioning causing conflicts with infrastructures	The wrong tree can interfere with the hard surfaces, for example roots systems damaging sidewalks (Bloniarz, 2011) The tree not having enough roots space also leads to a less vital tree due to water and O_2 limitations (Embrén et al., 2009). In these case methods such as structural soil techniques can be employed were the soil bed is limited.

Table 4 - Overview of the characteristics used to evaluate the ecosystem services provided by trees.

ES Category	Characteristic	Ecosystem Service
General	BVOC's	Some trees can emit Biogenic Volatile Compounds (BVOC's) which can negatively affect the air quality. (McPherson et al., 2007)
	Habit and form	The form of the tree influences the surface area covered by the crown and subsequently the ES provided. Hydrologic, air quality and energy savings are linked to crown volume, leaf area and crown area as well a tree height (Peper et al., 2001).
	Water usage	The amount of water needed by a tree affects the respiration rate and subsequently the uptake of greenhouse gases and cooling effects as a positive climate regulating benefit of the process (Nowak, 2008).
	Tree type	Deciduous trees are more solar friendly in the winter months but otherwise evergreens provide certain benefits year-round (McPherson et al., 2007).
Particle interception	Leaf type	Complex leaf types intercept more harmful particles in the air to then be washed away by rain events (Nowak, 2008).
	Edge type	Complex leaf types intercept more harmful particles in the air to then be washed away in rain events (Nowak, 2008).
	Leaf top	Hairs, unevenness and stickiness intercept more harmful particles in the air to then be washed away in rain events (Nowak, 2008).
	Leaf bottom	Hairs, unevenness and stickiness intercept more harmful particles in the air to then be washed away in rain events (Nowak, 2008).
Water Interception	Bark texture	Rough uneven bark holds more intercepted rain water in the tree which can evaporate instead of entering the run-off system (McPherson et al., 2007).
	Leaf size	The total leaf area combined with course surfaces and small gaps increases the amount of water intercepted then evaporated back into the atmosphere (McPherson et al., 2007).

As the GAF value is not intended to be expressed as a ratio of the eco-effective surfaces over the total area, a unit of measure was required to describe the pixel value provided by the layer overlays. Service Providing Units (SPU's) provided a suitable way of expressing the outputs of the GIS raster analysis where the pixel and SPU are one and the same and are ultimately the sum of the GAF values for all pixels in the study area. A non-monetary approach was desired for the project as simply mapping and assessing the ecosystem services does not adequately address the supply and demand (Wurster and Artmann, 2014) which plays a pivotal role in the decision making process. Furthermore, there is the desire to contrast these services with their need by urban residents (Bolund and and Hunhammar, 1999) and to this end the GAF is found to be a suitable system of combining the elements of land cover, land use and need into a single layer.

3. Methodology

The methodology behind this research project is divided into two major parts, the creation of a GAF tree database and then using the database to carry out the ecosystem service analysis first at a large scale, where a single development project was chosen, then again at a small scale where an entire district was analyzed.

3.1 Description of the study area

Annedal is a district of Bromma in the Stockholm region (see Figure 1) previously home to Mariehälls Industrial Park. The district has been developed in stages with the first residents moving in in 2011. Annedal is scheduled to be completely developed in 2016 with a total of 5000 new residents as well as business properties, new parks and a school (Stockholms Stad, 2016). The area is bordered by Ulvsundavägen to the west and Bällstavägen to the south. Tappvägen provides a rough border to the east though there are properties located further east in an area known as Linaberg. The northern section of Annedal is clearly marked by small stream, Bällstaån, which widens into Ulvsunda, a bay of the larger bodies of water collectively referred to as Mälaren. Due to the history of industrial activities in the region Bällstaån is known for is poor water quality. Water quality studies conducted in 1983 and again in 2003 found high levels of unwanted metals and other organic compounds though after visits to the surrounding industries and implementation of 22 environmental improvement protocols the water quality is improving (Andersson, 2004). The stream has a high level of biodiversity in the form of a wetland landscape which can be experienced by local residents along pathways and wood deck walkways. The developments located alongside the wetlands are generally characterized by landscapes that build on the wetland theme using native plants and hard surfaces built with as little negative influence as possible. There is also a forested area within Annedal which is characterized by Oak, Pine and Aspen trees. This area also has paths and play areas incorporated into it which are well used by local residents especially the many schools and preschools located nearby. Aside from these two natural areas the rest of the Annedal area has been heavily excavated in preparation for the planned developments. Fill from these excavations was used to landscape Lönnebergaparkens rolling terrain which functions both as a visual barrier and sound barrier from the neighboring motorway Ulvsundavägen. Also located between the developments and Ulvsundavägen is a section of city gardening lots which have existed in this spot since the forties (Larsson, 2007). One particular development, Kulla Gulla, was chosen to be studied in detail while the detail level of the study of Annedal as a whole is more general. The study area is located in a humid continental climate which can be subjected to large seasonal temperature differences.

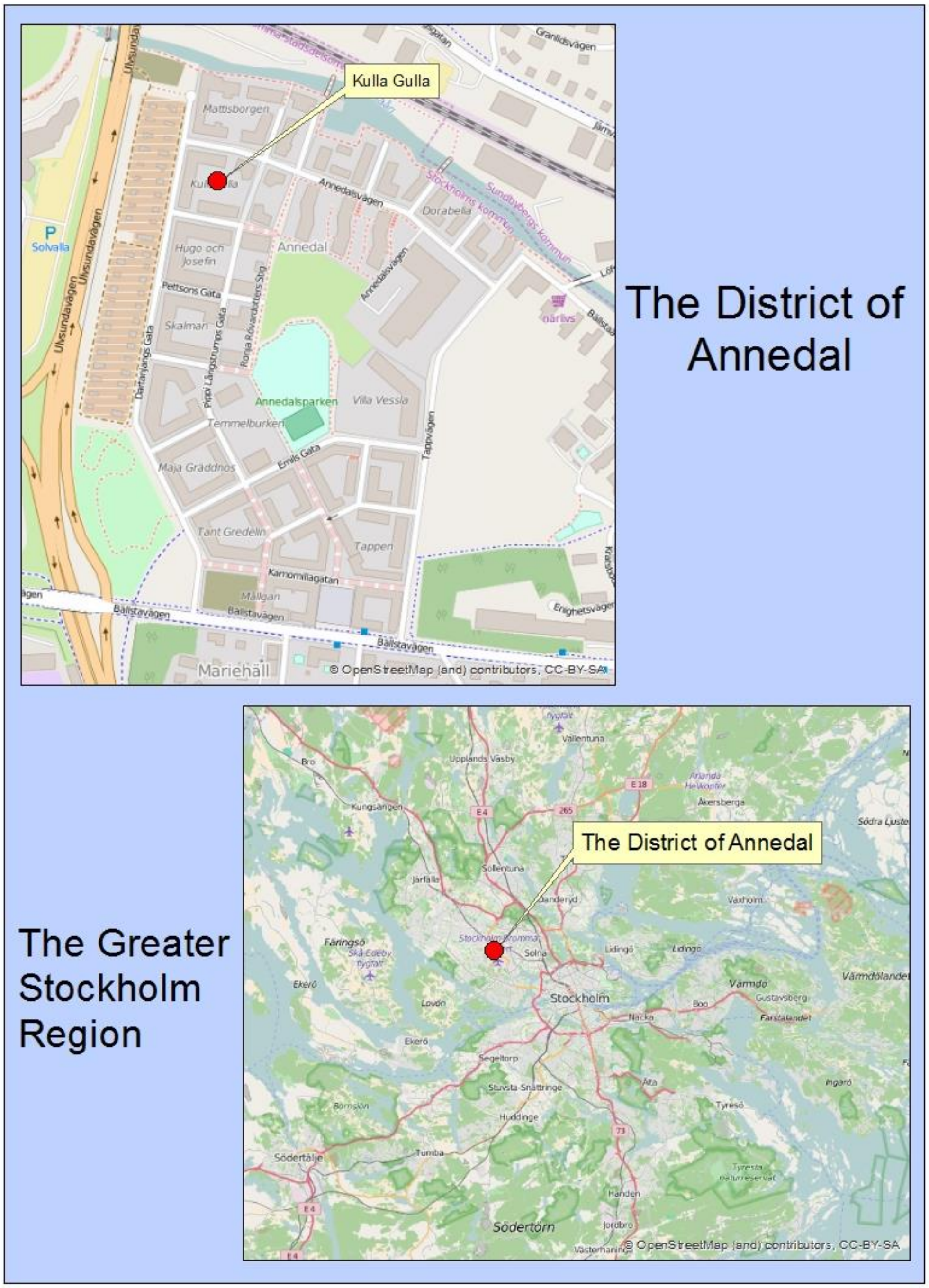

Figure 1 – Orientation map of the study area.

3.2 Species specific tree database

Creating the tree database was a work intensive portion of the project where data from many different sources was manually collected and inserted into an Excel worksheet to then be converted into a database file used within ArcGIS. It was important to have reliable sources for the tree characteristic data using similar terms throughout the entire range of trees in the database. The main sources used in the creation of the database can be found in Table 5.

Table 5 - Summary of the resources used to build the species database.

Tree Characteristic	Source
Tree Code	Borrowed from i-Tree, new codes created where no i-Tree code was available
Latin Name	Botanica, Beskärningsboken and Stångbykatalogen
English Common Name	Botanica
Swedish Common Name	Beskärningsboken and Stångbykatalogen
Volatile Organic Compound (VOC) Emissions	U.S. Department of Agriculture, Forest Service, Northern Research Station
Habit and Form	University of Connecticut, Plant Database
Water requirements	Horticopia Plant Database
Bark texture	The Book of Leaves
Tree type	Botanica
Leaf type	The Book of Leaves
Leaf edge characteristics	The Book of Leaves
Leaf top characteristics	The Book of Leaves
Leaf bottom characteristics	The Book of Leaves
Leaf size	The Book of Leaves
Tree height (min)	Stångbykatalogen
Tree height (max)	Stångbykatalogen
Tree spread (min)	Stångbykatalogen
Tree spread (max)	Stångbykatalogen

Botanica (Page and Olds, 1997), Beskärningsboken (Vollbrecht et al., 2001), Stångbykatalogen (Stångby, 2011/2012), The Book of Leaves (Coombes, 2010), Horticopia Plant Database (Horticopia), Plant Database (Connecticut), VOC emissions (Nowak et al., 2002)

196 tree species are included in the database which explains why it made up the bulk of the workload for the beginning of the project. This many tree species was not needed to conduct the study but in order to create the basis for a usable tool in the future as many trees as possible were researched. There are many more tree species which could be added, especially with the increasing use of uncommonly planted species in the urban landscape in order to increase biodiversity levels and reduce the homogeneity of the urban forest. Biodiversity within the urban forest has become a topic of interest and should also be considered within an urban planning context. It has been demonstrated that even small city gardens support much the same invertebrate wildlife as large suburban ones (Cameron et al., 2012) and the basic building block for supporting these species is the surrounding ecosystem where trees can play an important role. Care should be taken to avoid introducing invasive species into the urban forest (there are databases available, such as the Horticopia Plant Database, which can provide information on the invasive tendencies of a species) but otherwise a mix of trees species, even using non-native species, can be considered beneficial to the total value of the green space.

Table 6 - Summary of the rating scale used to rate the species characteristics where larger values positively influence ecosystem service levels. Scales of 0 to 2 were used to rate the different tree characteristics where a 0 represents a characteristic which provides little benefit with respect to ecosystem services, 1 provides moderate benefits and 2 provides the greatest.

Ecosystem Service Category	Characteristic	Scale	Scale Description	Value
General	VOC	0 to 2	high VOC emissions rate	0
			medium VOC emissions rate	1
			low VOC emissions rate	2
	Habit and form	0 to 2	columnar, oval	0
			rounded, pyramidal	1
			spreading	2
	Water usage	0 to 2	dry	0
			moist	1
			wet	2
	Tree type	1 to 2	deciduous	1
			evergreen	2
Particle interception	Leaf Type	0 to 2	simple	0
			pinnate	1
			needle	2
	Edge Type	0 to 2	toothed or null	0
			lobed	1
			leaflets	2
	Leaf Top	0 to 2	smooth, glossy	0
			rough, hairy on veins, indented, leathery	1
			hairy, densely hairy, sticky	2
	Leaf Bottom		smooth, glossy	0
			rough, hairy on veins, indented, leathery	1
			hairy, densely hairy, sticky	2
Water Interception	Bark texture	0 to 2	smooth, lenticils	0
			fissured, flaking, cracking, peeling, scaly	1
			rugged, deeply fissured, furrowed, blocky	2
	Leaf size	0 to 2	small total leaf area	0
			medium total leaf area	1
			large total leaf area	2

Once the physical characteristic data was gathered for all 196 tree species, the process of evaluating the characteristics began by establishing appropriate scales based on the i-Tree literature. The i-Tree Species Selector Beta Utility manual was a valuable resource when rating the different attributes with respect to their potential to provide ecosystem services. Table 6 outlines the different fields that comprise the database which were used as a basis for assigning a base GAF value to each tree species. Scales of 0 to 2 were used to rate the different species characteristics where a 0 represents a characteristic which provides little benefit with respect to ecosystem services, 1 provides moderate benefits and 2 provides the greatest.

After the species characteristics were rated the scores were transferred into supplementary GAF values similar to those found in the GAF project where 0, 1 and 2 values were assigned a value of 0, 0.1 and 0.2 respectively. The species expected crown dimensions were used to determine the base values where the crown height and spread was used to calculate a crown area and these crown areas were then used to categorize the trees as small, medium or large. Within the GAF project a tree is assigned a value of 1.0, 1.5 and 2.4 for small, medium and large respectively. Size is a definitive factor in the amount of ecosystem services provided by trees where large trees provide significantly more benefits than smaller ones (McHale et al., 2007). The supplementary values were added to the base factor depending on how the trees species performed with respect to the characteristics described in Table 6. Points could be earned in ten categories allowing for a maximum of 20 or a minimum of 0 supplementary GAF points which was then divided by a factor of 10 and added to the base value. For example, if a large tree species scored a value of 2 in each category in Table 6 then a total of 2.0 or (2*10)/10 was then be added to its base value of 2.4 resulting in a total GAF value of 4.4 for the species.

$$GAF\ Tree\ Species = \text{GAF tree size value} + \left(\frac{Sum\ of\ supplementary\ values}{10}\right)$$

Figure 2 - Adjusting the Stockholm Royal Seaport GAF value for small, medium and large trees by supplementary ecosystem service factors determined by characteristics specific to the tree species.

The valuation of surface areas was taken directly from Stockholm Royal Seaport GAF and, aside from the base value of small, medium and large trees, is not connected to the characteristics in Table 6. These two separate GAF values, the crown cover projections and surface values are combined into a single total value later in the analysis process. Practically speaking this is a variation of the traditional Stockholm Royal Seaport GAF project where the tree values are singled out and analyzed based on species and location specific characteristics to then be added back to the initial GAF surface analysis and displayed using units, or pixel values, instead of a ratio. As previously mentioned, the surface GAF values used in this project taken directly from the Stockholm Royal Seaport project are based on a valuation scheme whereby points are assigned to surfaces based on two major criteria, the water drainage characteristics and vegetation characteristics. Within these two categories are three major subsets of criteria, biodiversity, recreation and social value and climate regulation. Surfaces can have many of the characteristics associated with the categories and sub-categories and in the end the points are summarized to give a total GAF of the area of the surface in question. More detailed information about GAF can be found in the Stockholm Royal Seaport GAF, 2011 project document.

3.3 Data sources

The analysis requires at least two inputs, a layer depicting the nature of the surfaces, as described in the Stockholm Royal Seaport GAF project, and a layer representing the tree species and position.

The data sources for the projected differed for the large scale and small scale analysis. The input data for the Kulla Gulla property was digitized from satellite photos (Google Map) where the landscape features could be clearly distinguished and polygons created based on this. The detail of the features was improved further by landscape drawings obtained from the developer's website. The nature of the surfaces, such as whether a surface was sealed or contained joints as well as what type of tree species was used, was gathered during a visit to the site.

Open Street Maps was the primary data source for the small scale district analysis. The open source data for the Annedal area was imported into ArcGIS. The layers required for the study were joined to create one surface layer for the entire Annedal area. These surfaces were assigned GAF values based on site visits. At the same time a tree inventory was conducted for the entire area. Some street trees had yet to be planted but their positions could be recorded based on planting site preparations and the species choice was assumed based on patterns of the other completed streets.

The GAF surface areas were recorded using a Mobile Data Collection (MDC) application where all GAF attributes present could be selected and the position of the surface also selected on a web map using open street maps. The data was sent to a cloud database to be further processed on a desktop computer. To do this a Comma Separated Values (CSV) file was exported from the MDC application where each GAF was assigned a code to then be matched with the corresponding value.

3.4 Large scale analysis

Once the two main inputs, the surface polygon shape file and tree point shape file, were created and each object within them assigned a code, the layers were then linked to a database file in order to import the predetermined base GAF values. The values were summarized when there was more than one. Figure 8 illustrates the level of GAF for the surfaces only before the tree data were added for the large scale analysis.

A field within the tree database also contained information on the tree's maximum, median and minimum spread divided by a factor of two. A buffer of the tree points was created for the point layer using the median value as a buffer distance to project the tree crown in two dimensions (see Figure 4). When creating the buffer, the fields were dissolved so that trees of the same species growing close together were represented by only one polygon object within the layer. A layer with only the outer boundaries of the study area (assigned a value of zero) was created and then merged with the tree crown buffer layer to ensure there was no empty data within the shape file over the range of the entire study area.

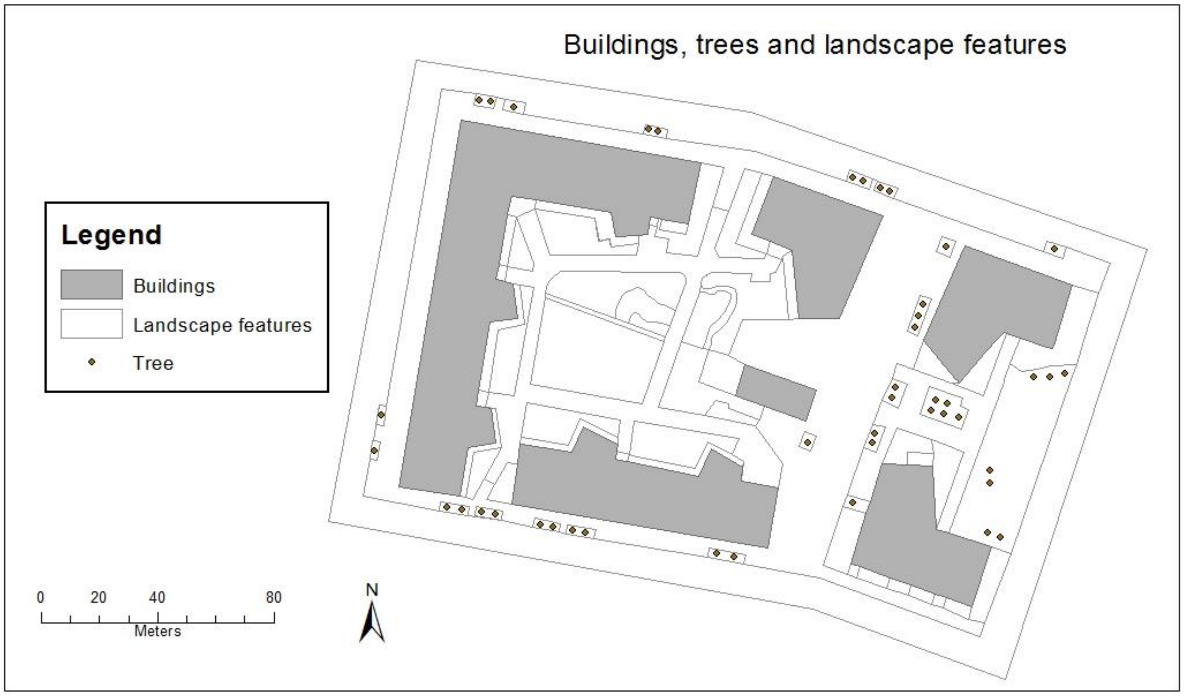

Figure 3 – The inputs required to conduct the analysis.

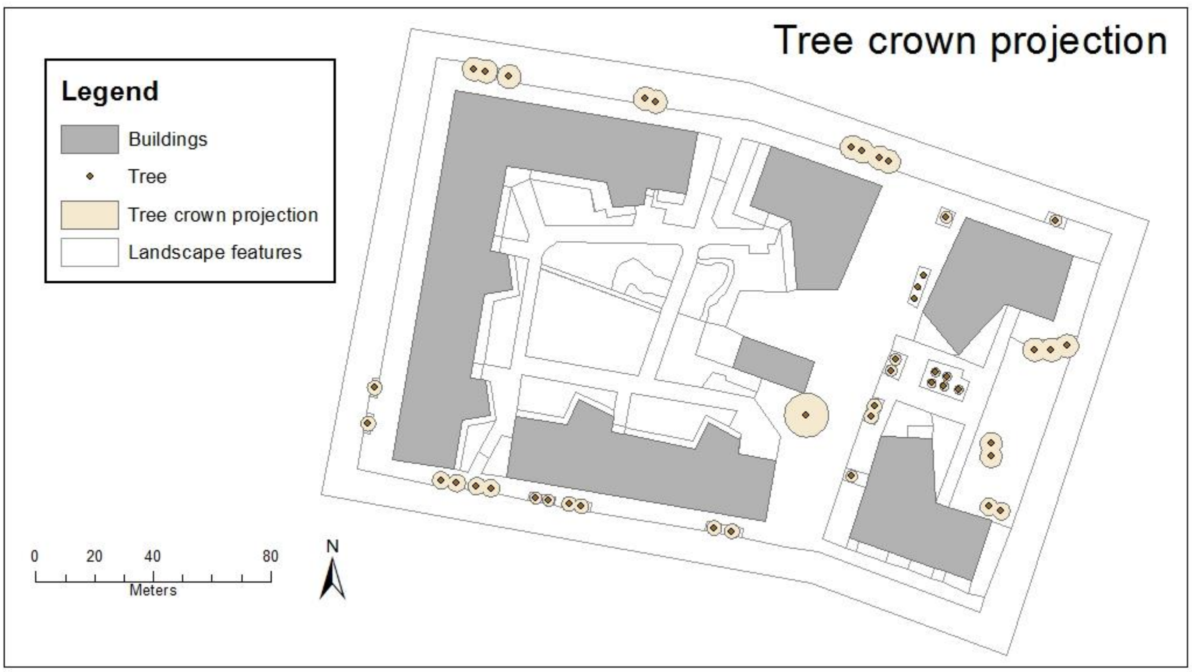

Figure 4 – Projecting the potential size of the different tree species' crown cover.

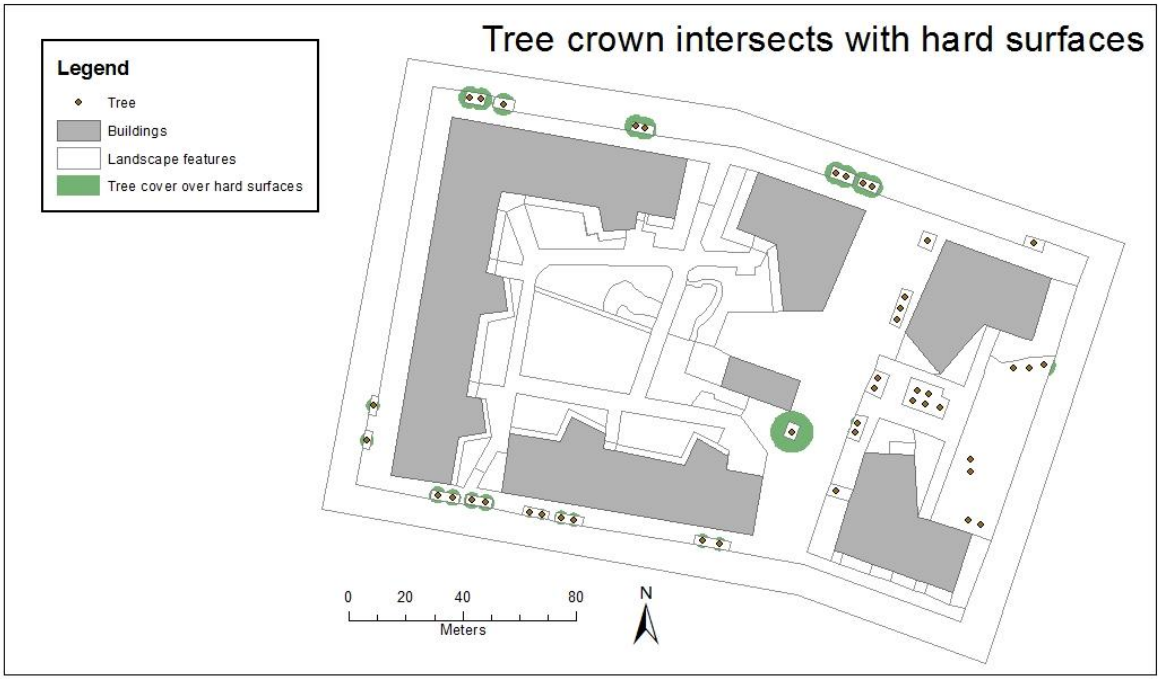

Figure 5 – Creating a new layer depicting all crown cover over hard surfaces.

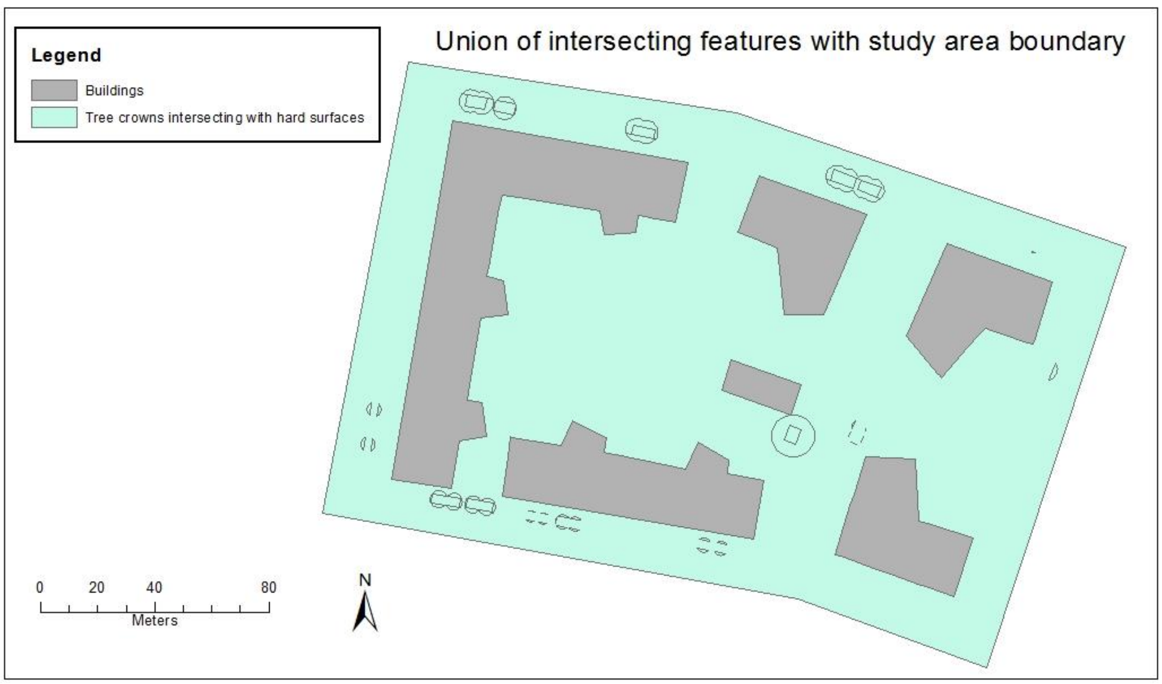

Figure 6 – The intersecting surfaces were joined with the study area boundary.

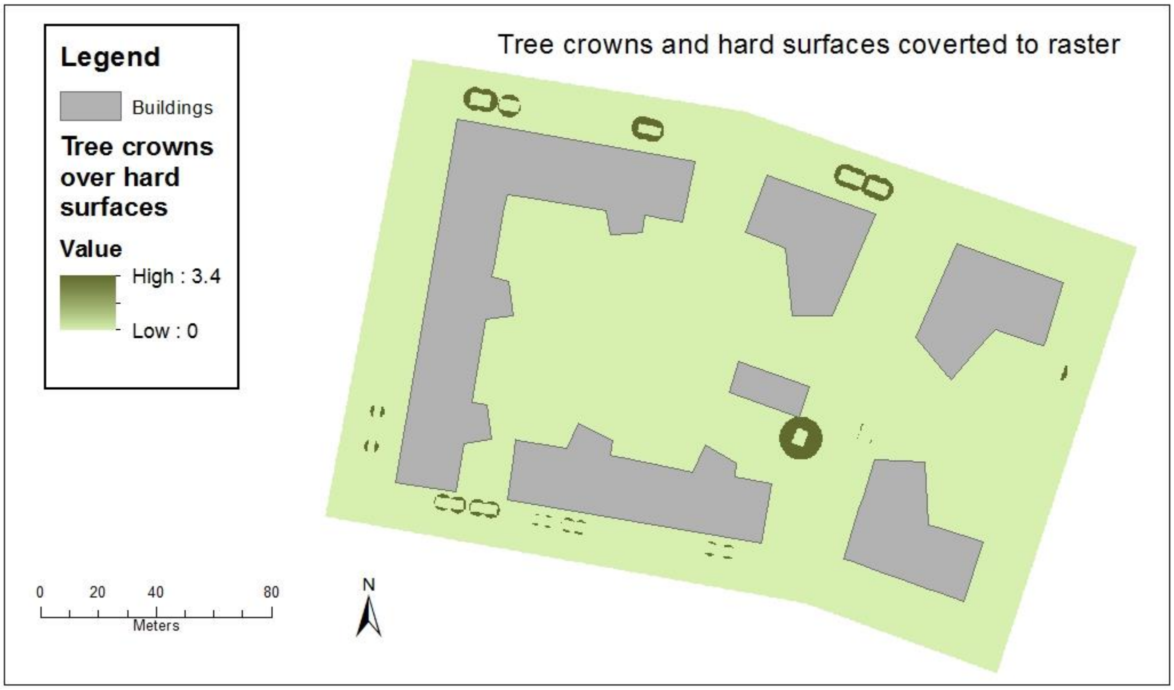

Figure 7 – The intersecting tree crowns and hard surface were converted to raster format.

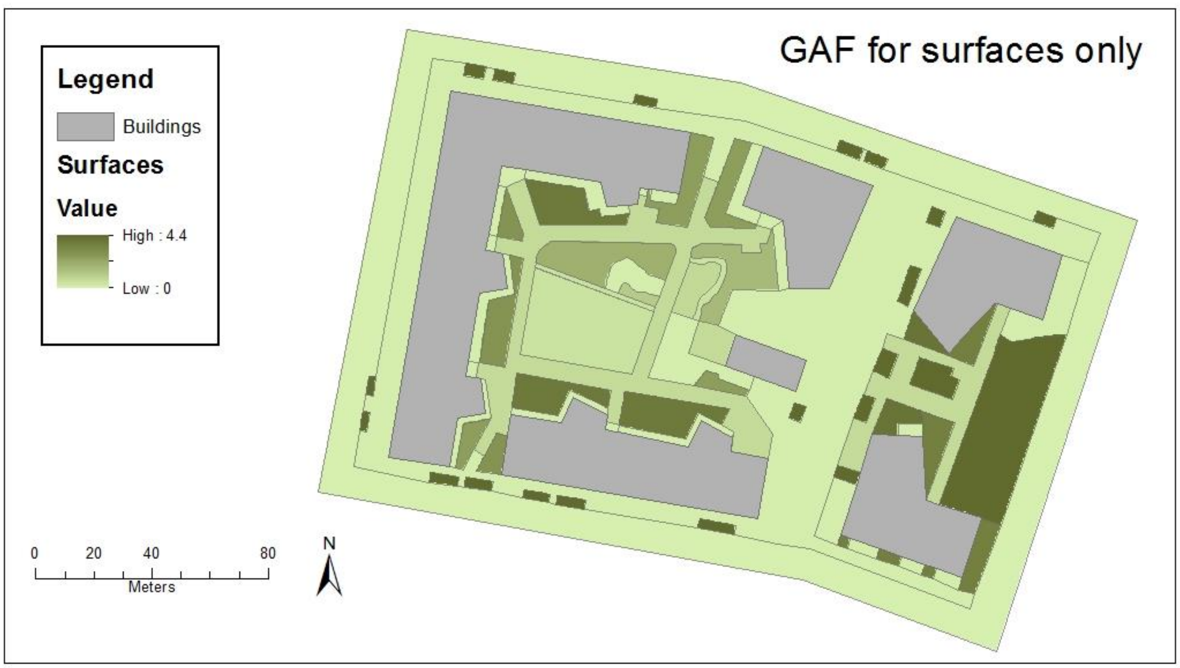

Figure 8 – The landscape features were assigned a GAF code.

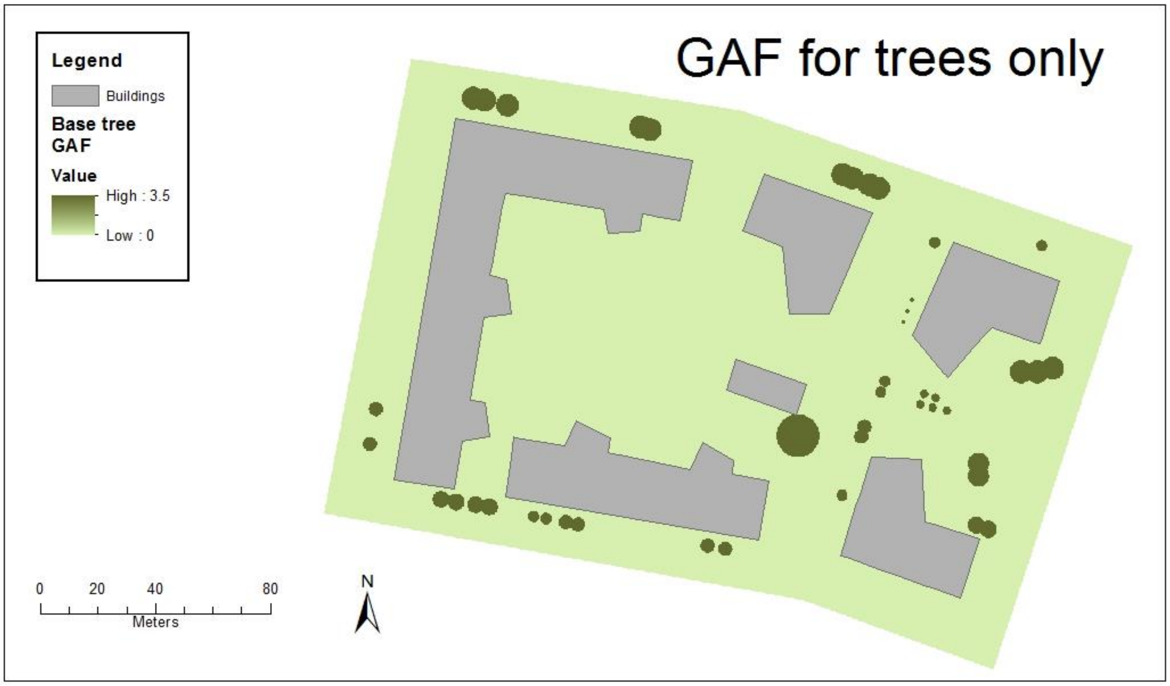

Figure 9 – The base GAF for each specific tree species was converted to raster format.

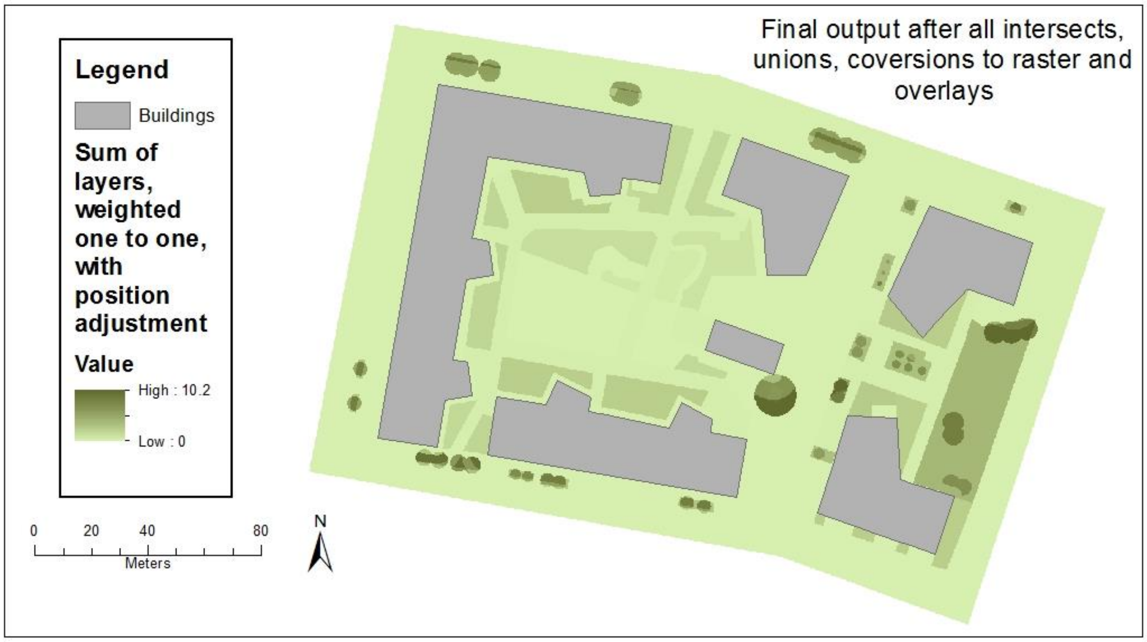

Figure 10 – The process was repeated with other types of intersects, such as trees and planting zones, the all layers were overlaid to sum the SPUs and create a final ecosystem service evaluation for the entire study area.

The two shape files, created and linked with GAF values, were then converted into raster format at a resolution of .25m using the total GAF value field as an attribute. These two layers were summed to create a layer displaying pixels of SPU's for the entire study area. At this point there was no adjustment for the position of the trees with respect to their surroundings which had the potential to either increase or decrease the total SPU's. This spatial analysis was carried out in the next phase of the process which can be viewed in Figure 12 while Figure 11 outlines the data preparation steps leading up to the analysis phase. An example of one of the layers produced in the spatial analysis can be seen in Figure 5.

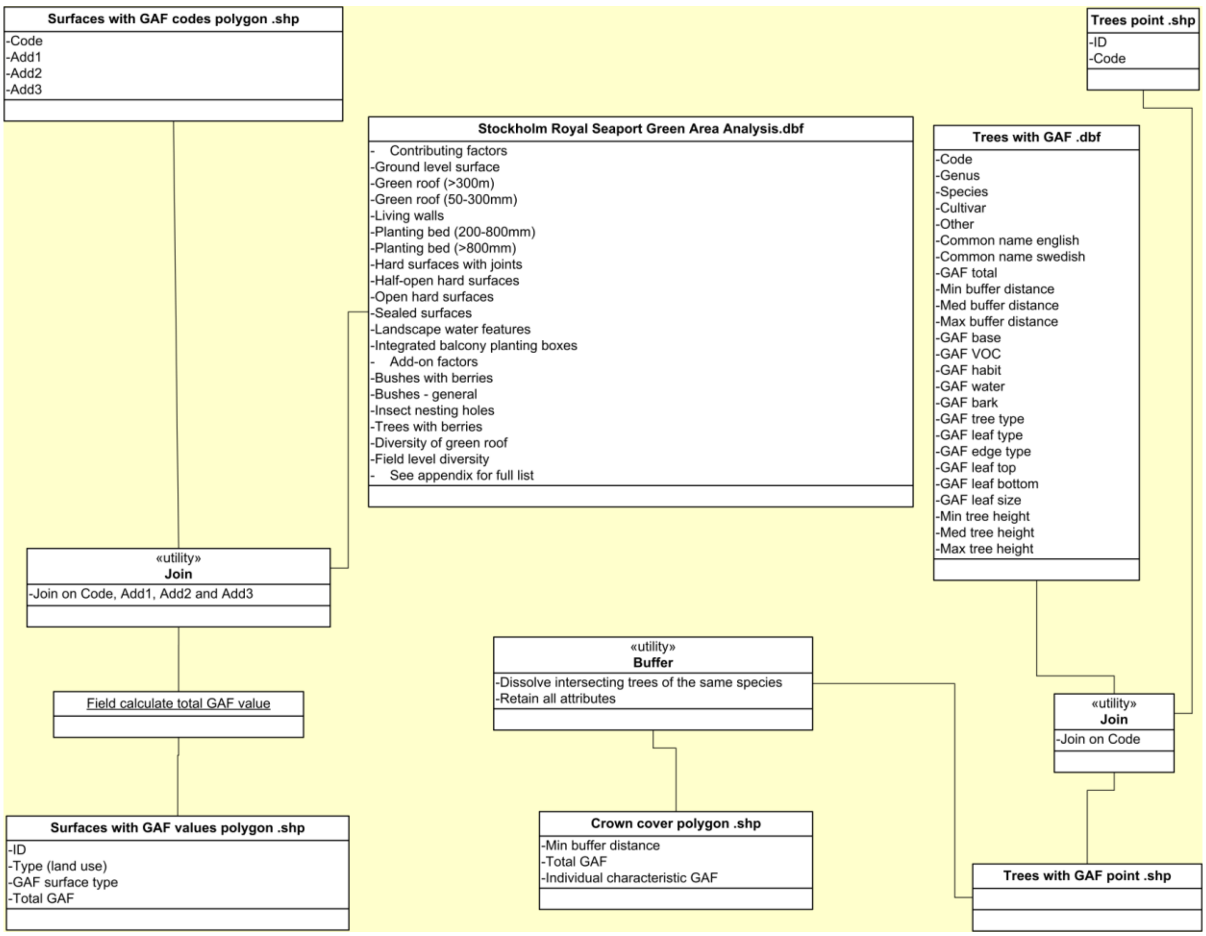

Figure 11 – Creating and manipulating input data

In order to adjust the SPU's provided by the trees with respect to buildings and energy savings, buffers were created at 3m, 6m, 9m and 15m around the buildings. A series of erase processes were conducted to create shape files buffers surrounding the buildings covering areas of 9-15m, 3-6m and 0-3m. A shape file with polygons covering the southern sections of building was created in order to erase all areas within 3-6m on all sides of the buildings except for the south side using the erase function. Figure 15 displays the resulting polygon areas where the trees should and shouldn't be placed in order to maximize the energy efficiency of the building. These polygons were intersected with the tree crown polygons in order to create a layer of polygons representing areas of the tree crowns considered to be too close to the buildings or located in areas which can benefit the energy effectiveness of the building. The recommended guidelines for planting distances considers tree placement with no consideration given to tree size. In the context of this study the anticipated tree size is considered allowing for tree placement even where space is limited. These conflict and benefit polygons were converted to raster layers, assigned with the GAF value of the tree, which could then be either added or subtracted to the final surface value.

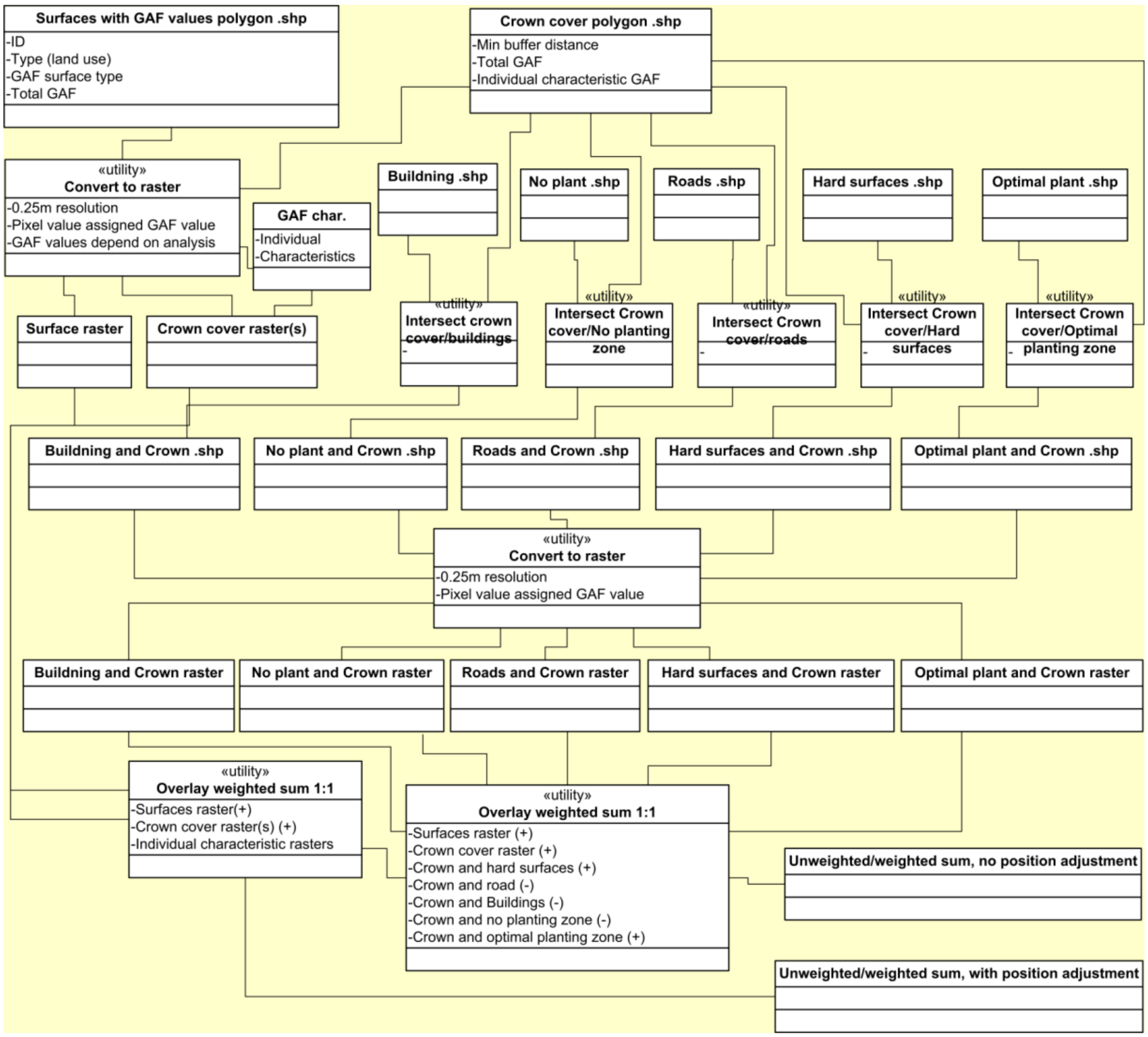

Figure 12 – Data analysis work flow

A similar process was conducted with respect to trees and hard surfaces as well as trees and roads. An example of the outputs involved in these processes can be seen in Figure 5. In the case of the hard surfaces it was assumed that the shading effects and water interception services provided by the trees are positive for the impervious layers. The interaction of the SPU's with respect to trees and roads can be considered positive due to the pollution particle interception potential trees have along roads with heavy traffic.

Placing trees along roadway can also have negative effects which are analyzed and discussed at a later stage. The SPU's from these spatial analyses were added to the previously created layer of summed surface and tree crowns to create a final layer representing the total value of all SPU's for surfaces, tree crowns plus the extra services or disservices, either gained, or lost, due to the position of the tree with respect to its surroundings.

In all overlays up to this point the values were summarized with no weighting. In order to explore the effect of the different service providing characteristics of the tree species with respect to their perceived importance as an ecosystem service, the individual values were categorized into the areas they provide their service. Three categories were used based on the characteristics and the values available. Table 7 outlines the weights assigned to the different ecosystem service characteristics with respect to the importance of the factor compared to the others. For example, within the general category it's assumed the base value, which represents the tree size, is most important while the trees form and emission of BVOC's are less important. According to the Northeast Community Tree Guide size matters with respect to energy benefits where a large tree produces 3-8 times more energy savings than a small tree due to wind, building shade and transpiration effects (McPherson et al., 2007). The weighting is based on the Northeast Community Tree Guide which in turn is based on the ecosystem service's importance in terms of monetary savings attributed to the service.

Table 7 - The weighting scheme for the categorized analysis.

Weighting Scheme	Attribute	Initial weighting	Equal weighting	Particle interception	Water interception
General	Base	3	1	1	1
	VOC	1			
	Habit	1			
	Water	2			
	Tree type	2			
Water interception	Bark	1	1	1	3
	Leaf size	2			
Particle interception	Leaf type	3	1	3	1
	leaf edge	2			
	leaf top	1			
	leaf bottom	1			

The three weighted category layers were then summarized, first with equal weights, and then two more times where there was a desire for a certain service. This was done to evaluate how the chosen trees performed with respect to their ability to provide these services in the event that they were sought after to solve a particular problem, such as air pollution along roads. New total surface and tree GAF layers were created based on this new weighting scheme, also taking into consideration the service and disservice units from earlier analysis into the final result. Zonal statistics were conducted on the different layers, first by tree species, to analyze how the specific species performed within the analysis, and then by land use type to determine the positive or negative effects the weighting had on the GAF values of the surfaces beneath them.

3.5 Tree choice analysis

The next analysis conducted was to explore how the wrong choice of tree species affects the ecosystem services provided. To do this a few key trees located by roads and close to buildings were changed to model trees species that were either too large or too small for their site with respect to the potential space available. The same initial procedures were followed to link the trees to the GAF database and the exact same surfaces shape file was used for this wrong-tree-in-the-wrong-place analysis. The tree crown vector file was intersected with the buildings and then again with roads to produce two shape files with polygons representing the tree crown conflicts with the building and roads respectively.

In both cases it is assumed that the overlapping areas will create the need for costly tree maintenance. In the first case, it is assumed that costly tree care will be needed to prevent the trees from damaging the face of the building, and in the case of the roads, to meet the safety standards need for clearance. Leaf litter and other problems associated with trees and vehicles both parked and in transit are also considered a disservice. Associated with this is the loss of tree biomass which can have negative impacts on the health of the tree while reducing pest resistance (City of San Francisco, 2006). These overlapping areas were converted to raster format at the same resolution as all other layers and subtracted from the raster layer representing the tree crowns before being added to the surface layer to produce a total GAF similar to that of the previous analysis. Zonal statistics were extracted by tree species zones and also by land use zones or in other words the shape features categorized by tree species and the surface features categorized by land use. The total GAF value for each zone was used to represent the total SPU’s. These SPU’s could then be compared by tree species to what the same tree would have provided having had the required growing space. The level of SPU’s for each land use type in this conflict tree scenario was then compared to the level of SPU’s provided in the same zones of the initial analysis.

To further illustrate the importance of proper tree species choice to maximize the benefits from trees, a solitary tree with ample growing space (oak) was changed to a Fastigate poplar. These choices were based on the fact that oaks are classified as large trees with spreading forms and a high GAF value. The poplar is also a large tree with a significantly high GAF value though the habit and form are much different to that of the oak resulting in a total GAF value for that surface which is much lower than what is potentially available based on the planting space. Finally, the zonal statistics were extracted for the study area categorized as ground level, where all trees are planted, compared to the raised surfaces with planting beds whose depth did not allow for tree planting. This was done to be able to analyze the SPU’s, or lack thereof, where there are no trees present in the landscape.

3.6 Small scale analysis

The method for the district scale analysis follows the same pattern of the large scale analysis with the exception that the input surface data was downloaded from Open Street Maps. Each property had its own theme or style which differentiated it from neighboring properties and during the survey stage points were awarded to the property on a whole instead of for each individual feature based on these characteristics. The Stockholm Royal Seaport GAF is comprised of a list of features and subsequent GAF values and the properties received points corresponding to the eco-effective and social factors present on this list. At the same time the tree data was gathered also using the data collection app by recording the position and species code to later be imported into ArcGIS. Natural areas as well as the play areas were assigned their GAF values relative to the property GAF's. The natural areas (forest and river) were assigned a value equal to the highest property value GAF plus 2 and the play areas a median value of all properties. Roads, buildings, footpaths and other areas consisting of paved surfaces, such as parking lots, were assigned a value of zero. In the position analysis phase of the district study trees along roads were considered a minus, as in the property level scale, however trees along footpaths were considered positive due to the aesthetic benefits of trees for the walkers as well as the other ecosystem services present such as wind barriers and shading without the risks associated with fast moving vehicles. The analysis of the trees with respect to hard surfaces was omitted due to the fact that at this scale the actual pervious versus impervious nature of the surface could not be determined. The recommended planting zones of 3-6m located on the southern portion of the buildings were also omitted from this analysis.

4. Results

The database created provides an indication of the how the different tree species rate with respect to the ecosystem services provided, based on GAF, for air particle interception, rain water interception, air pollution removal as well as the negative aspect of BVOC emissions. These values are added to a base value in relation to tree size awarded by the GAF. As shown in Figure 13, out of the 196 commonly found tree species in Sweden 24% fell in the GAF category 1.0-1.9, 55% in the GAF category 2.0-2.9 and 21% in the highest, or largest, tree category of 3.0-3.9.

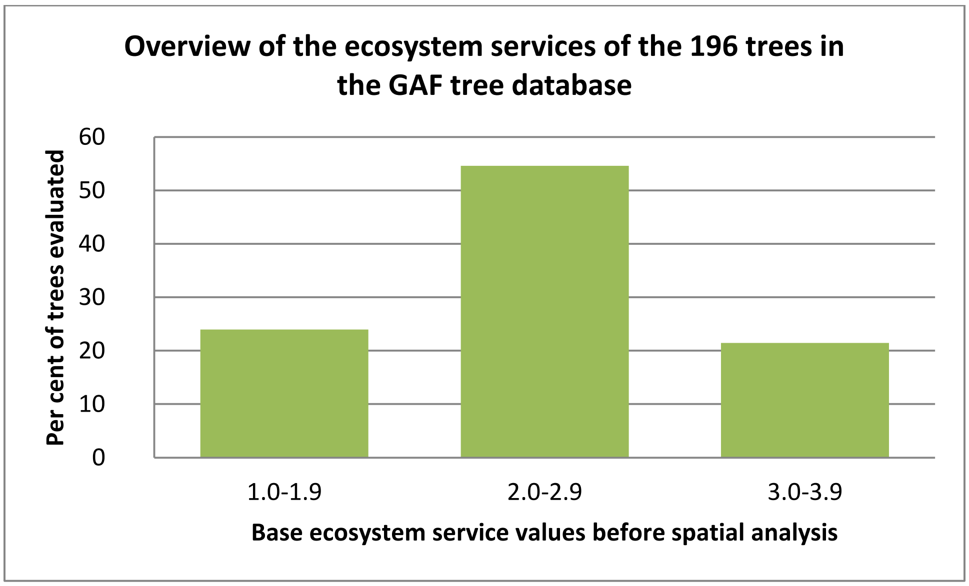

Figure 13 - Overview of the base GAF for the 196 trees included in the database.

The database in itself can be considered a valuable reference as the raw data available gives a good indication of the trees appearance with respect to its size, bark and leaves which can then be used as an aid in the planning process. Tree texture, for example, can be displayed to provide an overall view of the landscape with respect to this attribute. This can be helpful in the planning process to avoid too much homogeneity or too ensure homogeneity if that is the desired result.

The sum of the values of the SPUs were used as a measure of the ecosystem services provided and this sums could be compared to each other over the series of analyses conducted and a particular study area. For example in Figure 14 the sums of the different study area zones, in this case surface types, were extracted from three different total GAF layers, one with only surface GAF values, one with surfaces and trees but no adjustment for tree position and finally the surfaces, trees and adjustment for position combined. In this way the progressive increase the trees provide to surfaces can be followed. In a similar expression of ecosystem service levels the total SPUs of different tree species was extracted from total GAF values weighted according to a desired trait. Figure 17, for example, compares a particular tree species' SPU increase with respect to the analysis weighted for particle interception and water interception compared to generally weighted SPUs, which was used as a reference, in order to suggest a tree species choice to meet a specific requirement in the landscape. The Mountain ash, for example, shows a significant increase in SPUs for particle interception but only moderate amounts for water interception while the European Hornbeam shows increases in particle interception but none with respect to water interception. Other species show equal amounts of increases in both, for example Katsura or Silver maple. The size of the tree species plus the number of times it is used in the landscape is the determining factor with respect to the total amount of SPUs provided by a particular species and these comparisons are not representative of which species provide the most ecosystem services in general terms.

4.1 Large scale GAF analysis

By adding a spatial analysis of the trees with respect to their surroundings the level of SPUs increased where the ecosystem services provided were amplified due to the interaction with respect to the surfaces and land use forms surrounding them. The SPUs can have also decreased after this spatial analysis due to poorly placed trees or poor species choice for the site conditions. Looking at Figure 14 one can see that by using only a few simple analyses the SPU levels increased for most surface type categories (sealed surfaces, hard surfaces with joints and ground level surfaces). The absence of increase in planting beds 200-800mm and planting beds >800mm can be attributed to the fact that there are no trees planted there due to soil depth limitations. This same graph also illustrates that regardless of spatial analysis, the areas at ground level with sufficient soil depth to support tree planting have a substantially larger value of SPUs compared to all of the other surfaces combined. With no spatial adjustment the ground level surfaces, where all trees are located, have a total SPU value of 242 683 units with spatial adjustment and 209 797 without while the remaining raised surface areas, lacking tree crown cover and having low surface GAF values to begin with, have a total GAF value of 77 570 both with spatial adjustment and without. The large differences can be attributed to both the higher base surface values allotted to ground level surfaces but also by the increased tree crown cover provides to the surfaces.

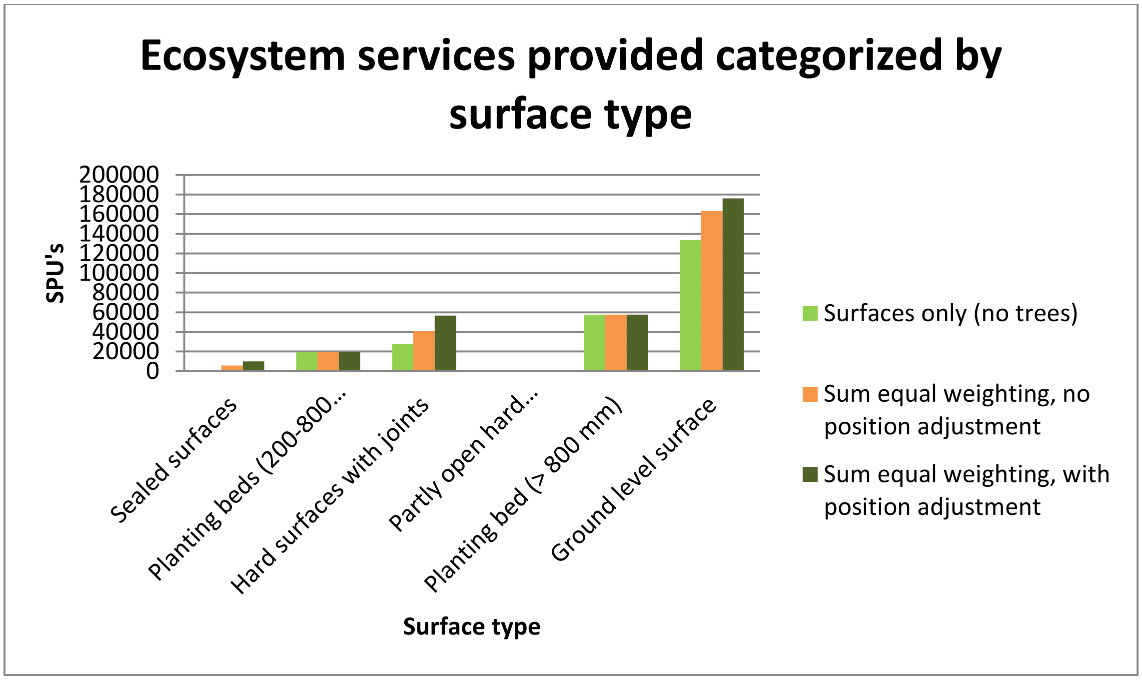

Figure 14 - The increasing GAF as the trees are added then spatially analyzed.

Aside from the non-monetary assessment of ecosystem services provided by trees, the analysis can also provide maps showing landscape planners the most optimal planting sites to maximize certain ecosystem services such as energy savings. Figure 15 shows the optimal planting areas to maximize energy savings according to the North East Community Tree Guide recommendations. This simple analysis can be conducted on landscape drawings as a means of confirming there are no trees placed in a “no planting zone” or to offer alternative planting areas to maximize the energy saving potential of the trees with respect to structures. By using the buffering functions around buildings maps can be created to aid in the final stages of the landscape planning processes where the tree placement can be shifted slightly to achieve maximum ecosystem services while not disrupting the aesthetic aspects of the landscape plans.

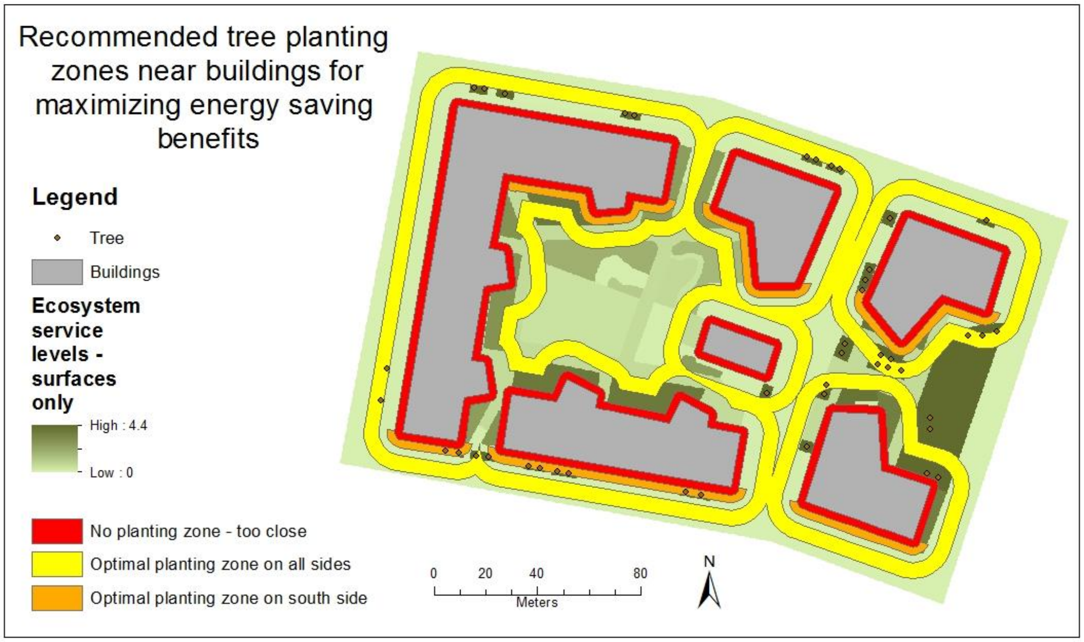

Figure 15 - Result of buffering to find the optimal tree placement with respect to energy savings.

Additionally, a summary map of SPUs can be a valuable tool in the landscape planning stages to visualize and identify landscape areas which are weak in ecosystem services. In these cases the designers could adjust their plans to include more eco-effective surfaces and increase the SPUs in the weak spots. This can be done in a number of ways such as planning for green roofs or living walls where, for example, the soil depth doesn't allow for tree planting. Figure 16 visualizes a basic summary of the ecosystem services for the study area with a simple un-weighted overlay. From this map it can be clearly seen that there is a definite imbalance within the GAF from the east side of the study area to the west. This is due to the fact that an underground garage beneath the entire inner courtyard (outlined in yellow on Figure 16) creates a situation where only bushes and perennial gardens were included in the landscape plans. Adding the values of the projected tree crowns increases the level of ecosystem services within the ground level portion of the property considerably however this is not the case for the raised surfaces due to the lack of trees. A raised surface over an underground parking does not exclude the potential for tree planting as long as it is incorporated into the design process and there are sufficient soil depths to support the trees. In this case, being able to visualize this weakness early in the planning stages could be sufficient to investigate other options such as deeper soil levels or using structural soil techniques.

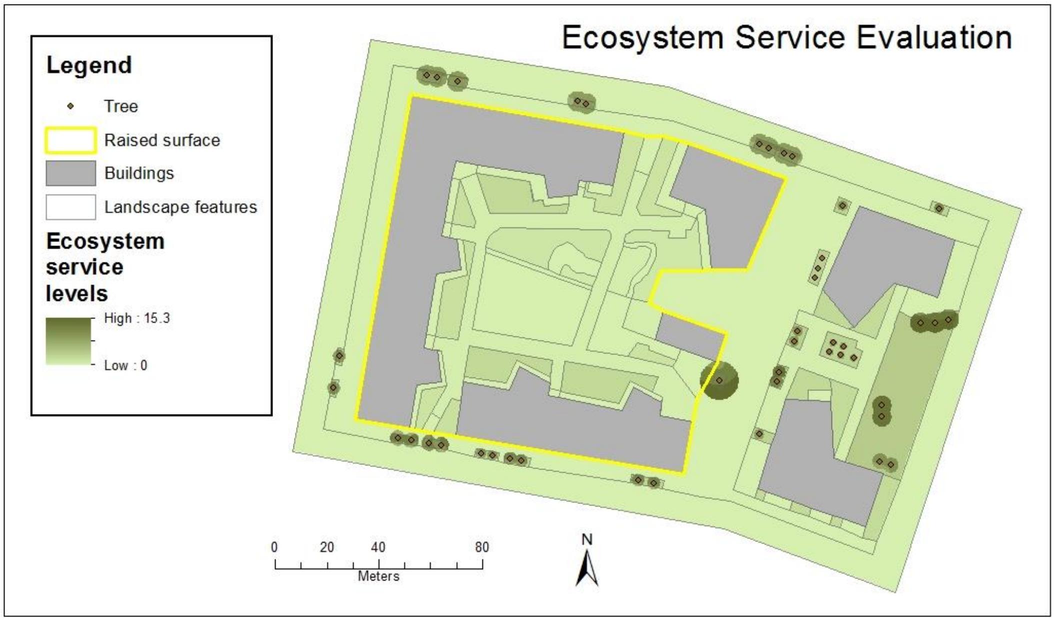

Figure 16 - A visual overview of the GAF levels of the study area with positional adjustment

The level of SPUs for the section of property containing trees (Figure 14, ground level surfaces) is over twice that of the treeless section (Figure 14, all other surfaces). The SPUs of this section increases even more after spatially analyzing the trees with respect to their surroundings. The raised section has no trees aside from those surrounding the building along the adjacent street and these trees do not provide any extra SPUs based on their positions which are measurable. This confirms the assumption that not only do the trees themselves provide significant levels of ecosystem services but also that their positions are important with respect to how much ecosystem services are provided. What is also noticeable in Figure 16 is how the placement of the trees affects the total GAF values due to the fact that certain positional factors were positive for the total GAF while others were negative as depicted by the shades of green.

Weighing the specific ecosystem service functions in terms of their overall influence on the estimation of the SPUs provided by trees was found to be the most determining factor with respect to the SPU levels. The motivation for this weighting was that tree characteristics, such as leaf size and subsequent Leaf Area Index (LAI), significantly influence other calculations with respect to ecosystem services. Hair on leaves, on the other hand, contributes to pollution particle interception but this function is otherwise overshadowed by service providing characteristics such as tree size and biomass. For example, according to the Species Selector Beta utility, the average decrease in mid-day temperatures due to urban tree canopies would be about 1°C assuming an average species transpiration factor of 1, based on relative transpiration factors generated from estimated species water needs (Costello and Jones, 1994), and an average LAI of 6 (Nowak, 2008). In this case the levels of transpiration for the species combined with the LAI provide valuable climate regulating services compared to a more localized service provided by the air particle interception. Weighting the different tree characteristics based on their overall importance significantly changes the total level of SPUs. This weighting can also be altered depending on the type of analysis being conducted if, for example, particle interception is a desirable trait in situations where there is an air pollution problem. In this case both the ability to intercept harmful particles in the air and the ability to tolerate polluted planting sites would be weighted heavier than, for example, the tree's ability to shade.

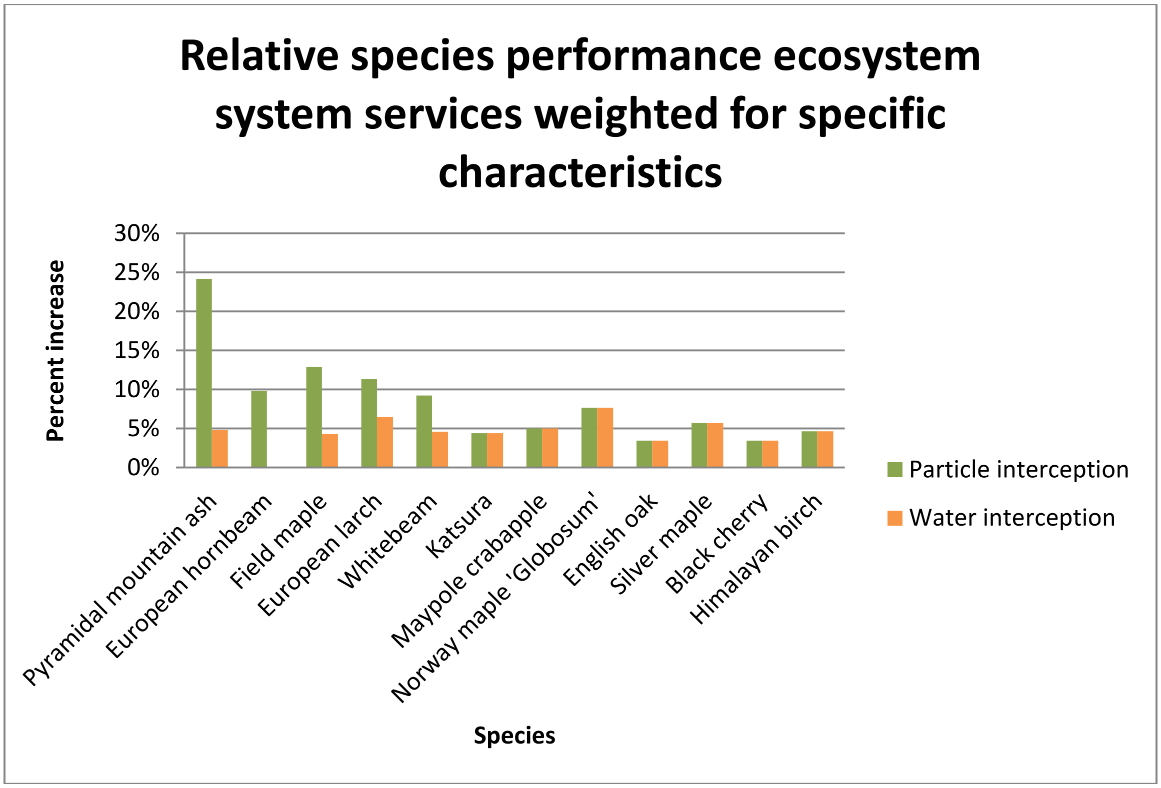

Figure 17 – Species performance for particle and water interception. Comparisons of SPU gains by weighting type using general weighting as a reference.

Figure 17 compares the species performance with respect to water and particle interception potentials. (see Table 7 for weighting). The characteristics were first weighted generally where they were divided into three categories, general ecosystem services, particle interception ecosystem services and rain interception ecosystem services. They were weighted based on their overall importance within the category to then be summed again without weighting to provide a reference point. The first bar in Figure 17 illustrates the percent increase in SPU's by tree species based on a desired service of particle interception. The same initial weighing procedure was conducted on the individual categories but then the particle interception category was assigned a heavier weight in the final summation. The second bar illustrates increases with respect to water interception which followed the same process but weighted the services based on a desire for water interception. Noteworthy is how the individual tree species performed when a desire for particle intercepting qualities was included in the weighting by increasing the factor to three and leaving the other two factors at one. The European Hornbeam, for example, scored better as a species which has the ability to intercept particles in the air compared to its ability to intercept rain water. SPUs from other tree species, such as the Norway maple, did not show any discernible differences between particle and water interception aside from the general increases. In these types of comparisons, however, it is important to consider the tree size and site conditions. As previously mentioned, size matters concerning ecosystem services from trees but in those instances where large trees are unsuitable, subtle differences in ecosystem service performance with respect to trees species performance can add up to large differences when considering large numbers of trees. It is also important to remember that at this scale roughly 40 trees were evaluated, comprised of 12 species, which is far too small of a sample to adequately evaluate if there are great differences in ecosystem services with respect to a desired trait.

Estimating the ecosystem services for the different tree species to compare their performances can be helpful in the landscape planning process while evaluating the ecosystem services by land use type is also an important step in the analysis process. The pervious and impervious natures of surfaces found in the urban landscape are important when evaluating the ecosystem services provided by trees. The GAF takes both the vegetative and the hydrological factors into consideration when evaluating the eco-effective nature of the surfaces. The ecosystem services provided by trees can be amplified by surfaces under the tree’s crown by, for example, shading a rest area, reducing the rain water run-off over impervious services or by providing a wind break and micro climates around buildings.

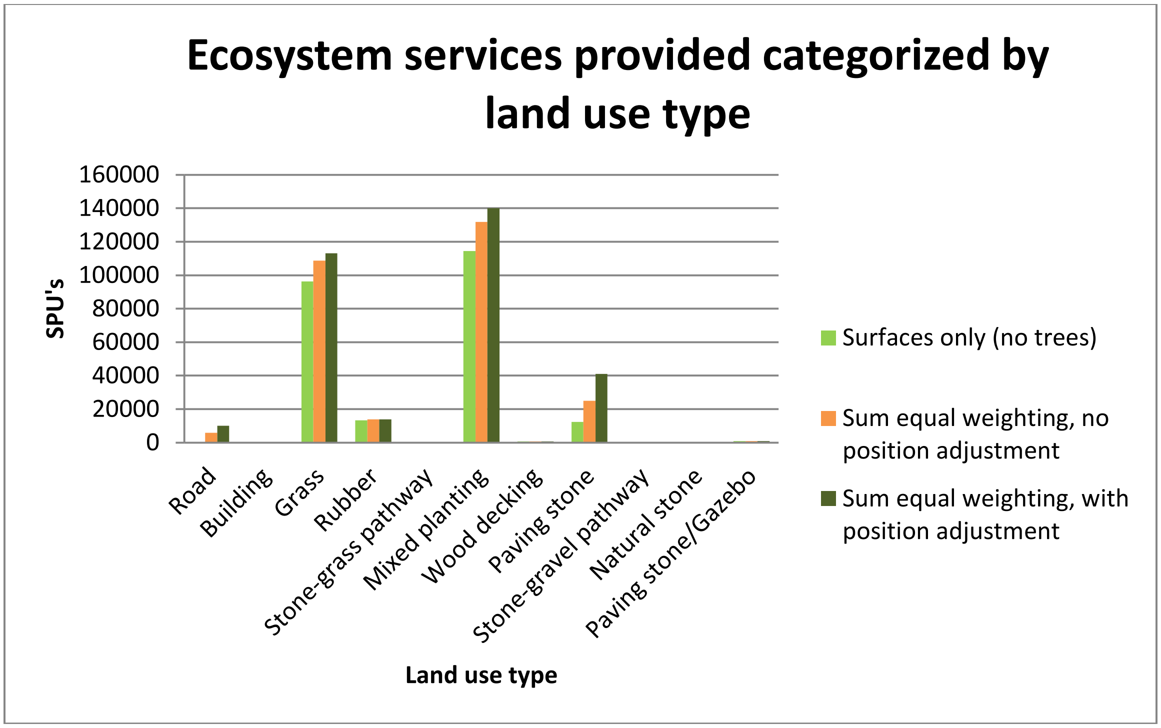

Figure 18 - Comparison of the how the different surface types increase their SPU's by tree placement.

Figure 18 illustrates the distribution of ecosystem services over the different surface types of the study area. The building category contains no service value but nevertheless makes up a significant portion of the total study area at 26%. Roads and paving stones follow closely accounting for 21% and 24% of the study area respectively. The buildings receive no GAF points from the trees however they do receive ecosystem services from trees in the form of energy savings which is added to the SPUs of the surrounding surfaces. What is more interesting is the road and paved surfaces which otherwise receive only negligible GAF points without the trees but improve their SPUs substantially through the ecosystem services the trees provide in the form of shade and water interception. The grass and mixed planting surfaces make up 8% and 10% of the total surface area respectively and, even without the trees, provide significant levels of SPUs. The SPUs of these parcels increase even more when adding the trees and make up the bulk of the high SPU values for the total area even though their surface area is only a small fraction of the total. It can be concluded that in this respect the service potential for impervious surfaces can be improved by adding tree cover while other impervious surfaces, such as buildings, cannot be easily improved using tree cover, however, there are other methods available, such a green roofs, which can greatly improve the eco-effectiveness of these surfaces.

Figure 19 illustrates a potential problem where certain trees were changed in order to analyze the effects a poor plant choice has on the SPUs of the tree. In the case of the Silver Leaf Willow and Little Leaf Linden, almost half of the SPUs are potentially lost due to conflicts with roads and buildings. This can be a complicated scenario because in one sense trees are needed along the roadway to provide shade to parked cars which can reduce sun damage and minimize hydrocarbon evaporation from leaky seals and fittings

(McPherson et al., 2007) not to mention other benefits, both aesthetic and functional. On the other hand, if the tree stretches too far out over the road then the maintenance costs increase dramatically. In some cases the road may need to be temporary closed for street tree maintenance or the maintenance will need to be carried out at night. In both cases the increased personnel costs to carry out the tree care will lessen the net benefits from the tree or even result in a net loss.

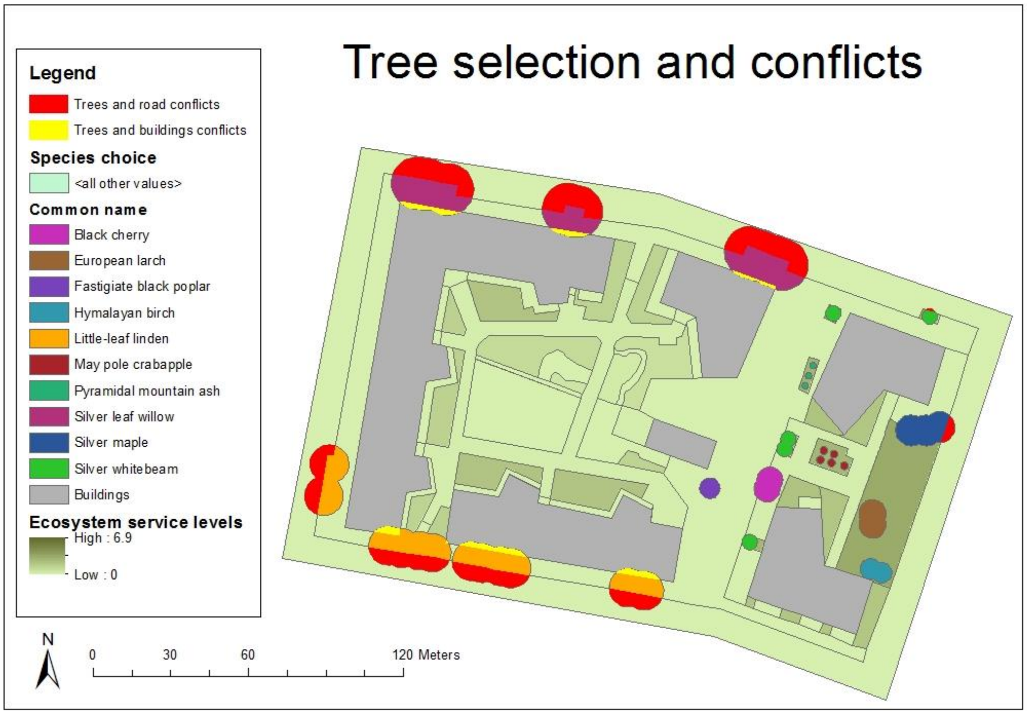

Figure 19 - Map depicting the potential conflicts between trees and infrastructure.

It is also important to remember that there are two losses which must be considered regarding the conflict between trees and infrastructure. The first loss concerns the added tree care costs involved in pruning the trees so that an acceptable level of maintenance is reached (such as pruning requirements in the red regions of Figure 19). The risks associated with a potential failure are greater due to the traffic and movement of people in the conflict zones. The second loss concerns the loss of the ecosystem services provided by the tree due to a reduced biomass and probable reduced tree vitality and longevity due to repeated pruning (such as the yellow regions in Figure 19). This loss can vary depending on the species type, for example JAS trees, or sensitive tree species which should only be pruned in the summer (July, August, September or JAS) are a poor choice for a street tree which undoubtedly will be subjected to clearance pruning compared to other tree species which have demonstrated a tolerance to heavy pruning.

Another factor to consider is the litter produced by the trees which can be an irritation for those who regularly park under the tree and can lead to a reduced appreciation of the trees. Certain trees species can also produce fruits that could pose slipping or tripping hazards to pedestrians when located near an area of high pedestrian traffic.

A poor choice of tree species for the site can also occur when the available space is not used to its full potential. Figure 20 compares the differences found between the SPUs from one tree to another. In this case the Fastigate black poplar is a poor choice in the conflict tree scenario (see Figure 19) where in the initial scenario the English oak in the same spot fills the open space with only minimal conflict with a low structure (see Figure 16).

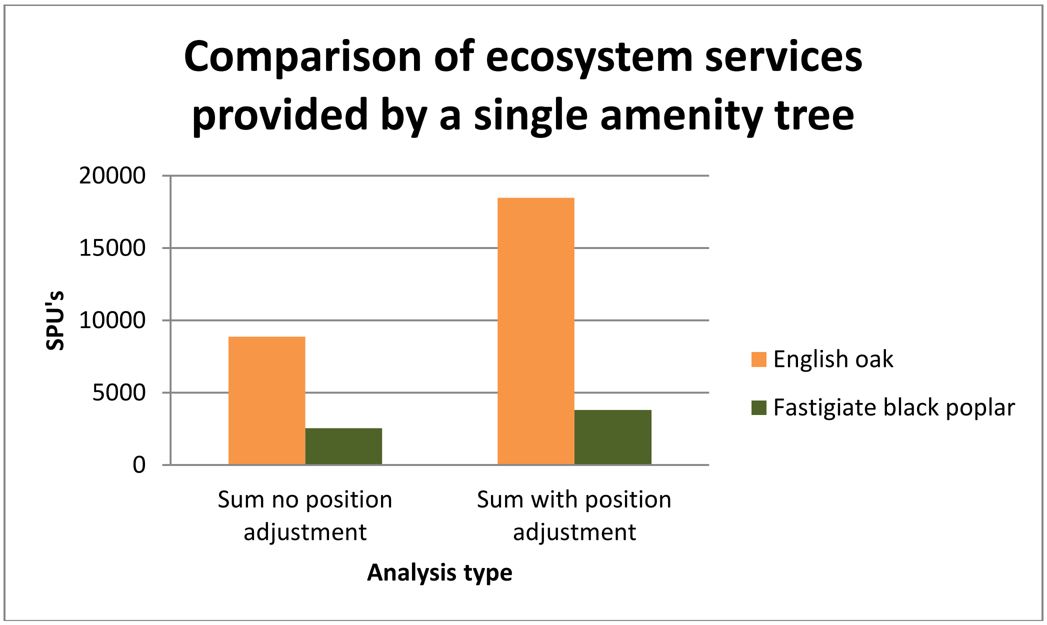

Figure 20 - Not using the full site potential can result in lower levels of SPU's.

4.2 Small scale GAF analysis

Though the detail of the base surface GAF at the district scale is limited it demonstrates similarities with respect to the positive effect trees have on the landscape. The level of base GAF is dependent on the site developer and in the case of Annedal high levels of GAF are found along the river bank where there was a marked effort to choose native plants and wetland themed landscapes which are a smooth transition from the natural wetland landscape to a more urban setting the further away one comes from the water. The street trees also follow this theme where the street running parallel to the water is lined with alders which are typical for wetland environments. Not all developers chose designs with a high GAF levels though the levels are distinctly higher closer to the water in most cases as can be seen in Figure 21. There are few trees incorporated into the landscapes of the developments with underground garages in comparison with the ground levels which suggest a high degree of compromise with respect to the need for parking spaces in contrast to the quality of the landscaped environments above. Figure 21 also illustrates how the high levels of GAF are focused along the natural areas and along the foot paths connecting them. Figure 22 gives an overview of the land use for the district of Annedal which can be compared to the GAF levels in Figure 21 to illustrate correlations between land use and GAF levels. This connectivity is positive from a fragmentation perspective though the level of GAF's for the inner courtyards are minimal except for the few projects located along the water's edge. Specific details of each project are not known and their level of consciousness with respect to the GAF of their development can only be speculated on. Added to this is the fact that there may have been other climate smart aspects of the building designs which could compensate for low levels of GAF.

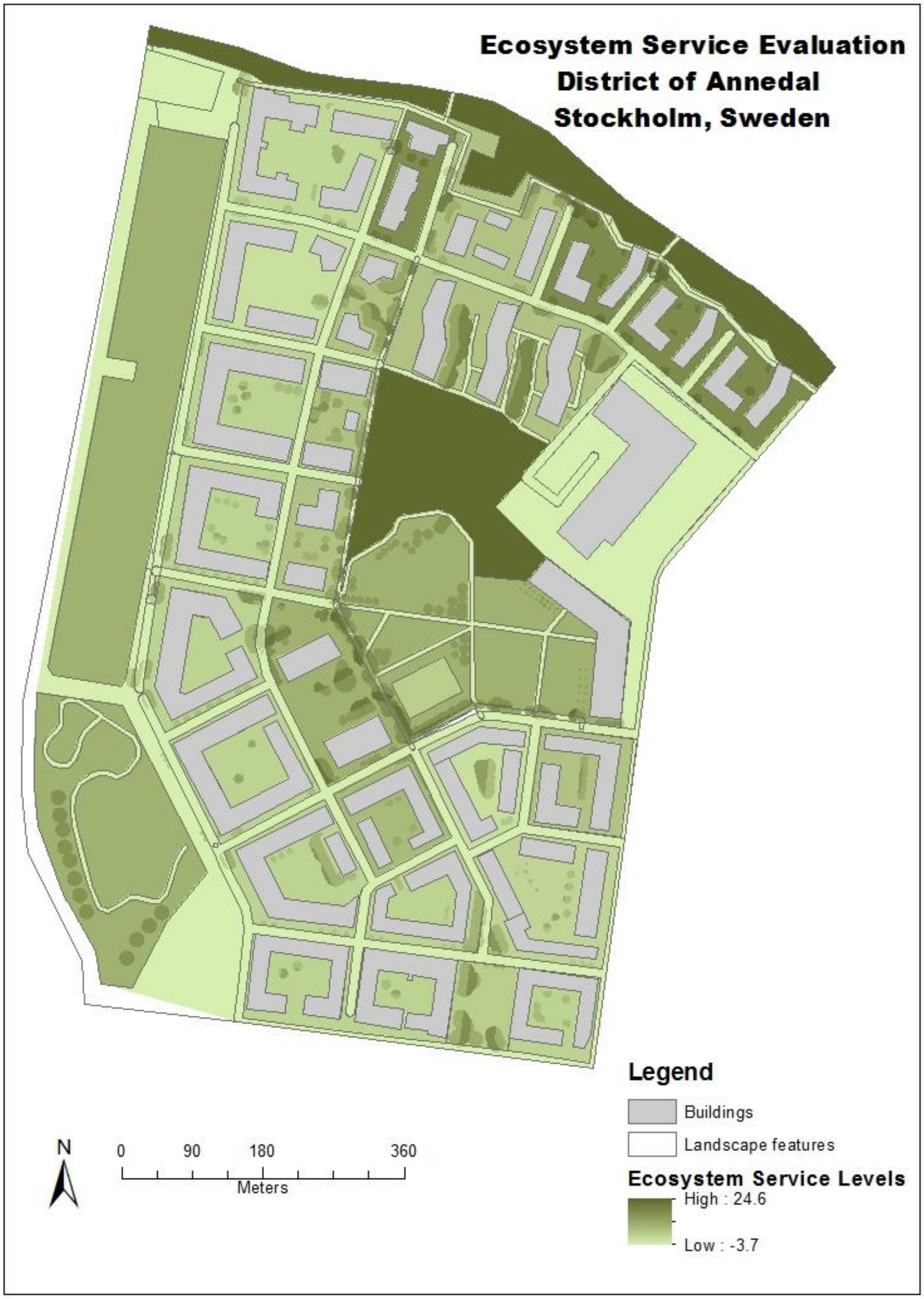

Figure 21 - GAF for the district of Annedal.

Figure 22 - Annedal land use.

Figure 23 illustrates how the positions of trees can either amplify the SPUs of landscape features or in some case reduce them. The foot paths and roads are one example where, in the case of the foot paths, SPU levels increase when tree positions, with respect to the footpath, are accounted for. The GAF levels of the roads, however, decreased because the SPUs provided by the trees were lost due to their position with respect to the roads. As previously mentioned this is a simplistic approach and the services and disservices provided by trees located close to roads is complex and requires further consideration. A similar situation is apparent with respect to trees and building where all portions of tree crowns overlapping building were considered a disservice due to pruning requirements.

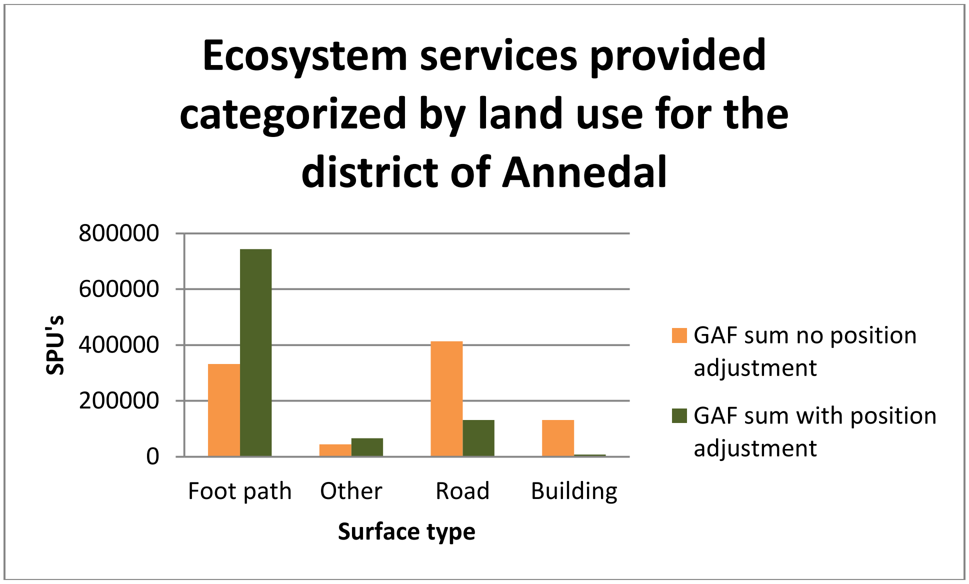

Figure 23 - Comparison of land use types most affected by trees.

The SPU gain made in the "Other" column can be attributed to the positive effects trees have over hard surfaces. Most of the surfaces included in the "Other" category consist of parking areas and other features with impervious qualities and in these cases the presence of the crown cover from trees results in positive ecosystem services. It should be noted here that these "Other" surfaces contain a base GAF of zero so that all of the SPUs shown in Figure 23 are a positive effect of the tree crown cover where the difference in levels can be attributed to the positional attributes of the trees. This is also the case with respect to the buildings where a building is also assigned a base GAF value of zero so that the tree data increases the GAF values in the overlay without the positional analysis and then lose the SPU's gained when considering the negative effect the interference of the trees with building infrastructure.

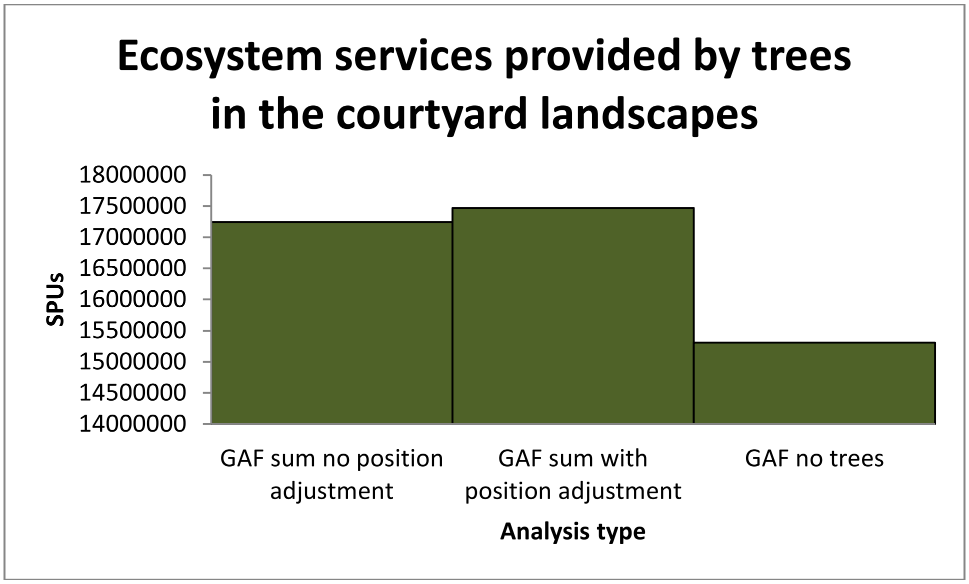

Figure 24 - Comparison of how trees affect the landscaped areas of the residential development projects.

Figure 24 illustrates the general gains in ecosystem services from trees over the entire residential area of Annedal. It can be seen that there are relative low levels of SPUs initially with only base GAF values but the values increase by 1 933 738 units by adding trees. The gains of 227 571units achieved by spatially analyzing the tree positions with respect to their surroundings are modest compared to the gains from the trees themselves but nevertheless are a good indicator of the importance of tree placement in order to maximize ecosystem services.

To summarize, it can be shown that there are many factors to consider with respect to trees and ecosystem services in the urban landscape. It is important that qualified individuals such as city planners, landscape architects and arborists work together to plan the urban landscape as each group may have insights which the others may have missed. More to the point, it is important to make use of available technology, such as GIS or Computer Automated Drafting (CAD), in order to recognize potential conflicts and adjust the plans accordingly before the actual building process is underway. GIS allows for the modeling of these situations and is able to visualize the potential conflicts or potential benefits making the decision making process much easier, especially for those who may have a decision making role but no technical expertise.

5. Discussion

By using GAF as a valuation system in combination with a series of spatial analyses, it can be shown that the trees themselves provide a base ecosystem service which can be measured in SPUs. This in itself is a valuable indicator of the level of ecosystem services provided by both the eco-effective surfaces of the planned development which can be used in a detailed planning process to determine if the ecosystem services meet the desired levels or whether they create, strengthen, protect or skip aspects which need to be addressed or readdressed.

The right tree in the right place is possibly the most important factor when analyzing the benefits from trees. The costs associated with tree care can be significant if the wrong tree species is chosen for a specific site. The costs incurred can be monetary, in terms of the cost of maintenance which counter acts benefits received from, for example, energy savings. Costs can also come in the form of CO_2 released from tree care operations or the release of sequestered carbon, if the tree needs to be removed. A weak tree may also provide a breeding ground for pests and diseases which can then spread to healthy species. Trees developed naturally in forests and it is there they get their genetic programming and can sometimes resist being planted “off site” to the point that if trees become weakened any stress agent can take over (Shigo, 1991).

The monetary valuation of ecosystem services is a difficult topic considering the systems involved are complex and interrelated and their value can be subjective. In certain situations ecosystem services from trees can be accurately measured based on scientifically proven methods such as the Eco Biogenic Emissions Model (Hirabayashi, 2012) or ultraviolet leaf reflectance of common urban trees and the prediction of reflectance from leaf surface characteristics (Grant et al., 2003). The i-Tree suite, for example, uses complex algorithms and advanced statistical analysis to estimate the ecosystem services provided by a single tree or entire urban forests within an acceptable margin of error. As previously mentioned these monetary values are based on concrete ecosystem services which can be measured based on the costs of local services, such as waste water treatment or heating costs, combined with local climatic and pollution data. It is more difficult to take into account less easily measured values such as the contribution of green spaces to the health and well-being of the urban citizen as well as other aesthetic benefits concerning trees.

Combining models such as i-Tree Eco and GAF in a GIS is one way of visualizing the data in order to address different audiences. The results can be tailored to best suite the audience in order to communicate the message that green infrastructure is necessary in urban environments. A contributory GIS process, for example, can visualize different types of geographic information in a variety of ways and during different phases of the planning process to ultimately guide the groups involved to the best decision. By being able to present the information in the form of easily understandable maps and figures to those who may not have a strong background within the subject of ecosystem services opens up new opportunities to incorporate them within the project.

A GIS platform, in this case ArcGIS, offers many tools which can be effectively used to analyze the ecosystem services provided by trees provided the input data is of good quality. In the case of this study there were often a variety of tools which could be used providing similar results as long as the data was based on the same scale. The end goal for all data was a raster format at the same resolution for all layers so that the layers could then be summed, subtracted and compared to other outputs. The scale of project when applying the methods need not be an issue as large parcels of land can be analyzed just as easily as small ones however the detail of the spatial analysis would need be appropriate for the scale. For example, it is unlikely that a single tree's position with respect to a building would be relevant when conducting a large scale analysis but at the detailed planning level it is. At larger scales, other, more suitable, analyses can be conducted such as crown cover studies or the ratio of pervious to impervious surfaces. Suitable GAF values would need to be determined, if not already available, to reflect the surfaces values for these scales. The most important factor to consider is how to employ the right tool for the right project depending on what type of result is required.

With careful scrutiny many flaws can be found within the methods of this analysis. One only needs to look at the situation from another perspective to begin to realize that all of the relevant factors may not be considered. Trees by roads, for example, intercept particles in the air and, in this sense, contribute to cleaner air (Nowak and Crane, 1998). On the other hand, if the prevalent winds are not taken into consideration the trees could trap polluted air along the road corridor instead (Nowak, 2015). Related to this is the fact that the trees pose potential risks to motorists or pedestrians along these routes. A study in the USA reveals that collisions with trees were often harmful where 61% of the collisions resulted in an injury (Bratton and Wolf, 2005). What is an acceptable level of risk of having large trees along a roadway and who decides what this acceptable level will be? Further complicating the situation is the fact that these potential risks must be evaluated by a person and there is always the risk for human error or missing risk factors that are hidden by the fact that trees are natural and complex entities which do not always behave in a predictable nature. An in depth evaluation of both the services and disservices with respect to trees and ecosystem services is a potential area of future study where additional aspects can be incorporated into the analysis providing a more detailed and complete picture.

It should also be noted that there is an element of subjectivity on how the different tree species characteristics were rated in order to assign them a GAF value and how the importance of these characteristics and their values were weighted in the analysis process. The values assigned to the supplementary ecosystem services were, as much as possible, based on the literature and previous work on the topic but the inherent nature of the topic, for example how leaf size and complexity can influence ecosystem services, could be considered too general and difficult to compare. Another example is how the size of the tree species is such a determining factor in how the tree species rates with respect to ecosystem services. In reality there can be large variations in the final size of a particular tree species based on the growing conditions and quality of the plant material. To summarize this subjectivity, choosing a large tree with a complex leaf structure (and possibly many other characteristics which can potentially provide ecosystem services) may or may not, in reality, provide more ecosystem services that another comparable species due to the complexity of the elements involved. The methods described can, however, be used as a general guide as long as the subjectivities and complexities are accounted for and the resulting GAF analysis is considered one part of a multi-part decision making process. A Multi-Criteria Analysis (MCA) method, for example, could be used in order to better weight the importance of the services and disservices where an appropriate methodology and criteria can be chosen to compare criteria and account for trade-offs (Atkinson et al., 2005). Using a MCA can, at the same time, address these subjectivity issues where the elements suspected of having a high level of subjectivity can be weighted accordingly to reduce the margins of error in the evaluation of the individual tree species. In order to carry this out with the best result, input is needed from industry professionals to be able to establish a suitable weighting scheme.

To conclude, there are no guarantees with respect to nature and how it interacts with urban infrastructure but what many recent studies show is that urbanism benefits from green infrastructure. A recent study in Toronto demonstrates this fact by linking the existence of urban trees to an improved health and well-being of its residents (Kardan et al., 2015). According to the C/O city project, cities contain more than 50% of the world's population and these people are dependent on the food, clean water, oxygen and moderate temperatures that nature provides (Keane et al., 2014). The question to be asked is if nature is necessary for urban environments then why are we taking it for granted or at least not including it as a high priority in the urban planning process? As suggested by Keith Logie, the Park Development Manager of the City of Edinburgh, desire often proceeds rationality and this can also be true in the case of tree planning and management (Logie, 2015). This can be both an advantage or a disadvantage for the fate of green spaces within the planning process depending on by whom and how the decisions are made. Countless green spaces, be it forests, wetlands or meadows, are at a disadvantage based on the fact that their true value is often overlooked due to the problems associated with properly valuing them and taking into consideration all of the services they provide. Raising the general awareness of the importance of green infrastructure by using a GAF analysis, or some other type of analysis, is key to sustainable development and building smart cities. The success of this rests, in part, on the presentation method whereby the results are presented in terms meaningful to the decision makers. In some cases monetary terms may be most effective where in other cases non-monetary units may be more relevant.

6. Conclusions

It can be concluded that a GIS spatial analysis using an appropriate valuation system can be used in the planning process to better incorporate and account for the ecosystem services provided by trees in the urban landscape. A GIS analysis using GAF is an effective way of evaluating the potential of ecosystem services in the sense that different scenarios can be compared in order to estimate the gains and anticipate the costs and, in doing so, provides a solid ground to make informed decisions during the planning stages. It can also be concluded, however, that the interactions between the built-up environment and the natural environment are complex and the services and/or disservices from trees are difficult to measure with any certainty. Using scientific methods based on sound principles can aid in choosing the right tree for the right place but can also never replace the aesthetic and practical aspects which can only be addressed by experience. A balance is needed when weighing the costs and benefits with respect to urban development and ecology and this study demonstrates that, with the right inputs, GIS can be a valuable tool to aid in this process.

GAF already takes into consideration ecosystem service providing traits, such as flowering or fruit bearing trees of bushes, and assigns them extra GAF points based on these traits. This research has built on this point system to include many other characteristics which provide ecosystem services in different forms and, by compiling this information in the form of a species specific ecosystem service database, the true service providing potential of each specific tree species can be better represented.

There are many geoprocessing and analysis tools available in modern GIS systems and with only a small amount of input data both best case and worst case scenarios can be modelled. The tree crown buffers are a good example of this. Plant books often give a range of both spread and height of a tree species and the actual size the tree species reaches depends on growing conditions such as soil and climate. The buffering of the different crown spreads and heights provides insight into the potential crown spread and this, combined with intersects with buildings and roads can reveal potential conflicts while still in the design stages. The overlay functions are also an important tool in these types of analysis in the sense that they can add ecosystem services value to otherwise low service providing surface areas such as asphalt. By being able to incorporate all functional layers in the landscape, such as the spread of tree crowns, into a two dimensional analysis the total value can be represented by a meaningful scale such as GAF.

The methods described in this study are realistic but any attempt to incorporate all relevant aspects into a single planning tool is still unrealistic. These methods are intended as tools to be used in conjunction with other tools, processes and, most important of all, the education and experience of city planners and landscape architects. It is only when a balance of function and aesthetics with respect to limitations and opportunities is achieved that the true value of trees can be appreciated and ecosystem services maximized.

The task of estimating, analyzing and maximizing ecosystem services is not an easy one due the complex nature of the topic. Tools are already available to aid in this endeavor and using GIS and GAF in combination with tree species choice and positional analysis is one more tool which can be added to the sustainable city planning toolbox.

References

AKBARI, H., POMERANTZ, M. & TAHA, H. 2001. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar energy* 70**,** 295–310.

ANDERSSON, Å. 2004. Ulvsunda industriområde: Inventering av industriella verksamheter samt mätning av spillvattenkvalié år 2003. Stockholm: Stockholm vatten.

ATKINSON, DEADMAN, P., DUDYCHA, D. & TRAYNOR, S. 2005. Multi-criteria evaluation and least cost path analysis for an arctic all-weather road. *Applied Geography***,** 287–307.

BLONIARZ, D. V. 2011. Street Trees, Overhead Utlitly Distribution, and Physical Infrastructure: Design Implictions, Maintenance Costs and Proposed Alternatives. *In:* FORESTRY, N. C. F. U. C. (ed.). Amherst, MA: USDA Forest Service.

BOLUND, P. & AND HUNHAMMAR, S. 1999. Ecosystem Services in Urban Areas. *Ecological Economics* 29**,** 293-301.

BRATTON, N. J. & WOLF, K. L. 2005. Trees and Roadside Safety in U.S. Urban Settings. *Proceedings of the 84th Annual Meeting of the Transportation Research Board.* Washington.

CITY OF SAN FRANCISCO, P. W. 2006. PRUNING STANDARDS FOR TREES CITY AND COUNTY OF SAN FRANCISCO. *In:* WORKS, S. F. P. (ed.). San Francisco City of San Francisco.

CONNECTICUT, U. O. *Plant Database* [Online]. Available: www.hort.uconn.edu/plants/search 2014].

COOMBES, A. J. (ed.) 2010. *The Book of Leaves: A leaf-by-leaf guide to six hundred of the world's greatest trees,* Chicago: The University of Chicago Press.

COSTELLO, L. R. & JONES, K. S. 1994. WUCOLS: Water Use Classification of Landscape Species -- A guide to water needs of landscape plants. Half Moon Bay, CA: University of California Cooperative Extension.

EMBRÉN, B., ALVEM, B. M., STÅL, Ö. & ORVESTEN, A. 2009. Växtbäddar i Stockholm stad - En handbook. *In:* TRAFIKKONTORET (ed.). Stockholm.

FORMAN, R. T. T. 2014. *Urban Ecology: Science of Cities,* Cambridge University Press.

GRANT, R. H., HEISLER, W. G. & JENKS, M. 2003. Ultraviolet leaf reflectance of common urban trees and the prediction of reflectance from leaf surface characteristics. *Agriculture and Forest Meteorology.*

HANSON, C., RANGANATHAN, J., ICELAND, C. & FINISDORE, J. 2012. The Corporate Ecosystem Services Review. World Resources Institute.

HIRABAYASHI, S. 2012. i-Tree Eco Biogenic Emissions Model Descriptions. New York: The Davey Tree Expert Company.

HIRABAYASHI, S. 2013. i-Tree Eco Precipitation Interception Model Descriptions. New York: The Davey Tree Expert Company.

HORTICOPIA. *Horticopia Plant Database* [Online]. Available: www.horticopia.com 2014].

KACZYNSKI, A. T. & HENDERSON, K. A. 2007. Environmental correlates of physical activity: a review of evidence about parks and
recreation. *Leisure Sciences,* 29**,** 315–354.

KARDAN, O., GOZDYRA, P., MISIC, B., MOOLA, F., PALMER, L. J., PAUS, T. & BERMAN, M. G. 2015. Neighborhood greenspace and health in a large urban center. *Scientific Reports,* 5:11610.
KEANE, Å., STENKULA, U., WIJKMARK, J., JOHANSSON, E., PHILIPSON, K. & HÅRD, L. 2014. Ekosystemtjänster i Stadsplanering: En vägledning. *In:* CITY, C. O. (ed.).
KUO, F. E. & SULLIVAN, W. C. 2001a. Aggression and violence in the inner city - Effects of environment via mental fatigue. *Environment and Behavior***,** 543.
KUO, F. E. & SULLIVAN, W. C. 2001b. Environment and crime in the inner city - Does vegetation reduce crime? *Environment and Behavior,* 33**,** 343.
LARSSON, D. 2007. Detaljplan för Lönnebergaparken mm i stadsdelen Mariehäll i Stockholm (del av Annedal). *In:* STADSBYGGNADSKONTORET (ed.). Stockholm: Stadsbyggnadskontoret, Strategiska avdelning.
LOGIE, K. Estimating the value of trees and green spaces in Edinburgh using i-Tree and impact assesment tools. European i-Tree Conference
2015 Alnarp, Sweden.
MCHALE, M. R., MCPHERSON, E. G. & BURKE, I. C. 2007. The potential of urban tree plantings to be cost effective in carbon credit markets. *Urban forestry & Urban Greening,* 6**,** 49–60.
MCPHERSON, E. G., SIMPSON, J. R., PEPER, P. J., GARDNER, S. L., VARGAS, K. E. & XIAO, Q. 2007. Northeast Community Tree Guide: Benefits, Costs, and Strategic Planting. *In:* SERVICE, F. (ed.). Albany: U.S. Department of Agriculture.
MILLENIUM ECOSYSTEM ASSESMENT BOARD 2005. Ecosystems and Human Well-Being: Synthesis. Washington: World Resources Insta.
NOWAK, D. J. 2008. Species Selector (Beta) Utility. *In:* STATION, N. R. (ed.). New York: USDA Forest Service.
NOWAK, D. J. i-Tree History and Overview. European i-Tree Confrence, 2015 Alnarp, Sweden.
NOWAK, D. J. & CRANE, D. E. 1998. The Urban Forest Effects (UFORE) Model: Quantifying Urban Forest Structure and Functions. *In:* STATION, N. R. (ed.). New York: USDA Forest Service.
NOWAK, D. J., CRANE, D. E. & STEVENS, J. C. 2006. Air pollution removal by urban trees and shrubs in the United States. *Urban forestry & urban greening,* 4**,** 115–123.
NOWAK, D. J., CRANE, D. E., STEVENS, J. C. & IBARRA, M. 2002. Brooklyns urban forest Gen. Tech. Rep. NE-290. Newton Square: U.S. Department of Agriculture, Forest Service, Northern Research Station.
PAGE, S. & OLDS, M. (eds.) 1997. *Botanica: The illustrated A-Z of over 10,000 garden plants and how to cultivate them,* Königswinter: Könemann.
PEPER, P. J., MCPHERSON, E. G. & MORI, S. M. 2001. Equations for predicting diameter, height, crown width, and leaf area of San Joaquin Valley street trees. *Journal of Arboriculture,* 27**,** 12.
SMARDON, R. C. 1988. Perception and aesthetics of the urban-environment - review of the role of vegetation. *Landscape and Urban Planning,* 15**,** 85–106.
STOCKHOLMS STAD 2011. Norra Djurgårdsstaden Grönytefaktor 2.0 ed. Stockholm: Stockholms Stad Exploteringskontoret

STOCKHOLMS STAD 2016. Stockholm växer: Bromma, Annedal. *In:* STAD, S. (ed.).
STÅNGBY 2011/2012. Stångbykatalogen. Stockholm: Stångby.
TELL, J. 2008. *Träd kan rädda världen*, Värnamö, Max Ström.
VOLLBRECHT, K., ALM, G. & VELTMAN, H. 2001. *Beskärningsboken*, Natur och Kultur.
WURSTER, D. & ARTMANN, M. 2014. Development of a Concept for Non-monetary Assessment of Urban Ecosystem Services at the Site Level. *Ambio*, 43**,** 454-465.

Appendix A: Stockholm Royal Seaport Green Area Factor (GAF)

GAF is a system of evaluating outdoor surface areas based on the characteristics which contribute to minimizing the negative effects of climate change, increasing the social value of the space while also promoting high levels of biodiversity. A full description of the GAF methods and how the valuation system is derived can be found in the project documents. The value for each factor is scientifically based on the most important ecosystem services for the Stockholm Royal Seaport development.
http://www.stockholm.se/-/Sok/?q=norra+dagvattensystemet+gr%C3%B6nytefaktor&resid=1625635766&ss=t&uaid=20E378B7B3B2CDBF5D39A75B28C90A19:3137322E32332E3232382E313339:5247668831599662689

Type	Desciption_en	Value
Base Factor Vegetation	Integrated balcony planting boxes	0.3
Base Factor Vegetation	Ground level surface	2
Base Factor Vegetation	Green roof (>300m)	0.4
Base Factor Vegetation	Green roof (50-300mm)	0.1
Base Factor Vegetation	Living walls	0.4
Base Factor Vegetation	Planting bed (200-800mm)	0.2
Base Factor Vegetation	Planting bed (>800mm)	1.2
Base Factor Water	Hard surfaces with joints	0.05
Base Factor Water	Half-open hard surfaces	0.2
Base Factor Water	Open hard surfaces	0.3
Base Factor Water	Sealed surfaces	0
Base Factor Water	Landscape water features	1
Supplementary Factor Vegetation and Biodiversity	Bushes with berries	0.4
Supplementary Factor Vegetation and Biodiversity	Bushes - general	0.2
Supplementary Factor Vegetation and Biodiversity	Insect nesting holes	2
Supplementary Factor Vegetation and Biodiversity	Trees with berries	0.4
Supplementary Factor Vegetation and Biodiversity	Diversity of green roof	0.1
Supplementary Factor Vegetation and Biodiversity	Vegetation level diversity	0.7
Supplementary Factor Vegetation and Biodiversity	Oak habitat	3
Supplementary Factor Vegetation and Biodiversity	Nurse log	2
Supplementary Factor Vegetation and Biodiversity	Bird nesting sites	2
Supplementary Factor Vegetation and Biodiversity	Butterfly habitat	1
Supplementary Factor Vegetation and Biodiversity	Hanging or climbing plants	0.3
Supplementary Factor Vegetation and Biodiversity	Medium sixed tree (stem 20-30)	1.5
Supplementary Factor Vegetation and Biodiversity	Native plant species choice	0.5
Supplementary Factor Vegetation and Biodiversity	Large tree (stem >30)	2.4
Supplementary Factor Vegetation and Biodiversity	Small tree (stem 16-20)	1
Supplementary Factor Vegetation and Climate Smart Effects	Multilayered green roof	0.1
Supplementary Factor Vegetation and Climate Smart Effects	Pergola, foliage corridor providing shade	0.5
Supplementary Factor Vegetation and Climate Smart Effects	Shade providing tree placement	0.5
Supplementary Factor Vegetation and Recreational Value	Bushes providing berries with edible fruit	0.2
Supplementary Factor Vegetation and Recreational Value	Floral features	0.2
Supplementary Factor Vegetation and Recreational Value	Balcony and terrace cultivation	0.5
Supplementary Factor Vegetation and Recreational Value	Bushes, aesthetic value	0.1
Supplementary Factor Vegetation and Recreational Value	Bird nesting boxes, aesthetic value	0.2
Supplementary Factor Vegetation and Recreational Value	Green area for ball play	1.2
Supplementary Factor Vegetation and Recreational Value	Cultivation areas	0.5
Supplementary Factor Vegetation and Recreational Value	Pergola ect.	0.3
Supplementary Factor Vegetation and Recreational Value	Visible green roof	0.1
Supplementary Factor Vegetation and Recreational Value	Fruit trees and flowering trees	0.2
Supplementary Factor Vegetation and Recreational Value	Shared terrace	0.2
Supplementary Factor Vegetation and Recreational Value	Tree, aesthetic value	0.5
Supplementary Factor Water and Biodiversity	Hard surface drainage to vegetation	0.1
Supplementary Factor Water and Biodiversity	Water available for biological elements	4
Supplementary Factor Water and Biodiversity	Delay of surface run-off in gutters and basins	0.2
Supplementary Factor Water and Biodiversity	Delay of surface run-off in underground basins	0.1
Supplementary Factor Water and Biodiversity	Gutters with temporary run-off retention characteristics	2
Supplementary Factor Water and Climate Smart Effects	Fountains providing cooling effects	0.3
Supplementary Factor Water and Climate Smart Effects	Ponds and other types of reservoirs which hold water during dry periods	0.5
Supplementary Factor Water and Climate Smart Effects	Water collection system for irrigation	0.05
Supplementary Factor Water and Recreational Value	Water available for biological elements, aesthetic value	1
Supplementary Factor Water and Recreational Value	Sound effects from water features	0.3
Supplementary Factor Water and Recreational Value	Water mirroring features	1

Series from Lund University

Department of Physical Geography and Ecosystem Science

Master Thesis in Geographical Information Science

1. *Anthony Lawther:* The application of GIS-based binary logistic regression for slope failure susceptibility mapping in the Western Grampian Mountains, Scotland. (2008).
2. *Rickard Hansen:* Daily mobility in Grenoble Metropolitan Region, France. Applied GIS methods in time geographical research. (2008).
3. *Emil Bayramov:* Environmental monitoring of bio-restoration activities using GIS and Remote Sensing. (2009).
4. *Rafael Villarreal Pacheco:* Applications of Geographic Information Systems as an analytical and visualization tool for mass real estate valuation: a case study of Fontibon District, Bogota, Columbia. (2009).
5. *Siri Oestreich Waage:* a case study of route solving for oversized transport: The use of GIS functionalities in transport of transformers, as part of maintaining a reliable power infrastructure (2010).
6. *Edgar Pimiento:* Shallow landslide susceptibility – Modelling and validation (2010).
7. *Martina Schäfer:* Near real-time mapping of floodwater mosquito breeding sites using aerial photographs (2010).
8. *August Pieter van Waarden-Nagel:* Land use evaluation to assess the outcome of the programme of rehabilitation measures for the river Rhine in the Netherlands (2010).
9. *Samira Muhammad:* Development and implementation of air quality data mart for Ontario, Canada: A case study of air quality in Ontario using OLAP tool. (2010).
10. *Fredros Oketch Okumu*: Using remotely sensed data to explore spatial and temporal relationships between photosynthetic productivity of vegetation and malaria transmission intensities in selected parts of Africa (2011).
11. *Svajunas Plunge:* Advanced decision support methods for solving diffuse water pollution problems (2011).
12. *Jonathan Higgins:* Monitoring urban growth in greater Lagos: A case study using GIS to monitor the urban growth of Lagos 1990 - 2008 and produce future growth prospects for the city (2011).
13. *Mårten Karlberg:* Mobile Map Client API: Design and Implementation for Android (2011).
14. *Jeanette McBride:* Mapping Chicago area urban tree canopy using color infrared imagery (2011).
15. *Andrew Farina:* Exploring the relationship between land surface temperature and vegetation abundance for urban heat island mitigation in Seville, Spain (2011).
16. *David Kanyari*: Nairobi City Journey Planner: An online and a Mobile Application (2011).

17. *Laura V. Drews:* Multi-criteria GIS analysis for siting of small wind power plants - A case study from Berlin (2012).
18. *Qaisar Nadeem:* Best living neighborhood in the city - A GIS based multi criteria evaluation of ArRiyadh City (2012).
19. *Ahmed Mohamed El Saeid Mustafa:* Development of a photo voltaic building rooftop integration analysis tool for GIS for Dokki District, Cairo, Egypt (2012).
20. *Daniel Patrick Taylor*: Eastern Oyster Aquaculture: Estuarine Remediation via Site Suitability and Spatially Explicit Carrying Capacity Modeling in Virginia's Chesapeake Bay (2013).
21. *Angeleta Oveta Wilson:* A Participatory GIS approach to *unearthing* Manchester's Cultural Heritage '*gold mine'* (2013).
22. *Ola Svensson:* Visibility and Tholos Tombs in the Messenian Landscape: A Comparative Case Study of the Pylian Hinterlands and the Soulima Valley (2013).
23. *Monika Ogden:* Land use impact on water quality in two river systems in South Africa (2013).
24. *Stefan Rova:* A GIS based approach assessing phosphorus load impact on Lake Flaten in Salem, Sweden (2013).
25. *Yann Buhot:* Analysis of the history of landscape changes over a period of 200 years. How can we predict past landscape pattern scenario and the impact on habitat diversity? (2013).
26. *Christina Fotiou:* Evaluating habitat suitability and spectral heterogeneity models to predict weed species presence (2014).
27. *Inese Linuza:* Accuracy Assessment in Glacier Change Analysis (2014).
28. *Agnieszka Griffin:* Domestic energy consumption and social living standards: a GIS analysis within the Greater London Authority area (2014).
29. *Brynja Guðmundsdóttir:* Detection of potential arable land with remote sensing and GIS - A Case Study for Kjósarhreppur (2014).
30. *Oleksandr Nekrasov:* Processing of MODIS Vegetation Indices for analysis of agricultural droughts in the southern Ukraine between the years 2000-2012 (2014).
31. *Sarah Tressel:* Recommendations for a polar Earth science portal in the context of Arctic Spatial Data Infrastructure (2014).
32. *Caroline Gevaert:* Combining Hyperspectral UAV and Multispectral Formosat-2 Imagery for Precision Agriculture Applications (2014).
33. *Salem Jamal-Uddeen:* Using GeoTools to implement the multi-criteria evaluation analysis - weighted linear combination model (2014).
34. *Samanah Seyedi-Shandiz:* Schematic representation of geographical railway network at the Swedish Transport Administration (2014).
35. *Kazi Masel Ullah:* Urban Land-use planning using Geographical Information System and analytical hierarchy process: case study Dhaka City (2014).
36. *Alexia Chang-Wailing Spitteler:* Development of a web application based on MCDA and GIS for the decision support of river and floodplain rehabilitation projects (2014).

37. *Alessandro De Martino:* Geographic accessibility analysis and evaluation of potential changes to the public transportation system in the City of Milan (2014).
38. *Alireza Mollasalehi:* GIS Based Modelling for Fuel Reduction Using Controlled Burn in Australia. Case Study: Logan City, QLD (2015).
39. *Negin A. Sanati:* Chronic Kidney Disease Mortality in Costa Rica; Geographical Distribution, Spatial Analysis and Non-traditional Risk Factors (2015).
40. *Karen McIntyre:* Benthic mapping of the Bluefields Bay fish sanctuary, Jamaica (2015).
41. *Kees van Duijvendijk:* Feasibility of a low-cost weather sensor network for agricultural purposes: A preliminary assessment (2015).
42. *Sebastian Andersson Hylander:* Evaluation of cultural ecosystem services using GIS (2015).
43. *Deborah Bowyer:* Measuring Urban Growth, Urban Form and Accessibility as Indicators of Urban Sprawl in Hamilton, New Zealand (2015).
44. *Stefan Arvidsson:* Relationship between tree species composition and phenology extracted from satellite data in Swedish forests (2015).
45. *Damián Giménez Cruz*: GIS-based optimal localisation of beekeeping in rural Kenya (2016).
46. *Alejandra Narváez Vallejo:* Can the introduction of the topographic indices in LPJ-GUESS improve the spatial representation of environmental variables? (2016).
47. *Anna Lundgren:* Development of a method for mapping the highest coastline in Sweden using breaklines extracted from high resolution digital elevation models. (2016).
48. *Oluwatomi Esther Adejoro:* Does location also matter? A spatial analysis of social achievements of young South Australians. (2016).
49. *Hristo Dobrev Tomov:* Automated temporal NDVI analysis over the Middle East for the period 1982 - 2010. (2016).
50. *Vincent Muller:* Impact of Security Context on Mobile Clinic Activities A GIS Multi Criteria Evaluation based on an MSF Humanitarian Mission in Cameroon. (2016).
51. *Gezahagn Negash Seboka:* Spatial Assessment of NDVI as an Indicator of Desertification in Ethiopia using Remote Sensing and GIS. (2016).
52. *Holly Buhler:* Evaluation of Interfacility Medical Transport Journey Times in Southeastern British Columbia. (2016).
53. *Lars Ole Grottenberg*: Assessing the ability to share spatial data between emergency management organisations in the High North (2016).
54. *Sean Grant:* The Right Tree in the Right Place: Using GIS to Maximize the Net Benefits from Urban Forests (2016).