Measuring the benefits of urban nature-based solutions through quantitative assessment tools

Oscar Alvarado
Master's Thesis - Water Science and Management
-
15 August 2019

Title	Measuring the benefits of urban nature-based solutions through quantitative assessment tools
University	Universiteit Utrecht
Host organization	Witteveen+Bos Raadgevende ingenieurs B.V.
Document	Master's Thesis
	Oscar Alfonso Alvarado Medrano
Status	Final version
Date	15 August 2019
Program	MSc Water Science and Management
Supervisor	Prof. Dr. Marc Bierkens
Supervisor	Dr. Ivana Prusina
Author	Oscar Alvarado
Contact	o.a.alvarado@students.uu.nl
	oscar.alvarado@witteveenbos.com
Initials	ALVO
Word count	13,000
Number of pages	69
Keywords	Nature-based solutions, Urban ecosystem services, Assessment tools, Comparative tools evaluation, i-Tree Eco, Value case

TABLE OF CONTENTS

ABSTRACT

A growing number of tools have been developed and applied to measure the benefits that healthy and functioning ecosystems provide to human well-being. However, few of these tools have been specifically designed for urban environments, which could be a reason for their limited adoption by urban decision-makers and spatial planners. This has resulted in widespread under-estimation of the potential and actual ecosystem services, and thus societal benefits, that nature-based solutions (NBS) can provide within cities.

In order to facilitate the use of empirical evidence as a rationale for greater NBS implementation in cities, this study developed and applied a comprehensive and systematic methodology for selecting, comparing and scoring ecosystem services assessment tools according to scientific criteria and practical requirements. This evaluation was undertaken from the perspective of Witteveen+Bos, an engineering consultancy firm in the Netherlands that wishes to enhance its empirical knowledge base of the contributions of NBS to human well-being in cities.

The scoring matrix presented in this study was aimed at assessing and ranking the suitability of open-access, quantitative assessment tools in capturing multiple ecosystem services across different urban landscape domains and societal contexts. Based on specific screening and evaluation criteria, i-Tree Eco was judged to be the best performing tool out of six tools and was subsequently applied to an urban case study (i.e. a large park in Amsterdam called Park Frankendael).

The application of i-Tree Eco served to further test its effectiveness, feasibility and limitations under Dutch urban conditions. i-Tree Eco is the flagship software of a suite of tools developed to analyse ecosystem structure, function, services and values. The basis for i-Tree Eco suite is tree allometric relationships between biomass, volume and function using measurements such as diameter at breast height (DBH), crown size and tree height.

The end product of this study was the creation of a value case for Park Frankendael which highlights key quantitative, qualitative, monetised and non-financial insights into the multiple ecosystem services that are currently being provided by the park to the city and its residents. Future applications of the i-Tree Eco tool in urban projects with natural ecosystem elements can further strengthen the value case for urban NBS and promote their inclusion into urban planning and decision-making.

ACKNOWLEDGMENTS

First and foremost I would like to sincerely thank my two main supervisors, Dr. Marc Bierkens for his valuable critiques that helped elevate my work, and Dr. Ivana Prusina for her professional guidance during the research process and beyond. I am also very grateful to Jaïr Smits for the expertise and insights that he continues to share with me.

The friendliness and knowledge of the Smart+Healthy Cities and Energietransitie teams at Witteveen+Bos is also greatly appreciated.

I would also like to express my heartfelt gratitude to my family for all of their support throughout my study. To Astghik for her ability to inspire and bring out the very best in me. To Oscar and Maribel for encouraging me to pursue my career as a scientist no matter where it led, and to Christopher for always being in touch even from far away.

Finally, I could not have reached the end of this Master's study without my close friends Sotirios, Bart and Jack. I genuinely hope a time will come in the near future where we have the opportunity to once again study and learn together.

My special thanks are also extended to Henk Nieboer, Fokke de Jong, Dr. Rens van Beek, Dr. Alexander van Oudenhoven as well as Marion van der Bliek and Jacqueline Rijken (Vereniging Vrienden van Frankendael) for their assistance during my research.

ABBREVIATIONS

ARIES	Artificial Intelligence for Ecosystem Services
B£ST	Benefits Estimation Tool
ES	Ecosystem services
ESTIMAP	Ecosystem Services Mapping Tool
EU	European Union
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
IUCN	International Union for Conservation of Nature
MEA	Millennium Ecosystem Assessment
NBS	Nature-based solutions
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (Dutch National Institute for Public Health and the Environment)
SolVES	Social Values for Ecosystem Services
TEEB	The Economics of Ecosystems and Biodiversity
UN	United Nations
USDA	United States Department of Agriculture
UU	Universiteit Utrecht
W+B	Witteveen+Bos

1

INTRODUCTION

Our cities are growing but our nature is dying.

1.1 Background

Cities and their populations all around the world continue to expand at an unprecedented rate. There is general agreement that for the first time in human history, more than half of the world's population now lives in cities. By 2050 the global urban population is expected to reach 68 percent, rising to 85 percent by 2100 (UN, 2018). In order to accommodate this mass migration of people from rural to urban areas, natural landscapes in almost every region of the world have been transformed into sprawling urban settlements commonly defined by the prevalence of constructed 'grey' urban infrastructure (Davies & Lafortezza, 2019). This includes roads, pavements, buildings and other forms of constructed assets that displace previously existing natural habitats and ecosystems. These patterns of development are often accompanied by measurable decreases in the quantity and quality of natural areas in cities, and reductions in regular human interaction with the natural world (Bratman et al., 2019).

It is becoming increasingly visible that the rise and growth of modern cities on almost every continent is the most prominent feature of our collective human development within the last two centuries. The widespread land use transformations that have taken place over the past two centuries not only require massive amounts of energy and resources, but also place intense pressure on local, regional and global natural ecosystems, resulting in extensive habitat fragmentation, biodiversity loss, collapse of natural resources and degradation of important ecosystem functions (Haase et al., 2014; Boumans et al., 2015). Modern cities can thus no longer afford to ignore the disproportionate footprints that their developmental paths continue to have on life supporting systems near and far (Pickett et al., 2008).

At the same time, growing urban populations are facing numerous environmental, socioeconomic and public health challenges that are significantly impacting the quality of life and liveability of cities. These urban challenges include poor air quality (Hartig et al., 2014), urban heat stress (van den Bosch & Ode Sang, 2017) and flooding (van Wesenbeeck et al., 2017), as well as the accumulation of physical and psychological stressors that are detrimental to human health (Rugel et al., 2019).

Furthermore, the risks and impacts of extreme events to vulnerable urban populations are pushing cities to the forefront of the global response to climate change mitigation and adaptation (Frantzeskaki et al., 2019). With climate change accelerating and urbanisation largely continuing in an unsustainable manner, cities are under increasing pressure to minimise their emissions of greenhouse gases, improve the resiliency of urban infrastructure to future climate change, and tackle their urban challenges with solutions that also make positive contributions to human well-being and biodiversity. This implies a shift away from historic urbanisation paradigms and trends towards more nature inclusive pathways.

1.2 Nature-based solutions

One of the many responses to the environmental challenges that have arisen as a result of large-scale urbanisation and land use transformations is the field of urban ecology; the study of the ecological sustainability of cities embedded within biophysical-social complexes (Pickett et al., 2008). Within this field, the desire to promote the inclusion of nature in urban environments is brought forward as an attempt to (partially) restore some of the extent to which natural ecosystems have been degraded (Davies & Lafortezza, 2019) as well as to restore humanity's connection to natural settings, both physically and psychologically (Kaplan, 1984). However there is a third dimension to establishing cities that are more inclusive of ecosystems and the habitats they provide for biodiversity; the use of natural structures and processes as a means of addressing specific urban challenges. In this context, natural ecosystems in urban areas can be viewed as nature-based alternatives to traditional grey infrastructure solutions and unsustainable spatial planning patterns.

The emergence of the concept of nature-based solutions (NBS) is relatively recent and builds upon previous ‘metaphors’ related to introducing nature in cities, such as urban forestry, ecological engineering, building with nature, (blue-)green infrastructure, natural capital, and ecosystem-based adaptation (Escobedo et al., 2019). For the purposes of this study, NBS are defined as *the use of natural or modified ecosystems to address societal challenges while simultaneously providing a range of long-term benefits to human well-being and biodiversity* (European Commission, 2015).

The benefits of NBS to address urban challenges can also be summarised into four broad themes (European Commission, 2015):

1. Enhancing sustainable urbanisation
2. Restoring degraded ecosystems
3. Developing climate change adaptation and mitigation
4. Improving risk management and resilience

However, the usefulness of NBS in cities goes beyond providing direct solutions to challenges. In fact, the multifunctional capacity of NBS, derived from its underlying ecosystem properties and processes, enable such interventions to enhance spatial quality (i.e. living environment) of the surrounding area in a variety of tangible and intangible ways. For example, NBS have been shown to improve the social capital of a neighbourhood by facilitating a sense of community and belonging that is closely associated with improvements in mental health (Rugel et al., 2019). From an economic perspective “investing and maintaining a city's NBS asset base yields economically valuable services which support value addition and employment in the local economy” (de Wit et al., 2012).

This growing body of evidence of the many benefits of NBS (van den Bosch & Nieuwenhuijsen, 2017) has led to the prioritisation of NBS within international environmental policy agendas (IUCN, 2016), multi-lateral research programmes such as the European Union’s (EU) Horizon 2020 (European Commission, 2015), and World Bank strategies for disaster risk management (van Wesenbeeck et al., 2017).

However, despite the fact that “most research of today points in the direction that public health, in general, can be improved by exposure to natural spaces” (van den Bosch & Nieuwenhuijsen, 2017), there continues to be a significant “implementation gap” (Cook & Spray, 2012) for NBS in general, and within cities in particular. Therefore, ***additional efforts are still required to demonstrate how empirical evidence of the multiple benefits of urban NBS can be collected and incorporated into decision-making processes in cities***. The current study attempts to contribute to such efforts by undertaking a replicable approach to assess and quantify ecosystem services (ES) from urban NBS in a manner that is comprehensible and accessible to all (Nemec & Raudsepp-Hearne, 2013; Eggermont et al., 2015).

Annex I contains several examples of well-known urban NBS for illustrative purposes.

1.3 Problem description

Societal problem

The publication of the UN Millennium Ecosystem Assessment (MEA) in 2005 was a significant milestone in examining the two-way relationships between humans and ecosystems on a global scale, while at the same time mainstreaming the idea that humans and society benefit from ES.

Yet despite greater acknowledgment of the potential benefits of NBS, their practical implementation in cities remains “marginal, fragmented, and highly uneven within and between cities” (Naturvation, n.d.). This is partially a result of the fact that access to empirical evidence, and the tools required to collect such information, is largely still restricted to academic and research circles.

There is an increasing need among city planners and local stakeholders for readily available information and accessible assessment tools to guide, or at least inform, NBS decision making in cities (O'Farrell et al., 2012). The unceasing, large-scale loss of natural areas in cities implies that urban authorities (and society in general) continue to underestimate or fail to comprehend the value that NBS can offer (Bos & Vogelzang, 2018; Short et al., 2019).

By improving both the accessibility to tools and the knowledge transfer of empirical evidence, the barriers for adopting NBS can be lowered to the point where they become the "new normal" in urban infrastructure management and spatial planning (Davies & Lafortezza, 2019).

Scientific problem

The complex dynamics that embody human-ecosystem relationships have received much attention throughout an ever growing body of literature (Hassan et al., 2005; Elmhagen et al., 2015; Brown et al., 2018; Czúcz et al., 2018). Despite this attention urban ecosystems, where natural landscapes have experienced the largest amount of change and degradation, continue to be greatly underrepresented in global assessments of ecosystems (Haase et al., 2014). As cities and their populations keep expanding, research is required to understand the connections between ecosystems and human well-being in *urban contexts*, especially since intense land use pressures continue to negatively affect the health and integrity of urban ecosystems, their capacity to deliver benefits, and in turn their ability to meet societal expectations (Elmhagen et al., 2015; Krauze & Wagner, 2019).

Within urban contexts, empirical evidence of the benefits of urban NBS should be collected in a systematic way that allows for the measuring of *multiple benefits at a time*, something which continues to receive limited attention (O'Farrell et al., 2012). A full accounting of the benefits of urban NBS is an important prerequisite for understanding the dynamics across benefits (i.e. synergies and trade-offs) and for further optimising the design of urban NBS vis-à-vis traditional "grey" engineering infrastructure and other common forms of urban development (Dammers et al., 2019).

Finally, a number of authors have highlighted the urgent need to compare, test and validate the performance of a rapidly growing range of benefit assessment tools across a wide variety of settings (Vigerstol & Aukema, 2011; Bagstad et al., 2013; Nemec & Raudsepp-Hearne, 2013). While there have been several useful reviews of standardised 'off the shelf' assessment tools in the literature, certain limitations of those previous reviews include: being limited in scope in the number (Nelson & Daily, 2010) and type (Crossman et al., 2013) of tools reviewed, being purely qualitative in nature (Bagstad et al., 2013), and focusing only on general trends in data sources (Martínez-Harms & Balvanera, 2012), services measured (Haase et al., 2014) or frequency of particular indicator types (Egoh et al., 2012).

Thus, a quantitative and systematic approach for screening, ranking and scoring a variety of assessment tools would provide a useful framework for future tool evaluations where direct comparisons are desired, and where criteria can be selected according to the scientific or practical needs of end users.

Ultimately, testing the urban suitability of assessment tools also requires *in situ* application on urban NBS case studies. By attempting to measure multiple benefits from a local urban NBS, new insights can be obtained that complement the current body of knowledge surrounding urban NBS while laying the foundation for additional research into how future assessments can be validated and integrated with other methods.

Specific problem for Witteveen+Bos

Witteveen+Bos (W+B) is an engineering and consultancy firm based in the Netherlands. Most of their projects are in the infrastructure, construction, water and the environmental sectors. Since 2010, W+B has committed itself developing its own sustainable design principles (Figure 1) aimed at promoting sustainability-oriented solutions in every project (Witteveen+Bos, n.d.). Amongst these principles is that of nature-based design, which focuses on integrating the use of natural processes to strengthen engineering designs and deliver additional project benefits. The seven design principles shown in Figure 1 are currently being embedded within all business operations of W+B (Witteveen+Bos, 2018).

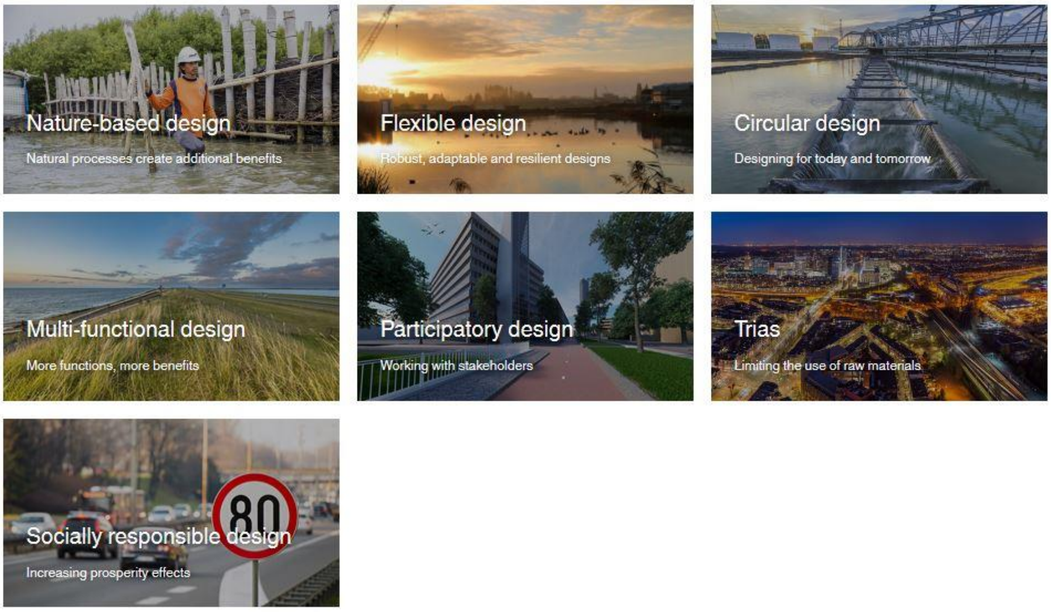


Figure 1 - The seven sustainable design principles developed and employed by Witteveen+Bos to contribute to the Sustainable Development Goals (Witteveen+Bos, n.d.)

To this end, a comprehensive review of assessment tools for NBS in urban areas will allow W+B to determine which, if any, tools for valuing ES are suitable for operational use across the company. This knowledge and capability is particularly desired within urban contexts for two main reasons. First, since the majority of NBS projects at W+B currently relate to coastal management or renewable energy infrastructure, W+B hopes to expand its services to include a greater range of urban NBS projects. The ability to accurately measure the ES of diverse urban NBS projects is crucial to enhancing its service offering to clients. It is also crucial that any company, including W+B, understand the costs and resources needed to apply and integrate these tools into existing operations and future projects (Bagstad et al., 2013).

Second, W+B aims to strengthen the value case for NBS in projects where there is potential for their inclusion. Once the ES of NBS are accurately measured, it is vital to be able to present this empirical evidence in a way that is relevant to a diverse set of potential clients, stakeholders and partners. Thus, W+B would further benefit from understanding the most effective methods for translating measurements of ES into societal benefits through the formulation and application of a value case for real-life NBS examples. Such an evidence-based value case would be grounded in peer-reviewed literature and best practices, and prepared according to the needs of different potential clients.

1.4 Aim and objectives

The principal aim of this study is to develop and facilitate the interpretation of empirical evidence of the multiple benefits of NBS as a rationale for their more widespread implementation in urban contexts by evaluating existing quantitative assessment tools and applying the best ranked tool to create a value case for an urban NBS case study.

The results of this study are therefore intended to raise awareness and encourage the adoption of existing assessment tools by urban decision-makers and spatial planners while simultaneously distributing the evidence and knowledge base regarding NBS benefits to non-technical but highly relevant urban community stakeholders.

1.5 Research question

The main research question that will be answered by this study is:

Which assessment tools are most effective for measuring the multiple benefits from NBS in cities, and how can the empirical evidence from such a tool be captured and presented for an urban case study in a way that is relevant to local stakeholders?

Related sub-questions include:

- What are the main strengths and weaknesses of a selection of existing assessment tools for measuring multiple ecosystem services from a wide range of urban NBS?
- How can such assessment tools be evaluated and compared in terms of scientific validity and feasibility for everyday use in measuring ecosystem services?
- How effective is the performance of the best ranked assessment tool when applied to an urban NBS case study, and what are the practical limitations for future applications?
- What features are required that would allow for a context-specific value case to be developed that is grounded in empirical evidence and remains relevant to non-technical audiences?

2 THEORETICAL FRAMEWORK

"Because almost no ecosystems remain un-impacted by humans and humans cannot exist without ecosystems, protection and sustainable use of ecosystems are no longer an isolated interest but a key component of global sustainable development." - Haase et al. (2014)

As previously mentioned, the definition of NBS used for this study is *the use of natural or modified ecosystems to address societal challenges while simultaneously providing a range of long-term benefits to human well-being and biodiversity* (European Commission, 2015). The principle components of this definition, highlighted in bold, are further defined below in order to ensure clarity and consistency moving forward.

The term **ecosystems** refers to complex **natural and semi-natural systems** containing abiotic and biotic elements, as well as natural processes, that interact with each other and underpin ecological habitats for biodiversity (MEA, 2005). Compared to rural and natural areas, ecosystems in urban landscapes are often found to be more fragmented, degraded and vulnerable to land conversions that negatively impact biodiversity and functionality (Kabisch et al., 2016).

The **societal challenges** that are most relevant for NBS to address in urban areas include environmental pollution that negatively impacts physical health (Rugel et al., 2019), stress-related factors of the urban environment that affect mental health (Kaplan, 1984), and increasing vulnerability to extreme events (i.e. flooding, urban heat stress) that are being exacerbated by climate change (Frantzeskaki et al., 2019).

The **long-term benefits** that humans gain from nature are synonymous with the analytical concept of **ecosystem services**. Ecosystem services (ES) are defined as the benefits that humans obtain from ecosystems, which are produced by interactions within the ecosystem (MEA, 2005). This concept has arguably become the most widely used approach in the literature for conceptualising and analysing how society depends on nature, and thus serves as a useful basis in this study for discussing the benefits of NBS (Lele et al., 2013).

2.1 Ecosystem health and services

Figure 2 illustrates the framework used by the MEA (2005) to show the general relationship between ES and human well-being. As can be seen, ES can be subdivided into four broad categories, representing a wide range of goods and services: provisioning, regulating, cultural and supporting. Some of these ES are local (provision of pollinators), others are regional (flood control or water purification), and still others are global (climate regulation) (Hassan et al., 2005). In a similar fashion, there are numerous ways that human well-being can benefit from the provision of ES (Figure 2).

This study makes a significant distinction between the *instrumental value of nature*, reflected in the utilitarian provision of ES to enhance human well-being, and the *intrinsic value of nature*, which reflects a biocentric perspective that is prominent in the field of conservation biology (Jax et al., 2013; Lele et al. 2013). While the former is crucial to building a strong value case for greater NBS implementation in cities, the latter is equally valid to ensure that biodiversity and ecological integrity are central to all considerations of urban ecosystems.

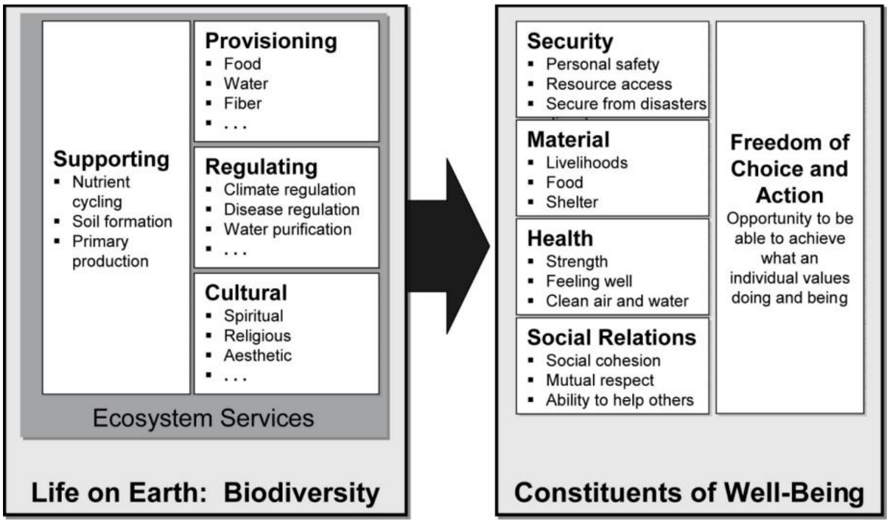


Figure 2 - The Millennium Ecosystem Assessment (2005) framework as presented by Lele et al. (2013)

Provisioning, regulating and cultural ES (Figure 2) are often perceived to be more beneficial to society due to the direct and tangible impacts that they can have on human well-being. The provision of food, the cooling effects of trees, and recreational space are examples of ES that can be easily viewed by people as benefits directly stemming from the instrumental value of nature (de Groot et al., 2002). On the other hand, supporting ES such as nutrient cycling or the provision of habitat for biodiversity are rarely viewed by societal actors in the same way as direct benefits. Despite this general perception, supporting ES are fundamentally (albeit 'indirectly') linked to human well-being since they are necessary for the production and maintenance of all other ES (Hassan et al., 2005).

Instead of viewing fundamental biophysical structures, processes and functions of ecosystems as supporting services (Figure 2), this study argues for viewing these elements through the lens of ecosystem health (Figure 3), which reflects the state or condition of the NBS that is providing the ES. Two main reasons why this modified approach is useful for the current study, and beneficial to the overall discourse surrounding NBS, are discussed below.

In order to maximise the relevance of (urban) ES assessments to the public, it makes sense to focus on those ES which are more straightforward to perceive, observe, measure and value. ES that are directly 'felt' by people, either physically, mentally, socially or economically, are much more likely to be valued and prioritised over abstract services such as soil formation or photosynthesis. By closely aligning the instrumental aspect of nature with the needs and perceptions of beneficiaries, the value case for NBS can more easily be acknowledged by a wider audience and thus lead to greater public support, while avoiding theoretical ambiguities over what is or isn't an ecosystem service (Lele et al., 2013).

That is not to say that the intrinsic value of nature should be ignored. Rather, the conceptualisation of ecosystem properties (i.e. biodiversity) and processes (i.e. functions) as characteristics of ecosystem health, instead of as supporting ES, can help increase recognition of this intrinsic value by making ecosystem health a goal in and of itself. Instead of being another category of ES, ecosystem health can be explicitly highlighted as the foundation upon which all other 'tangible' ES are based (Figure 3).

To quote Lele et al. (2013):

For instance, nutrient cycling is not a service; it is only a process that contributes to (say) timber production service. Valuing nutrient cycling in addition to timber would then lead to double counting… And studying the trade-off between an internal process such as litter decomposition and a benefit such as income is misleading, because the process underpins the benefit.

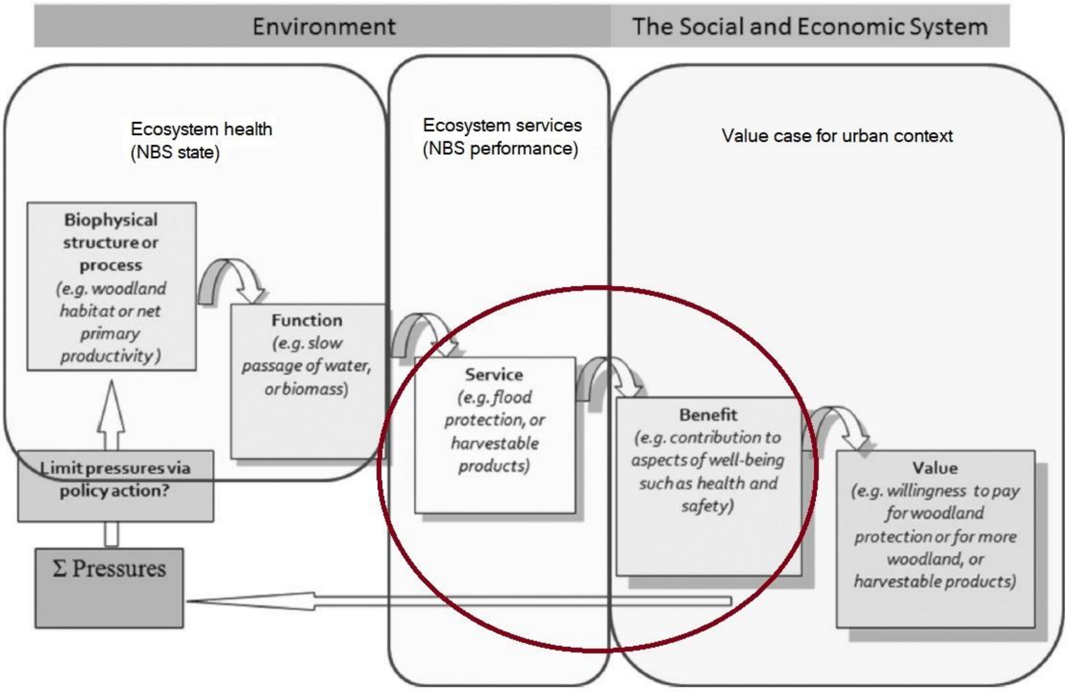


Figure 3 - Modified version of the cascade model for ES adapted from Potschin-Young et al. (2018). The red circle represents the elements of the model that ecosystem service assessment tools are usually designed to capture.

2.2 Ecosystem services in cities

Within urban settlements, the primary concern from a human well-being perspective is to provide a healthy and satisfying living environment for residents. Naturally, many aspects that define quality of life in cities (i.e. safety, resilience, liveability, etc.) are directly and indirectly influenced by locally generated ES (Gómez-Baggethun & Barton, 2013).

The focus of the current study is on provisioning, regulating and cultural ES that are classified by Gómez-Baggethun & Barton (2013) and Veerkamp et al. (2018) as being most relevant for urban areas and residents. A list of these urban ES can be found in Annex II, which is a subset of a much larger and more complete list of ES compiled by the MEA (2005). These ES are distinguished in the urban context by their relevance to common urban societal challenges and urban quality of life indicators.

Provisioning ES such as urban agriculture can contribute to urban food security and still be an important source of food and income for many urban residents (Gómez-Baggethun & Barton, 2013). Cultural ES is a broad category that includes many nonmaterial benefits that people obtain from NBS through spiritual enrichment, cognitive development, education, recreation, and aesthetic experiences (Hassan et al., 2005). These types of ES are highly relevant for urban lifestyles where stress, anxiety, social isolation, obesity and non-communicable diseases are prevalent and expected to increase in the future (van den Bosch & Ode Sang, 2017).

Regulating ES, often biophysical in nature, are also extremely relevant for urban areas. These benefits arise from the regulating function of ecosystem processes including air quality maintenance, climate regulation, erosion control, and water purification (Hassan et al., 2005). In addition to reducing urban morbidity and mortality related to pollution and the heat island effect, regulating ES can provide protection to residents by buffering extreme events and stabilising features of the surrounding landscape (Gómez-Baggethun & Barton, 2013).

2.3 Quantitative assessment tools

The integration of ES into mainstream urban decision-making is part of a greater paradigm shift towards: a) greater appreciation of natural systems as vital assets worthy of conservation, b) recognition of the central role these assets play in supporting human well-being, and c) incorporating their material and intangible values into sustainable policies (Daily et al., 2009).

Therefore, the proper and full accounting of ES has emerged as a priority in literature and practice that serves two separate but linked purposes; to measure changes to biophysical structures and functions driven by alternative management decisions or environmental change, and to quantify nature-based outcomes that are demonstrably and directly relevant to human welfare (Olander et al., 2018). By identifying and linking measurable scientific variables of ecosystem health with relevant ES, the wide range of benefits from NBS can be better understood, more accurately measured and appropriately communicated to a wider range of decision-makers and beneficiaries.

Assessments of ES aim to provide credible, quantitative estimates of their provision as well as their impact value to human welfare (Nelson et al., 2009). Figure 3 highlights these elements (red circle) within the overall cascade model of the ES 'production chain' (Potschin-Young et al., 2018). Until recently, assessments were often conducted through the use of individual indicators for measuring a single ecosystem service. While such assessments are empirically sound in their use of local variables, and have significantly contributed to the growing evidence base for ES, the dynamic and multi-functional characteristics of NBS suggests that they lack the scope (i.e. multiple ES) and scale (i.e. spatial and temporal) to be relevant in decision-making processes (Nelson et al., 2009). As a consequence, they can be considered to be inadequate in fully capturing the diversity, quality and complexity of the services that people derive from the ecosystems that underpin NBS (Haase et al., 2014).

In contrast to such ad hoc methods, recently developed comprehensive assessment tools are designed to enable replicable and quantifiable measurements of multiple ES. These 'pre-packaged' or 'off the shelf' assessment tools are meant to be flexible enough for use across diverse scales on a routine basis and facilitate consistency in comparative analyses (Nemec & Raudsepp-Hearne, 2013). Through the input of key variables and data, assessment tools can incorporate ecosystem properties and processes to produce estimates of ES, sometimes accompanied by economic valuations.

2.4 Value case for nature-based solutions

Once a range of ES has been measured or estimated for a given NBS, the next logical step is to translate these services into relevant, easily understood benefits that can then be appropriately valued by humans (right side of Figure 3). How these benefits are valued by individuals and society as a whole can vary significantly and should not be restricted solely to economic (financial) value. Other important non-financial dimensions of value include health value, sociocultural value, insurance value, and conservation value (Maes et al., 2016). In fact, non-monetised benefits can be an important consideration for local beneficiaries of NBS and if overlooked, there is a risk that these sources of value will be ignored during policy decisions (Nelson & Daily, 2010).

The purpose of developing a value case[1] for NBS is therefore to capture and present this wide range of relevant values to multiple decision-makers and stakeholders. By incorporating and aligning a broad set of financial and non-financial values, a value case can produce a mutual understanding of what NBS are worth and allow for a more even comparison with traditional grey infrastructure solutions that solely rely on 'financial tunnel vision' (Dittrich & van Dijk, 2013).

---

[1] The difference between a value case and a business case lies in the fact that a business case includes both benefits and costs, whereas a value case only presents benefits.

3 MATERIALS AND METHODS

"Nature is impersonal, awe-inspiring, elegant, eternal… You can travel far to be in a beautiful natural setting, or you can observe it in your backyard." - Rubin (2013)

3.1 Research strategy

The general research design that was selected for this study is a form of exploratory research using a combination of systematic review, meta-analysis and descriptive methods. This overall approach first seeks to identify and understand the current selection of assessment tools that have been developed for measuring a wide range ES across diverse settings. Only those assessment tools that meet certain screening criteria were chosen for further evaluation. The criteria used for scoring the remaining assessment tools were developed in-house as well as adapted from the literature, taking into account scientific validity and practical requirements of W+B. Through a comparative scoring matrix, the most suitable assessment tool was chosen for application on an urban case study. The final deliverable for W+B is a value case for the urban case study that brings together the findings and relates them to the needs of local stakeholders. This overall framework is depicted in Figure 5.

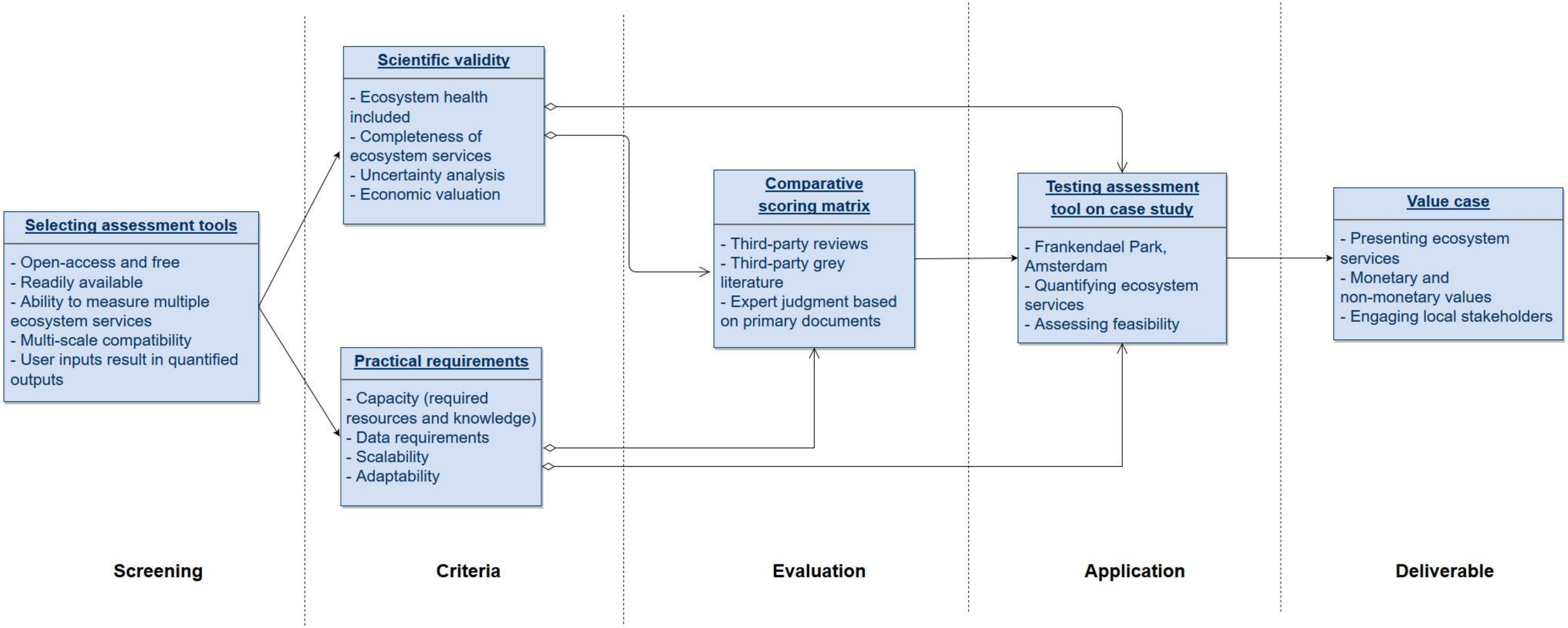


Figure 4 - Research framework

3.2 Screening of tools

The first step of identifying existing ES assessment tools was carried out through a combination of reviewing online platforms related to NBS and/or ES (Ecosystems Knowledge Network, OpenNESS, Oppla), participation in NBS forums and workshops (see Annex III for additional information), and a search on Google Scholar using the keywords "urban multiple ecosystem services assessment tools".

Given the need and desire to capture multiple ES from NBS, screening criteria were developed (Table 1) to select 'off the shelf' assessment tools that can be readily employed without proprietary restrictions across relevant urban scales to quantify multiple ES through the use of user generated data.

Table 1 - Screening criteria to select assessment tools for analysis

Criteria	Description	Rationale
Open access and free	Open access and free to use without the purchase of software licences or contracting with third parties	Assessment tools that are in the public domain allow them to be independently applicable without restrictions for the current study and future research (Bagstad et al., 2013)
Readily available	Available in English as of 20/04/2019	To ensure that every assessment framework included for evaluation is sufficiently well-developed and well-documented, which promotes greater transparency and credibility (Bagstad et al., 2013)
Measure multiple ES	Explicit, central focus on measurement of multiple indicators for several ES	NBS are multifunctional by nature therefore capturing as many ES as possible is highly desirable
Multi-scale compatibility	Compatible with site, local and/or landscape scales that are most relevant to urban contexts (i.e. NBS, neighbourhood, city scales)	Assessment frameworks that are applicable across multiple spatial scales are attractive because it is easier to learn one tool than many (Bagstad et al., 2013)
User inputs result in quantified outputs	Quantitative and qualitative data can be input into the assessment tool to obtain outputs that reflect ES provision and distribution (supply)	Quantified results are essential for measuring ES and their trade-offs (Bagstad et al., 2013), though qualitative assessments are also appropriate for cultural ES and ranking preferences

3.3 Evaluation and scoring

In order to systematically evaluate and compare the selected assessment tools, a set of criteria was developed for which scores would be applied. These criteria aim to address two equally important perspectives when undertaking ES assessments; scientific validity and practical requirements. The selection of criteria began with a desktop review of scientific and grey literature regarding previous urban ES assessments. Specifically, the work of van Oudenhoven et al. (2018) in synthesising and organising criteria for selecting appropriate indicators for ES provided an enlightening approach which was adopted for assessment tools. Additionally, informal discussions were conducted with a range of actors including colleagues at W+B, external researchers, and local proponents of NBS in cities. The purpose of these discussions was to understand the needs and priorities of different NBS stakeholders that may not be immediately evident when reviewing literature.

From a scientific validity perspective, the inclusion of ecosystem health and performance indicators within the framework of each assessment tool was deemed to be of critical importance during the evaluation phase. An ecosystem's structure and integrity are key factors that enable resistance and recovery (i.e. resilience) to the kind of external perturbations that NBS often face in urban environments (Feld et al., 2009). It is difficult to understate the importance that resiliency has on an ecosystem's ability to provide future flows of services, particularly those related to risk reduction and climate change adaptation. Thus in order to be relevant for urban areas, any comprehensive assessment of the performance of NBS should be able to link ecosystem service flows to the underlying ecosystem's structure and integrity (Table 2).

Table 2 - Evaluation criteria related to ecosystem health

Category	Description	Criteria	Scoring guidance
Ecosystem health / state of NBS *Based on the work of Feld et al. (2009)*	Can the tool incorporate data on ecosystem health properties and thus provide a link to ecosystem service flows?	*Structure (abiotic and biotic elements that underpin ecological habitats for biodiversity)*	3 = tool can incorporate structural NBS elements when analysing ES 0 = no room for including structural NBS elements in the tool
		Integrity (spatial dimensions, connectivity to other ecosystems)	3 = tool accounts for spatial connectivity of NBS to greater ecosystem network 0 = tool cannot incorporate NBS connectivity within ES analysis

In order to fully capture the multiple dimensions of human well-being that NBS can positively affect, assessment tools should encompass all three categories of ES; provisioning, regulating, and cultural (Nemec & Raudsepp-Hearne, 2013). Furthermore, the ability to include as many relevant ES as possible in an assessment can lead to a more in-depth understanding of the complex relationships between ES (i.e. trade-offs, synergies and bundles) (Cord et al., 2017). Annex II presents a checklist of relevant urban ES that was used to determine how each assessment tool scored in terms of completeness (Table 3).

The inherent complexity of NBS, and the ecosystem properties and functions that they are based on, implies a great deal of uncertainty when attempting to quantify ES (Crossman et al., 2013). This uncertainty may differ across assessment tools, complicating the comparison and interpretation of results. Therefore, it is important to consider whether each assessment tool acknowledges this uncertainty and if so, how it is incorporated into the final results.

Some assessment tools include their own economic (monetary) valuation of measured ES. Incorporating this feature within an assessment tool is beneficial but not critically necessary given the existence of independent valuation methods for ES, however discrepancies can arise when combining different economic approaches and so as much consistency as possible is preferred (Haase et al., 2014). It should be noted that the inclusion of an economic valuation component within an assessment tool does not prevent additional forms of ES valuation.

From a practical perspective, a clear understanding of the feasibility requirements for using each assessment tool is essential for widening their adoption among technical and non-technical decision-makers (Bagstad et al., 2013). Common limitations and barriers for the use of existing assessment tools include data and resource needs, especially human/technical capacities (Dammers et al., 2019), as well as the flexibility to apply the same assessment tool over different scales. Therefore, the inclusion of the feasibility criteria in Table 4 is intended to be user-centred whereby the perceived needs of end users are taken to account when undertaking ecosystem service assessments (van Oudenhoven et al., 2018).

Table 3 - Evaluation criteria related to ES

Category	Description	Criteria	Scoring guidance
Ecosystem services / NBS performance *Based* services *on the work of Crossman et al. (2013) and Nemec & Raudsepp-Hearne (2013)*	Does the tool capture a wide range of urban ES and their relevant characteristics?	*Completeness (out of a possible 28 relevant urban ES - see Annex II)*	3 = relatively high number of ES that the tool can measure 0 = relatively low number of ES that the tool can measure
		Uncertainty (how much confidence can be placed in tool results)	3 = uncertainty is explicitly accounted for and presented alongside tool results 0 = no explicit handling or mention of uncertainty for tool results
		Economic analysis (monetary valuation of ES)	3 = monetary valuation of all ES is included within the tool 0 = tool does not monetise any of the measured ES

Table 4 - Evaluation criteria related to feasibility

Category	Description	Criteria	Scoring guidance
Feasibility / practicality *Based on the work of Bagstad et al. (2013) and van Oudenhoven et al. (2018)*	What are the data, capacity and resource requirements to continuously and rigorously utilise the tool in a way that provides up-to-date results to inform decision making?	*Capacity (technical skills, required knowledge)*	3 = only basic non-technical skills required to use tool 0 = Extensive technical training and expertise required to use tool
		Data requirements (number of inputs and availability)	3= low data requirements (minimal inputs or required data is easily and readily available) 0 = high data requirements (large amounts of data required or perceived difficulty in data collection)
		Scalability (relevant urban scales: site, local, landscape)	3 = can measure at all three relevant urban scales and beyond 0 = can only measure at one of the relevant urban scales
		Adaptability (whether input data can be expanded beyond what the tool requires)	3 = Additional data sources can easily be incorporated to update results 0 = No room for additional data sources beyond tool requirements

Using the above criteria, each of the selected assessment tools was quantitatively evaluated through a scoring matrix. Scores ranging from 0-3 were assigned to each tool based on the types of sources described in Table 11 and Annex VI.

The creation of a scoring matrix allowed for a direct comparison of several assessment tools based on cumulative scores and resulted in one tool achieving the highest score based on the aforementioned criteria. This ‘winning’ tool was then chosen as the most suitable tool for application on an urban NBS case study.

3.4 Application

Once the evaluation phase was complete, the highest scoring assessment tool was subsequently applied to calculate the value of the ES provided by an urban case study (i.e. a large park in Amsterdam called Park Frankendael). This application is an important step in determining the suitability of the tool in an urban context as well as assessing its feasibility, flexibility and limitations (Bagstad et al., 2013).

Relevant datasets were collected from a variety of sources depending on the data requirements of the applied tool. Since i-Tree Eco was the highest scoring tool (see section 4.2), specific geospatial data sets necessary to run i-Tree were collected and used for analysis in the application phase.

i-Tree Eco

i-Tree represents a suite of tools developed in the U.S. that provide various levels of analysis for ecosystem structure, function, services and values (Figure 5). Within the suite, i-Tree Eco is considered to be the flagship tool with the most in-depth capability for estimating biophysical ES and structural characteristics of urban forests. The basis for the i-Tree suite is tree allometric relationships between biomass, volume and function using measurements such as diameter at breast height (DBH), crown size and tree height (Russo et al., 2014).

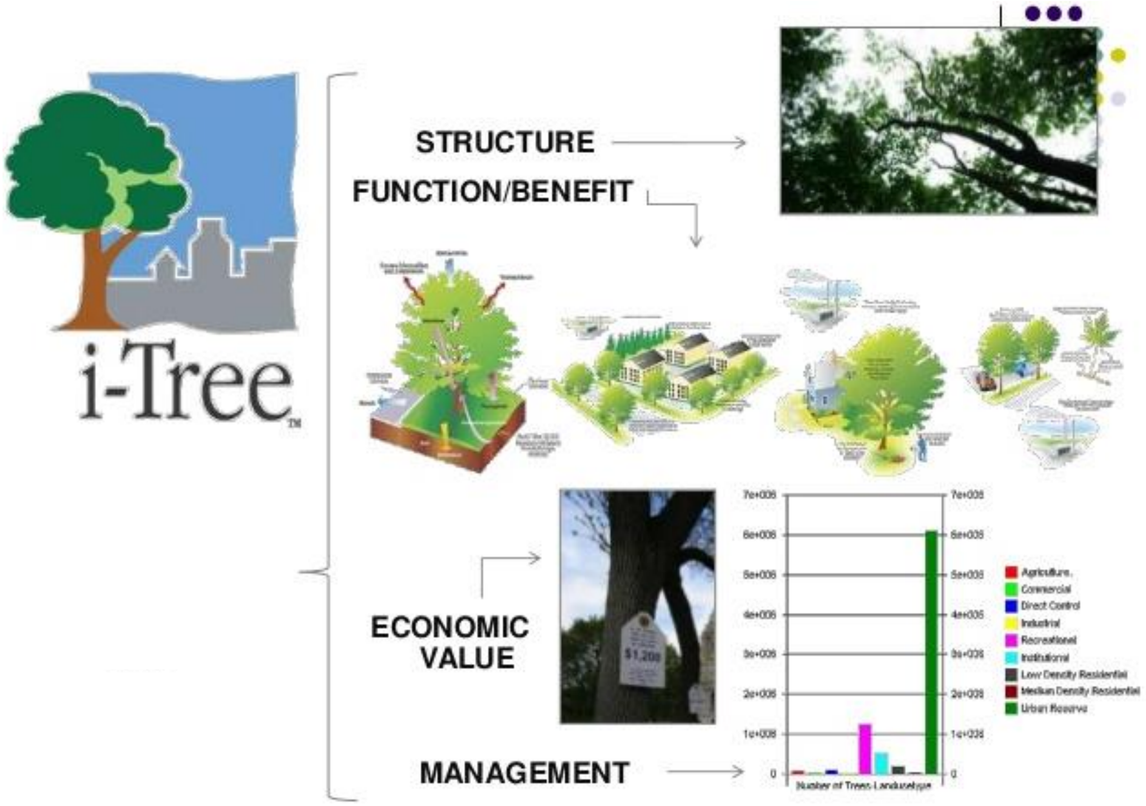


Figure 5 - Conceptual diagram for i-Tree suite of tools (USDA Forest Service, 2019)

Table 5 summarises the unique values obtained for as many trees as possible within Park Frankendael, largely sourced from the City of Amsterdam’s Maps Data portal (City of Amsterdam, n.d.-a) and through personal interactions with local i-Tree experts.

Several site visits were also conducted to validate or gather missing data, examine the context of the surrounding area, and share information about the current study with local stakeholders. Annex IV shows sample tree data from Park Frankendael that was formatted and organised for use in i-Tree Eco.

Table 5 - Data included for running i-Tree

Data set	Units	Source
Tree species*	Scientific name	(City of Amsterdam, n.d.-a)
Tree DBH (stem diameter at breast height - 1.37m above the ground)*	cm	Dirk Voets & Jarren Verbeek, Cobra Adviseurs (personal communication) Site visit (using measure tape)
Total tree height	m	Dirk Voets & Jarren Verbeek, Cobra Adviseurs (personal communication) Site visit (visual estimate)
Tree GPS coordinates	Longitude Latitude	(City of Amsterdam, n.d.-a) Site visit (mobile phone application)
Land use	Park, Agriculture, Transportation, Water/wetland, Commercial/Industrial	(City of Amsterdam, n.d.-a)
Street vs. non-street tree	Yes/No	(City of Amsterdam, n.d.-a)
Public vs. private tree	Yes/No	(City of Amsterdam, n.d.-a)

* = *Minimum required fields*

The benefit prices that are required by i-Tree Eco are presented in Table 6[1]. The default values for social cost of carbon and avoided runoff are based on U.S. research, data and case studies. Since Amsterdam-specific data was not available for these categories, values were updated using the same sources but with revisions that reflect a more relevant reference year (social cost of carbon) or the urban context of the case study area (avoided runoff).

Where possible, all biophysical ecosystems services within the measurement capabilities of i-Tree Eco, and for which sufficient information was available, were captured for the case study. For those ES that were deemed to be relevant to the case study, but which fell outside the capabilities of i-Tree Eco, additional calculations were made using methodologies from the literature that fit within the time and logistical constraints of the research period. These additions allowed for a more comprehensive picture of important ES that Park Frankendael delivers to the city of Amsterdam, which could still be captured in a sufficiently reliable way (Livesley et al., 2016).

---

[1] The top half of the table represent benefit prices that can be modified in i-Tree Eco. The bottom half of the table include benefit prices that are fixed to a particular source (median EU values) and cannot be changed to country-specific prices.

Table 6 - Benefit prices used in i-Tree

Benefit price	**Unit**	**Value**	**Source***	**Default i-Tree value**	**Comments**
Electricity	€ / kWh	0.17	(Eurostat, 2019)	0.16	Updated to 2018 prices
Heating (natural gas)	€ / therm	2.52	(Eurostat, 2019)	2.23	Updated to 2018 prices (1 therm = 29.3 kWh)
Social cost of carbon	€ / metric ton C	202.92	(United States Government, 2013)	161 (based on 2010 estimates)	Updated to 2020 estimates
Avoided runoff	€ / m^3 water	9.44	(McPherson et al., 2007)	1.90 (based on U.S. countrywide average)	Updated specifically for urban setting (from a U.S. city)
Exchange rate	US$ 1.00 = €	0.89257	(XE.com, n.d.)	Same	Rate on August 7, 2019
Social cost of CO	€ / metric ton	1,039	(van Essen et al., 2011)	Same	Median social costs for EU
Social cost of O_3	€ / metric ton	11,714	(van Essen et al., 2011)	Same	Median social costs for EU
Social cost of NO_2	€ / metric ton	1,749	(van Essen et al., 2011)	Same	Median social costs for EU
Social cost of SO_2	€ / metric ton	637	(van Essen et al., 2011)	Same	Median social costs for EU
Social cost of PM2.5	€ / metric ton	406,658	(van Essen et al., 2011)	Same	Median social costs for EU

3.5 Case study area

For this study, Park Frankendael in Amsterdam, the Netherlands was chosen as the urban case study upon which the highest scoring assessment tool from the evaluation phase would be applied. Park Frankendael was chosen for a variety of reasons related to its size, ecology and surrounding socio-environmental context.

Figure 6 - Variety of landscapes and vegetation types within Park Frankendael

As a large, dense metropolitan city, Amsterdam is experiencing an overall decline and fragmentation of its public green spaces at the expense of increases in the built environment (Giezen, 2018). Despite recent studies showing the significant economic, health, biodiversity and social cohesion costs of losing green spaces to housing developments in several areas of Amsterdam (Bos & Vogelzang, 2018), these pressures continue to be felt in neighbourhoods that are adjacent to large urban parks. Vereniging Vrienden van Frankendael, a community-run non-profit association, has been working since 1990 to preserve Park Frankendael as an ecological hotspot (Figure 6); first against plans for development atop the park, and more recently in the face of a growing number of visitors to the park (J. Rijken and M. van der Bliek, personal communication, May 22, 2019).

Figure 7 - Aerial view of Park Frankendael (Buro Sant en Co, 2016)

Despite these citywide trends, Park Frankendael continues to be an important source of ecological value within the Amsterdam-Oost borough. A significant portion of the park acts as an urban forest, providing important habitats for a wide range of flora and fauna in the area. At the same time, Park Frankendael is a cultural hub for recreation, relaxation, education and natural experiences for nearby residents. This includes the presence of a community garden ('volkstuin') and the oldest school garden in Amsterdam, which offers year-round educational activities in gardening and nature appreciation. Furthermore, the park hosts many popular events throughout the year that attract a significant number of visitors from around Amsterdam (City of Amsterdam, 2018). Park Frankendael also contains a wide range of natural and semi-natural areas such as forests, meadows, gardens, small-scale farming plots and water bodies (Figure 7). Thus, parks like Frankendael, which are located in dense urban areas, are widely considered to be valuable NBS due to the wide range of ES that they provide as well as their contribution to regional ecosystem networks.

Figure 8 - Location of Park Frankendael (highlighted in green) within the city of Amsterdam

Lastly, the area covered by Park Frankendael also represents an administrative unit within the City of Amsterdam (Figure 8), which is significant since a many studies on urban nature and public health use residential neighbourhood boundaries to examine people's environmental exposures (Kwan, 2018). Thus, Park Frankendael provides a unique and interesting case study where the assessment of ES is relevant on multiple scales to a wide range of affected stakeholders and decision-makers.

Table 7 - Select features of Park Frankendael

Feature	Value	Source
Total area	229,193 m^2 (22.92 ha)	(City of Amsterdam, n.d.-a)
Recreational area	84,000 m^2	(City of Amsterdam, 2018)
School gardens	1,500 m^2	(City of Amsterdam, n.d.-a)
Total water cover	35,759 m^2	(City of Amsterdam, n.d.-a)
Total number of trees	1,359	(City of Amsterdam, n.d.-a)
Number of trees input into i-Tree	1,208	
Total tree cover (estimate)	122,300 m^2	i-Tree Eco calculation
Unique tree species	220	(City of Amsterdam, n.d.-a)
Average annual precipitation	885 mm	i-Tree Eco calculation from local weather station data
Average distance travelled by park visitors	799 m	(van Kempen & Smeets, 2013)

3.6 Value case

The final output that will be delivered to W+B, in addition to this report, is the preparation of a value case for the urban case study. This value case will be based on the application of the highest scoring assessment tool (i-Tree Eco) on Park Frankendael, combined with ad hoc measurements of additional ES that are deemed to be relevant for the urban context. The value case will present a summary of key benefits that range from biophysical to cultural will include both quantitative and qualitative information as well as financial and non-financial aspects of the park’s value to society.

4 RESULTS

"The rainforest has been undervalued, because the value shouldn't be in the trees that you take out; it should be with leaving the trees to preserve the life system that sustains life on the planet." - Styler (2009)

4.1 Screening of tools

A total of 30 'off the shelf' ES assessment tools were identified in the initial stage of research. Table 8 summarises for each tool its name, link and reasoning for exclusion (if it did not meet the screening criteria).

Table 8 - List of identified ES assessment tools

Tool	Source	Included in current study (reason for exclusion)
Artificial Intelligence for Ecosystem Services (ARIES)	***http://aries.integratedmodelling.org/***	***Yes***
Atlas Natural Capital (ANK)	https://www.atlasnatuurlijkkapitaal.nl/en	No (does not allow for user input of data / only in Dutch)
Benefits Estimation Tool (B£ST)	***https://www.susdrain.org/resources/best.html***	***Yes***
Benefit Transfer Toolkit	https://my.usgs.gov/benefit-transfer/	No (does not allow for user input of data / does not measure ES quantities - valuation only)
CITYGreen	https://www.americanforests.org/our-work/community-releaf/	No (no longer available - out of service)
Co$ting Nature	http://www.policysupport.org/costingnature	No (incompatible with urban scales - max. 1ha resolution)
Ecological Assets Inventory and Management (EcoAIM)	Booth et al., 2014	No (proprietary - not open access)
EcoMetrix	https://www.ecometrixsolutions.com/ecometrix.html	No (proprietary - not open access)
EcoServ-GIS	https://www.forestresearch.gov.uk/research/ecoserv-gis-a-toolkit-for-mapping-ecosystem-services/	No (incompatible with urban scales / requires commercial software and licence)
Ecosystem Portfolio Model (EPM)	https://pubs.usgs.gov/sir/2009/5181/	No (not transferable / no longer accessible)
Ecosystem Services Mapping Tool (ESTIMAP)	***Zulian et al., 2013***	***Yes***
Corporate Ecosystem Services Review	https://www.wri.org/publication/corporate-ecosystem-services-review	No (qualitative only / incompatible with urban scales)
Ecosystem Valuation Toolkit	https://www.eartheconomics.org/ecosystem-valuation-toolkit	No (proprietary - not open access)

ESValue	https://esvalues.org/	No (does not allow for user input of data / does not measure ES quantities - valuation only)
GI Valuation Toolkit (GI-Val)	https://www.merseyforest.org.uk/services/gi-val/	No (not yet fully developed - prototype / only available for UK areas)
Greenkeeper	http://www.greenkeeperuk.co.uk/	No (not yet available)
i-Tree (formerly Urban Forest Effects Model)	***https://www.itreetools.org/***	***Yes***
Integrated Valuation of Ecosystem Services and Trade-offs (InVEST)	***https://naturalcapitalproject.stanford.edu/invest/***	***Yes***
IUCN NBS Global Standard	https://www.iucn.org/theme/ecosystem-management/about/our-work/a-global-standard-nature-based-solutions	No (not yet available)
Land Utilisation and Capability Indicator (LUCI)	https://www.lucitools.org/	No (not fully developed - prototype only / not yet open access)
Multiscale Integrated Model of Ecosystem Services (MIMES)	http://www.afordablefutures.com/orientation-to-what-we-do	No (not open access - requires commercial software licence)
Natural Assets Information System (NAIS)	Troy and Wilson, 2006	No (proprietary - not open access nor free)
Naturvation Index	Dammers et al., 2019	No (still not fully developed - prototype only)
Outdoor Recreation Valuation tool (ORVal)	https://www.leep.exeter.ac.uk/orval/	No (does not measure multiple ES / only available for UK areas)
Social Values for Ecosystem Services (SolVES)	***https://solves.cr.usgs.gov/***	***Yes***
Spatial Evidence for Natural Capital Evaluation (SENCE)	https://www.envsys.co.uk/sence/	No (proprietary - not open access nor free)
The Economics of Ecosystems and Biodiversity (TEEB) Valuation Database	http://www.teebweb.org/publication/tthe-economics-of-ecosystems-and-biodiversity-valuation-database-manual/	No (does not allow for user input of data / does not measure ES quantities - valuation only)
TEEB Stad	https://www.teebstad.nl/	No (not available in English)
Toolkit for Ecosystem Service Site-based Assessment (TESSA)	http://tessa.tools/	No (qualitative only / not transferable)
Viridian	https://viridianlogic.com/#about	No (proprietary - not open access nor free)

The final six assessment tools that met the criteria of the screening process and thus were selected for more in-depth evaluation and scoring are presented in Table 9. This list features readily available assessment tools that are replicable and flexible enough for use in diverse urban contexts, using context-specific data to quantify multiple urban ES within the tool’s own framework.

Table 9 - Final list of assessment tools

Tool	Organisation (year first created)	Type	Version evaluated (current year)	Primary data inputs	Brief description
InVEST (Integrated Valuation of Ecosystem Services and Trade-offs)	Natural Capital Project (2008)	GIS software	3.7.0 (2019)	Spatial data	InVEST is a GIS-based modelling software that estimates ES values using the ecological production function approach, which calculates how ecosystem processes, composition and structure contribute to the provision and distribution of ES (Nemec & Raudsepp-Hearne, 2013)
ARIES (Artificial Intelligence for Ecosystem Services)	University of Vermont / Earth Economics / Conservation International (2012)	Probabilistic model	Web-based Explorer (2018)	Spatial data	ARIES uses probabilistic models to map the flows of multiple ES based on ecological and socioeconomic factors. The valuation of ES is done using a benefits transfer approach, whereby ES flow analyses are transferred to different settings (Villa et al., 2009)
SolVES (Social Values for Ecosystem Services)	U.S. Geological Survey (2010)	GIS application	3.0 (2015)	Personal surveys	SolVES is an ES model developed to assess, map and quantify the perceived social values for ecosystems. Within SolVES, social preferences are emphasized in order to measure and rank the value of ES from a demand perspective (Sherrouse et al., 2011)
B£ST (Benefits Estimation Tool)	CIRIA - Construction Industry Research and Information Association (2015)	Spreadsheet	2.0.0 (2019)	NBS size, type and scale	B£ST is a tool designed to assess and monetise the financial, social and environmental benefits of blue-green infrastructure. B£ST uses the ES approach to estimate the performance of the sustainable urban drainage systems for a given area over a specified time period (susDrain, n.d.)
ESTIMAP (Ecosystem Services Mapping Tool)	European Commission (2013)	GIS application	Original (2013)	Land cover classes	ESTIMAP is a set of separate process-based models that assess the supply, demand and flow of different ES, for use within a GIS. ESTIMAP provides a spatially explicit assessment of several ES with the objective of supporting EU policies with information on how ES are provided and consumed (Zulian et al., 2013)
i-Tree (formerly Urban Forest Effects Model)	USDA Forest Service (2006)	Desktop software	Eco v6 (2016)	Tree species and tree dimensions	i-Tree Eco is a desktop software application that uses tree measurements to estimate biophysical ES and structural characteristics of urban forests. Field data for individual trees are collected for a study area and combined with local hourly air pollution and meteorological data to quantify urban forest structure, function, and value to communities (USDA Forest Service, 2019)

4.2 Evaluation and scoring

Table 10 shows the results of the scoring matrix for every selected assessment tool, including the eight evaluation criteria and total cumulative scores. Table 11 describes the colour scheme used to highlight the type of literature source that was used for each assigned score. Furthermore, Annex VI includes information on the exact literature sources that were used for each tool during the scoring process while Annex VII contains the reasoning and justifications behind each score. i-Tree Eco achieved the highest score out of all assessment tools, narrowly beating out ARIES and B£ST.

Table 10 - Scoring matrix for evaluating assessment tools

Criteria		InVEST	ARIES	SolVES	B£ST	ESTIMAP	i-Tree
Ecosystem health	*Structure*	3	2	1	1	3	3
	Integrity	3	2	1	1	3	2
ES	*Completeness*	1	1	2	2	1	0
	Uncertainty	0	3	0	3	0	2
	Economic analysis	3	3	0	3	0	3
Feasibility	*Capacity*	1	1	2	3	1	3
	Data	1	2	2	1	2	1
	Scalability	2	2	2	2	2	3
	Adaptability	3	3	3	3	3	3
Total score (max = 27)		**17**	**19**	**13**	**19**	**15**	**20**

Table 11 - Description of methodology for scoring matrix

Score breakdown	Types of sources
3 = Desirable (excellent)	Peer-reviewed scientific papers that independently reviewed or applied a tool
2 = Acceptable (fair)	Third party grey literature that provide summaries and descriptions for a tool
1 = Undesirable (poor)	Peer-reviewed scientific papers authored by a tool's own developers
0 = Absent (not applicable)	Expert judgement based on a review of primary documents for a tool

4.3 Application of i-Tree Eco

As a result of achieving the highest score during the evaluation phase, i-Tree Eco was subsequently applied to the urban case study of Park Frankendael in Amsterdam. The ES that i-Tree Eco measured for the park are summarised in Table 12.

Table 12 - ES directly measured by i-Tree Eco

Category	Ecosystem service	Quantity	Value
Regulating (air quality)	Air pollution removal	664.4 kg per year	€32,600 per year
	Oxygen production	73.55 metric tons per year	
	Volatile organic compounds (VOCs)$^+$	134.7 kg per year	
Regulating (climate change)	Carbon sequestration	27.58 metric tons per year	€5,560 per year
	Carbon storage	3,430 metric tons	€696,000
Regulating (water management)	Avoided runoff	2,307 m^3 per year	€21,800 per year
Cultural (economic)	Structural value		€9.69 million

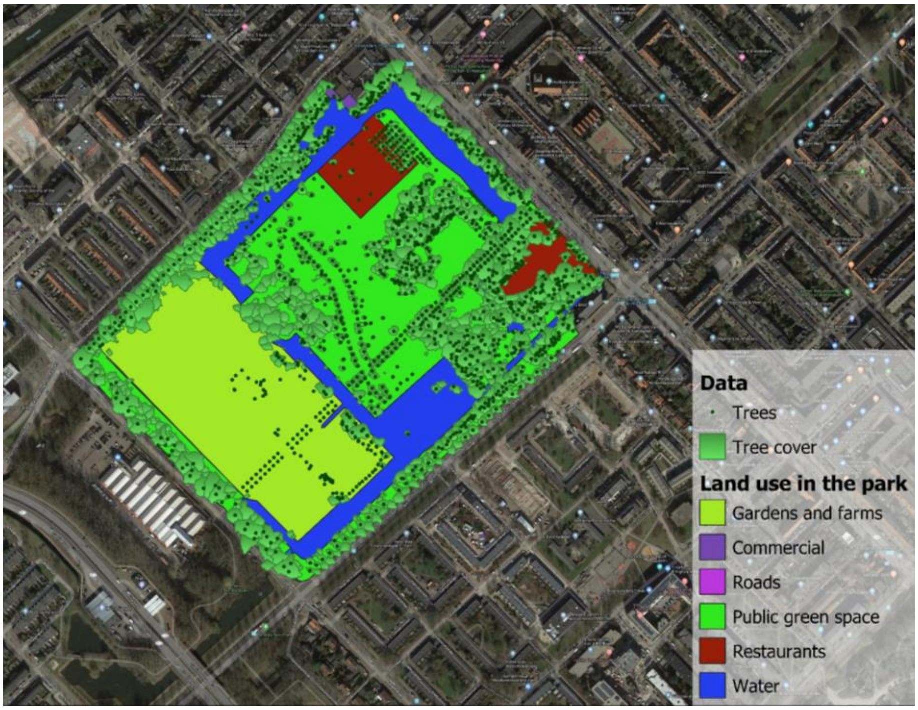


Figure 9 - Park Frankendael tree data points and land use categories

Air pollution removal

The total amount of air pollution removed by the trees in Park Frankendael is estimated at 664.4 kg per year. This quantity consists of removal rates for a combination of air pollutants including particulate matter (PM2.5), ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and carbon monoxide (CO). Figure 10 shows a breakdown of the annual removal rates and value for each pollutant. Air pollution removal rates are based on well-established deposition models (Hirabayashi et al., 2015) and hourly air quality data from local weather stations, which are then combined to estimate the effects of pollutant removal on local atmospheric concentrations (Nowak et al., 2014).

The cumulative estimated monetary value of annual air pollution removal by Park Frankendael is €32,600. This total value is derived from EU median social (i.e. external) costs described in Table 6 (van Essen et al., 2011). The social costs of air pollution mostly reflect avoided adverse respiratory and cardiovascular health effects but also include building and material damages, crop losses, and biodiversity losses.

Consideration should also be given to the effect of tree emissions in reducing air quality. On average, trees in Park Frankendael emit an estimated 134.9 kg of volatile organic compounds (VOCs) per year, which are precursor chemicals to ozone formation. The economic costs of VOC emissions were not estimated since more information is required to determine their effect on ozone formation, which also prevents a direct comparison between ozone removal by trees and ozone formation via VOC emissions (Hirabayashi et al., 2015).

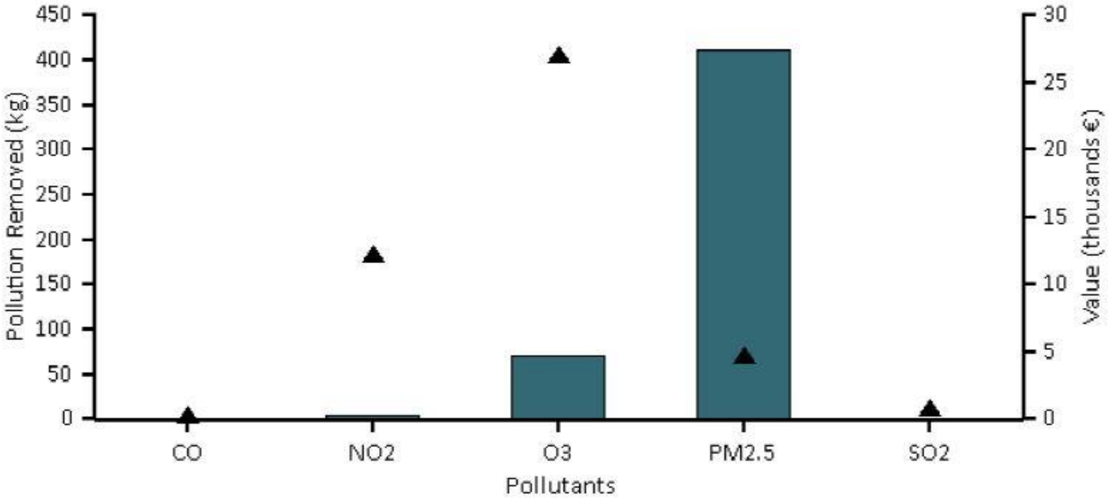


Figure 10 - Annual pollution removal by trees (triangle points) and monetary value (blue bars) for Park Frankendael. Although pollution removal was highest for O_3, removal of PM2.5 was associated with the highest monetary value.

Oxygen production

Trees in Park Frankendael are estimated to produce 73.55 metric tons of oxygen per year. However, this ES is relatively insignificant compared to other services because of the large and relatively stable amount of oxygen in the atmosphere, even in urban areas. For this reason, no monetary value was calculated for oxygen production in this assessment.

Carbon sequestration and storage

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of Park Frankendael trees is approximately 27.58 metric tons of carbon per year with an associated annual value of €5,600. Figure 11 shows the gross annual quantities and monetary values for the top carbon sequestering tree species in Park Frankendael.

Existing trees in Park Frankendael are estimated to currently store 3,430 metric tons of carbon as accumulated biomass at this point in time. This figure is an indication of the amount of carbon that can be released if these trees are allowed to die and decompose, or are removed via maintenance (i.e. pruning, cutting). The total value of the stored carbon in the trees of Park Frankendael amounts to €696,000.

Within i-Tree Eco, carbon storage and carbon sequestration monetary values are calculated based on a carbon price of €202.92 per metric ton (Table 6). This price reflects the social cost of carbon (i.e. damages associated with an incremental increase in carbon emissions in a given year) as estimated by the United States Government (2013) and converted to euros using August 2019 exchange rates. Due to the absence of a Dutch-specific social cost of carbon, this U.S.-based approach was also applied in a previous Dutch case study by Remme et al. (2015) resulting in a carbon price of €150 per metric ton. The variation in the carbon price between the two studies can largely be attributed to the changes in the dollar-euro exchange rates.

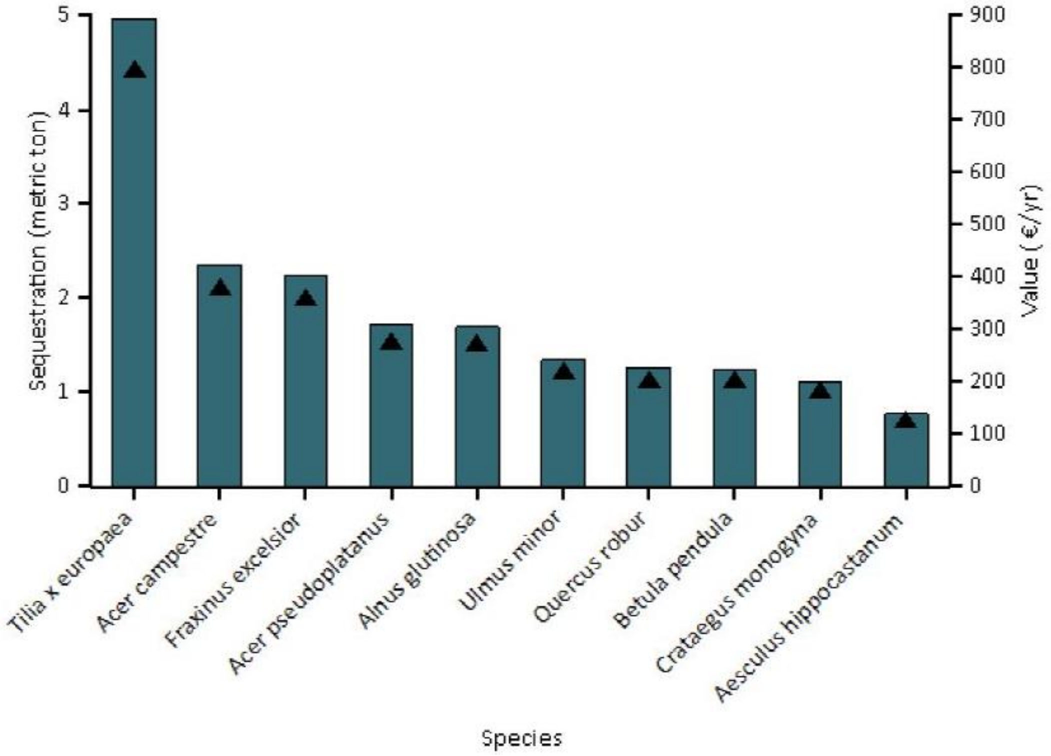


Figure 11 - Estimated annual gross carbon sequestration (triangle points) and monetary value (blue bars) for tree species with the greatest effects in Park Frankendael

Avoided water runoff

The trees of Park Frankendael reduce surface water runoff by intercepting precipitation, while their root systems promote infiltration and storage in the soil. The total reduction in stormwater runoff provided by the park is estimated at 2,307 m^3 per year.

For calculating hydrological processes of precipitation, interception, evaporation, infiltration, and runoff, i-Tree Eco employs a physical-based hydrology model (UFORE-Hydro) that makes use of tree canopy, land cover and local weather data in urban areas (Wang et al., 2008). The results of the model are then compared with a hypothetical scenario where the area of interest is completely devoid of vegetation. The resulting difference in total annual surface runoff volume, as a function of the hydrological processes mentioned above, is then calculated and attributed to the effect of vegetation (and soil cover) in the case study area (Hirabayashi, 2013).

The associated value for this reduction in runoff is approximately €21,800 based on a price of €9.44 per m^3 (Table 6). This price differs from the default i-Tree value based on a U.S. national average (€1.90 / m^3) that includes a wide range of urban, suburban, rural and natural landscapes, as well as different climatic zones. The use of an urban-specific value derived from the city of Washington D.C. (McPherson et al., 2007) was preferred for the following reasons: a) to better reflect the urban nature of Park Frankendael, b) to incorporate the fact that both cities have a combined sewer system, and c) to better approximate the climatic setting of Amsterdam in within U.S. climate zones. This chosen price reflects what society is willing to pay for stormwater management and is based on projected savings on water treatment as well as expected costs of preventing or repairing damage from flooding. Not included in this annual value are the benefits of groundwater recharge, particularly as a defence against saltwater intrusion in coastal cities.

Structural value

In addition to the regulating ES that trees provide (also known as functional values), urban forests also have a structural value. This reflects the compensatory cost of having to replace an existing tree with an equally mature one. The structural value of a tree (and urban forest) is based on modified U.S.-based valuation procedures of the International Society of Arboriculture and the Council of Tree and Landscape Appraisers.

Through the use of tree species, DBH, condition, land use, and location information, replacement costs are calculated and then converted into euros (Nowak et al., 2002).

The estimated structural value of the urban forest in Park Frankendael is €9.69 million. Such a high figure reflects the fact that structural value is positively correlated with the number, size and age of healthy trees in the park, which is evident in the forested areas of the park.

4.4 Additional ecosystem services assessment

Limitations in the completeness of relevant ES that can be captured by i-Tree Eco alone (Table 12) led to the calculation of additional ES that are deemed to be of great importance to the urban context, either in the literature (Gómez-Baggethun & Barton, 2013) or through personal interviews with urban experts.

These additional ES include local temperature regulation (i.e. cooling effect), recreation, education, economic (municipal revenue) and mobility. While some aspects of these ES from Park Frankendael can be quantified, others can only be presented qualitatively at this point.

Cooling effect
Figure 12 shows the cooling effect of Park Frankendael as calculated by the Natural Capital Model developed by the Dutch National Institute for Public Health and the Environment (RIVM) (Remme et al., 2017). Although this model did not pass the current study's screening criteria due to the fact that the calculation platform is not yet publicly accessible, many of the model results can be visualised in the Atlas of Natural Capital, an open access information platform with maps and background information related to the natural capital of the Netherlands (RIVM, n.d.)

Park Frankendael is estimated to provide a cooling effect ranging from 1.6 to 2.4 °C. The highest cooling effect (blue patch on the eastern corner of the park in Figure 12) corresponds to the forested area where tree density is highest.

Within the Natural Capital Model, the cumulative cooling effect in a given urban area is calculated in relation to the maximum (potential) average annual urban heat island (UHI) effect that could be expected to occur in that area given population density, soil sealing and average wind speeds. Through the use of land cover type and vegetation maps, the current (actual) UHI effect is calculated and subtracted from the maximum UHI effect. This difference is attributable to the *in situ* presence of vegetation, water and soil cover with an impact range of 30 m (Remme et al., 2017).

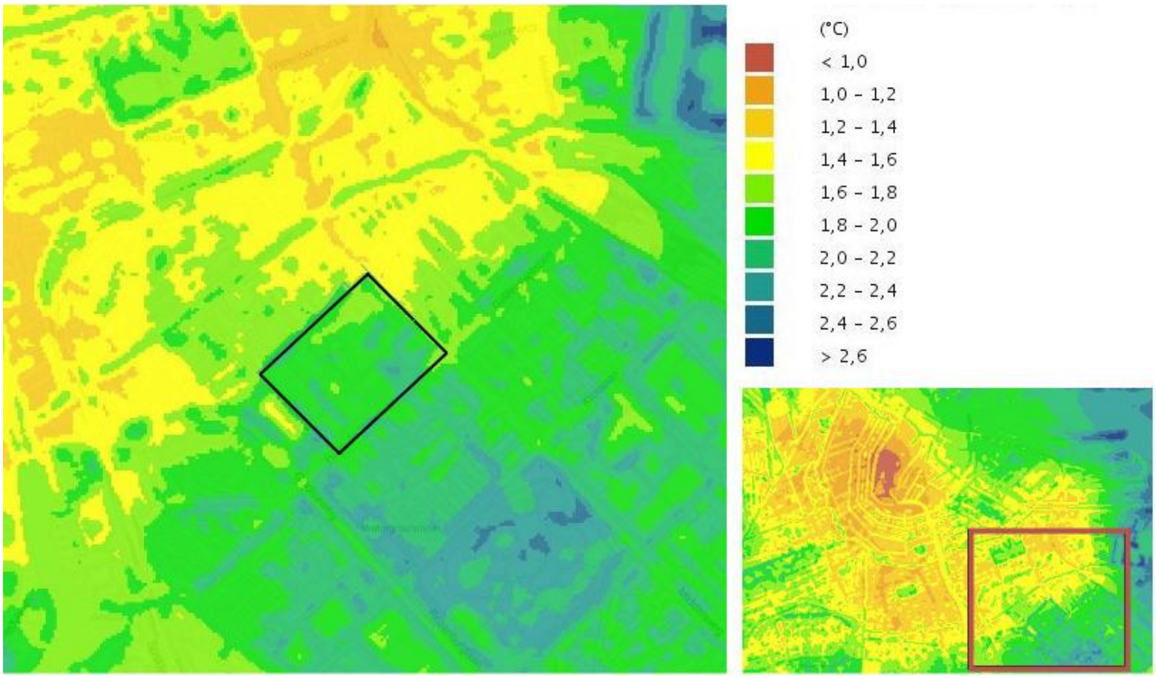


Figure 12 - Cooling effect of green and blue areas in Amsterdam including Frankendael Park (black outline, left image) (RIVM, n.d.)

Recreation

Parks in Amsterdam such as Frankendael are used by people for diverse activities; physical exercise, transportation by bike or foot, and relaxation (van Kempen & Smeets, 2013). In a 2013 survey, Park Frankendael obtained a score of 7.7 (out of 10) from respondents who occasionally visited the park. This score reflects satisfaction with the park (average score was 7.2) and since 2008, both the number of visitors and their satisfaction with the park have steadily increased (ibid).

The park is also capable of hosting small and medium sized events in some areas such as the grass meadows or paved pathways (on average, approximately 17 per year). However due to the vulnerability of the park's more ecological diverse areas, the park is not permitted to host large events (greater than 2,000 visitors) that would cause major impacts to the surrounding natural environment (City of Amsterdam, 2018).

There are several potential methods to extract the monetary value of recreation as an ES provided by Park Frankendael. One method is to calculate the combined revenue earned for all of the events held within the park (i.e. money spent by all visitors) or alternatively to estimate the expected travel costs for nearby residents who would have to travel to other natural areas in the absence of the park. Since the required data for these calculations were unavailable for the current study, alternative methods were considered, both based on the TEEB Valuation Database (van der Ploeg & de Groot, 2010).

The average Dutch willingness to pay for visiting nature is estimated between €1.06-1.14 per visit (Ruijgrok & de Groot, 2006). However, in order to utilise this estimate, the annual number of visitors to Park Frankendael would have to be known, which is not currently the case. Therefore the chosen method for estimating the recreation value of Park Frankendael was a spatial unit value transfer approach whereby the meta-analysis of ES values from other sites similar in typology are transferred to the area of interest (Troy and Wilson, 2006). Although there are clear limitations of this approach in terms of local contextual sensitivities, these types of studies are common in the literature and provide a first order estimate of certain ES values that can be subsequently updated with more detailed local data.

Brenner et al. (2010) have used this valuation transfer method to arrive at an average value of €4,702 per hectare per year of recreation, aesthetic and spiritual ES that urban green spaces provide along the Catalan coast. Applying this figure to the area of Park Frankendael, while acknowledging the biophysical and socioeconomic differences between the two study areas, results in an estimate of €107,770 for the cultural ES mentioned above.

Figure 13 - Visitors attending the Pure Markt event held ten times a year at Park Frankendael (Pure Markt, n.d.)

Education

Within the confines of the park is the oldest 'schooltuin' (school garden) in Amsterdam. Every year approximately 500 school-aged children use the greenhouse, farm, gardens and classroom for year-round and seasonal educational activities related to agriculture and nature discovery (City of Amsterdam, n.d.-b).

The park also contains headquarters for two separate scouting associations; Scouting Frankendael and Gijsbrecht van Aemstel. The latter organisation has a membership of 90 children with ages ranging from 3-21 years old. These organisations are known for engaging children in a wide range of outdoor leadership and team-building activities.

The park allows provides a unique setting in the urban landscape that allows children of all ages to participate in hands-on activities in outdoor areas surrounded by natural features. Given the disconnection from nature that urban residents often experience (Kaplan, 1984), these opportunities are vital to foster greater awareness and appreciation of nature at early stages of child development (Betuel, 2019).

Economic

The community garden located inside Park Frankendael contains 128 individual plots (mean size = 200m^2) each of which is rented from the municipality by local residents at a cost of €500 per year (G. Kooi, personal communication, July 23, 2019). The total annual revenue that the City of Amsterdam receives from renting these plots is €64,000.

While there is evidence that property values are positively correlated with proximity to and within view of urban parks (Ruijgrok and de Groot, 2006), the exact effect of Park Frankendael on surrounding real estate is difficult to isolate without extensive economic analysis of the local area, and furthermore is not visibly evident in property value maps of Amsterdam (City of Amsterdam, n.d.-a).

Mobility

Based on anecdotal evidence from site visits, Park Frankendael acts as a car-free transit route for pedestrians and cyclists in the area (Figure 14). Despite the lack of usage statistics for routes in the park, there are significant benefits in safety and "contact with nature" that urban residents tend to value in choosing to travel through parks as opposed to streets populated by cars (Santos et al., 2016).

Figure 14 - Walking and cycling path through Park Frankendael

4.5 Value case for Park Frankendael

A summary of all ES measured for Park Frankendael, using i-Tree Eco and other methods, are presented in Table 13 along with the respective quantities, values and possible sources of uncertainty during calculations.

Table 13 - Summary of ES calculated for Park Frankendael

Category	Ecosystem service	Quantity	Value	Possible sources of uncertainty
Regulating (air quality)	Air pollution removal	664.4 kg per year	€32,600 per year	EU median social costs of air pollution
	Oxygen production	73.55 metric tons per year		Lack of data on tree mortality
	Volatile organic compounds (VOCs)⁺	134.7 kg per year		VOC effects on ozone formation
Regulating (climate change)	Carbon sequestration	27.58 metric tons per year	€5,560 per year	U.S. average social cost of carbon
	Carbon storage	3,430 metric tons	€696,000	
Regulating (water management)	Avoided runoff	2,307 m^3 per year	€21,800 per year	Price of avoided runoff from U.S. city
Regulating (temperature)	Local cooling effects	Daily average reduction of 1.6 - 2.4 °C		Heterogeneity across park elements
Cultural (economic)	Structural value		€9.69 million	U.S.-based estimates
Cultural (aesthetic)	Aesthetic value of natural elements of the park		€107,770 (combined) per year	Value transfer method from urban green spaces in Catalonia
Cultural (recreation)	Opportunities for leisure and space for events			
Cultural (spiritual)	Spiritual enrichment associated with natural elements of the park			
Cultural (education)	School gardens and scouting activities	500 children involved in gardening; 90+ children participating in weekly scouting activities at the park		No account of field trips and other external educational visits to park
Cultural (economic)	Municipal income from community garden		€64,000 per year	No comparison with willingness to pay
Cultural (mobility)	Transit routes for pedestrians and cyclists	Higher safety and increased contact with nature		Lack of usage statistics
Total economic value (per year)			**€231,730**	

⁺ = *ecosystem disservice (negative value)*

5 DISCUSSION

"The importance of fellowship with trees is historically, a large part of who we are as a species. Seeing trees as sacred is not an anomaly; it's the fact that we've somehow lost this fellowship that is an anomaly."
- Lydon (2018)

5.1 Screening of tools

The wide range of available 'off the shelf' ES assessment tools (Table 8) necessitated the narrowing down of tools to a more manageable number for evaluation and scoring. Screening criteria reflected the practical needs of W+B (open access, free, readily available) and the type of assessment desired (multiple ES, urban scales, quantified outputs). Some tools still in the prototype stage (LUCI, Naturvation Index) could eventually meet the current screening criteria once fully developed, while other tools restricted to certain geographical areas (GI-Val, TESSA) are planning to expand their transferability in the future. In particular, TEEB Stad and ANK may be promising options for future ES assessments based on their incorporation of extensive data sets and models, though their availability in Dutch only limits wider use.

By modifying the screening criteria according to specific requirements, it is also possible to broaden or further narrow the range of tools that can be subsequently evaluated. This will largely depend on the needs and capabilities of potential (non-technical) end users. For example, it may be an important prerequisite for tools to be open source so that the underlying code, equations and methodology can be modified by end users. Furthermore, a certain level of practical support may be necessary for studies that rely on community participation.

While the exact composition of screening criteria is open to modification, those used in the current study represent a strong basis for selecting 'off the shelf' assessment tools that can be readily employed without proprietary restrictions across relevant urban scales to quantify multiple ES through the input of user generated data.

5.2 Evaluation and scoring

While there is a clear shift in the academic and research communities away from individual indicators to measure single ES towards 'off the shelf' tools that measure multiple ES at a time (Nelson & Daily, 2010), more information is required by decision-makers about the existence, capabilities and requirements of these tools. This study is the first attempt to comparatively score and rank a selection of ES assessment tools in a systematic fashion that takes into account two separate but equally relevant perspectives; scientific validity in incorporating ecosystem health alongside the measurement of multiple ES, and practical requirements that reflect the feasibility of applying each tool *in situ*. The screening and scoring methodology presented in this study is aimed at standardising and facilitating the process of selecting an appropriate tool for a given set of circumstances.

Beyond identifying i-Tree Eco as the most suitable tool within the parameters of the current study, the results of the scoring matrix (Table 10) also demonstrate the unequal representation of each tool across the scientific and grey literature. While there is some merit in weighing the individual scores according to source type so that independent, peer-reviewed scientific analyses are more highly valued, the disparity in sources would skew the results and prevent recently developed tools, for which third party reviews are rare, from outscoring more established tools. Instead, an additional criterion such as peer-reviewed scientific backing (Annex VIII) could be inserted to reflect a preference for objective analyses of the tools under evaluation.

The narrow edge that i-Tree Eco received over other tools implies that the results of the scoring matrix are not as definitive as one would prefer when deciding on a tool to apply. The use of different criteria, or a different interpretation of the primary documents for each tool, could easily result in another tool achieving the highest score. Thus it is important that the source (Annex VI) and reasoning (Annex VII) behind each assigned score is presented as a reference for future scoring exercises. Some of these explanations are based on the analysis and opinion of third party reviewers, whereas others are derived from interpretation of each tool's primary documents. Any attempt to score multiple tools across different types of literature sources will always involve some level of subjectivity. However under the current circumstances and through the use of independent reviews where possible, the results of the scoring matrix are considered to be a reliable enough reflection of the performance of each tool according to the chosen evaluation criteria.

Supplemental evaluation criteria were also identified in the literature and assessed for each of the tools (Annex VIII). The criteria fall into three main categories described by Cash et al. (2003) and applied by van Oudenhoven et al. (2018): credibility, salience and legitimacy. Although these criteria are worthy of consideration for comparing and ranking tools, they were not viewed as relevant as the criteria that were eventually selected and used. Moreover, the inclusion of all 18 criteria would have resulted in a lengthy and complicated scoring matrix for which insights and conclusions would be difficult to extract.

The presence of additional criteria in Annex VIII does however highlight the flexibility that the scoring matrix method has in meeting the needs of end users wishing to select a suitable tool for ES assessments. Following the recommendation of fellow researchers and colleagues at W+B, expert judgment was used to divide the 18 criteria into two categories; critical and non-critical. Nonetheless, additional methods for selecting appropriate evaluation criteria could also be explored further. One option involves the use of surveys among end users to rank criteria. This could result in a straightforward process where the criteria with the highest votes are selected for insertion into the scoring matrix. Another approach involves the use of multi-criteria analysis (MCA) to rank criteria against each other, also through the use of surveys. Each of these approaches would better reflect end user priorities yet would require additional time and resources for collecting and analysing survey results.

One of the limitations of the current evaluation approach is the lack of a "comparative concurrent application of multiple tools to a common location" as a way of measuring tool feasibility under practical conditions (Bagstad et al., 2013). By simultaneously applying several tools to a common case study, feasibility criteria in the scoring matrix (i.e. capacity, data, adaptability) could be more accurately evaluated and compared, especially when contrasted with the current scoring method which is based on literature review. This type of practical assessment is an encouraging prospect for future tool evaluations, however the significant amount of data and time that would be required to undertake such an assessment would necessitate a large team and coordination across each tool's application. Building on the current study, a practical assessment could be carried out with two or three of the highest scoring tools (i-Tree, B£ST, ARIES) to further validate the feasibility scores that each of them received in the scoring matrix.

5.3 Application of i-Tree Eco

General features of i-Tree Eco

The design of the current study allowed for the application of the single highest-scoring tool (i-Tree Eco) on an urban case study. This enabled a more in-depth appraisal of the feasibility requirements and performance capabilities of i-Tree Eco.

When applied internationally, i-Tree Eco does not take into account non-tree forms of vegetation and water bodies, thus limiting the types of NBS for which it can be applied. i-Tree is therefore best suited to those NBS where trees represent the predominant vegetation (i.e. parks, urban forests, street canopies). However, the focus on trees is partially justified since they are strongly associated with many relevant urban ES. Trees have a higher impact on air pollution removal (Klimas et al., 2016), cooling potential of urban NBS (Zardo, Geneletti, Pérez-Soba, & Van Eupen, 2017) and produce a higher positive effect on mental health (Astell-Burt & Feng, 2019), than all other forms of vegetation. Furthermore, the growing popularity of tree planting initiatives around the world (Salmond et al., 2016) demands empirical evidence of the benefits that trees provide to humans and biodiversity.

For Park Frankendael 1,208 trees were included for assessment in i-Tree Eco (Figure 9), accounting for 89 percent of the total number of trees within the boundaries of the park. It is reasonable to assume that the ES measured by i-Tree Eco for Park Frankendael are underestimated for two main reason: a) only trees were used in calculations thus ignoring grass, shrubs, water bodies and other NBS elements that have been known to contribute to ES (van den Bosch & Nieuwenhuijsen, 2017), and b) 11 percent of the trees in Park Frankendael are absent from the current analysis due to data and logistical limitations.

Air pollution removal

Table 6 shows which benefit prices were used in i-Tree Eco calculations, and how they were updated. Air pollution removal prices were not subject to modification in i-Tree Eco. This is significant since Dutch social costs of air pollution are higher than the EU median social costs (van Essen et al., 2011) and would greatly increase the estimated value of air pollution removal for Park Frankendael.

One key pollutant that is not measured in i-Tree Eco is PM10, a form of particulate matter that is not as detrimental to health as PM2.5 but which many air quality indices include in their monitoring. This is a significant gap in the total amount of air pollutant removal measured by i-Tree Eco and should be prioritised in future versions of the tool.

The results of i-Tree Eco for Park Frankendael indicate, albeit with dampened evidence, that the park's trees can provide a valuable ES in improving urban air quality, and thus reduce the negative health impacts associated with air pollution.

Carbon sequestration and storage

Trees are an effective solution towards mitigating climate change through their ability to capture and sequester atmospheric carbon in their biomass. A recent study highlighted the potential of widespread forest restoration (more than 500 billion trees) to reduce atmospheric carbon concentrations by up to 25 percent (Bastin et al., 2019). Despite the fact that the study did not consider urban areas as potential locations for tree planting, recent policies and planning strategies are pushing cities towards offsetting their carbon dioxide emissions and eventually becoming carbon neutral in the long term (Russo et al., 2014). The measured quantities of carbon sequestration by the trees in Park Frankendael demonstrates that (tree-based) NBS can make significant contributions to the climate change mitigation goals of cities.

In terms of estimating the value of carbon sequestration and storage from urban trees, i-Tree uses a U.S.-derived carbon price (Table 6) that likely represents a conservative estimate of the social costs of carbon emissions due to uncertainty regarding future impacts of climate change (Remme et al., 2015). The physical quantities of carbon sequestration and storage that i-Tree calculates however are considered to be robust since clear relationships have been defined between tree dimensions (i.e. biomass) and carbon sequestration rates (Russo et al., 2014).

Avoided water runoff

Stormwater surface runoff is a major concern in many urban areas due to overflows in sewer capacities as well as pollution of water bodies. This problem is compounded in cities by the large extent of impervious surfaces. While the hydrological model used in i-Tree (UFORE-Hydro) is able to capture the effects of tree and land cover on hydrological processes, only total annual quantities of surface runoff are calculated. What is missing from i-Tree is the temporal dimension of peak runoff for storm events, and how vegetation can contribute to its reduction when it is most needed. Since UFORE-Hydro uses hourly timesteps, greater temporal resolution is required in order to produce a time-dependent urban hydrograph for Park Frankendael and its surroundings, as depicted in Figure 15. This arguably represents the most valuable form of runoff reduction that NBS can provide in the event of storms and cloudburst.

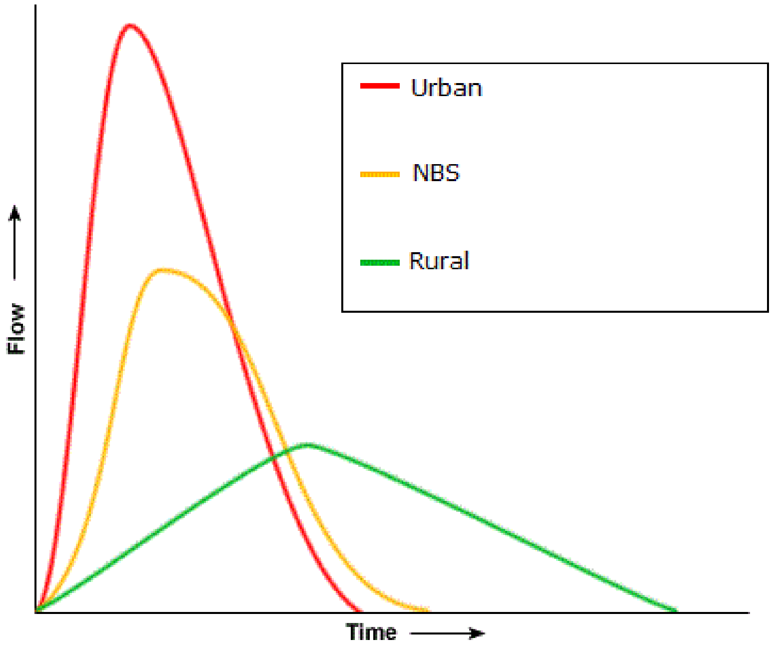


Figure 15 - Generic hydrograph showing the effect that NBS can have on peak runoff in urban areas (Vitale et al., 2009)

Regarding the value of avoided runoff (i.e. the unit price per m^3 of water), local prices are required to more accurately reflect what society (i.e. City of Amsterdam or its residents) is willing to pay to avoid water treatment costs, damages from flooding and pollution of urban water bodies. The use of a stormwater management value from Washington, D.C. reduces the reliability of the valuation associated with avoided runoff in i-Tree Eco, yet is still preferred to the U.S. national average that is used as a default value.

Structural value

The structural value of Park Frankendael as calculated by i-Tree Eco does not include key aspects that one would normally associate with the economic value of a park's structure, such as land value, resource value (i.e. of wood from trees), or heritage and bequest value. Instead, structural value only represents the estimated costs of replacing the measured tree with another tree of similar species, age and size. While such estimates can be useful for monetary settlements of property damage, insurance claims, and loss of property value estimates for income tax deduction (Nowak et al., 2002), replacement costs are not sufficient to capture a tree's inherent structural value (in addition the functional value it has in providing regulating ES). Furthermore, the i-Tree estimates for Park Frankendael in Amsterdam are based entirely on U.S. methods and values, which are subsequently converted into euros. Since there is no room for modifying these valuation methods within i-Tree Eco, an alternative and improved approach would involve calculating structural values separately using cost estimates from tree nurseries, municipalities and landscaping companies. Additional analysis, including surveys to determine willingness to pay, would be required to ensure that other aspects of the park's inherent structural value are also quantified and aggregated, with careful attention to ensure that functional values are excluded to avoid double counting.

Final thoughts on i-Tree Eco

The application of i-Tree Eco on Park Frankendael revealed new insights with implications for the scoring matrix results (Table 10). The performance of i-Tree Eco against the criteria of uncertainty and adaptability was lower during application than what was initially assessed. There is at times limited flexibility in incorporating non-U.S. methods and values to better reflect international case study sites, even when such data available (which is not always the case). At the same time, the application phase reinforced other scores for criteria such as capacity and data requirements. Thus if case study applications can be performed for every tool, then values in the scoring matrix can be perceived as more robust and also more transferable to other, similar contexts.

The following improvements to i-Tree Eco could improve its performance, scope and reliability for future application in the Netherlands and globally:

- The need to expand its international analysis beyond trees to include other elements of NBS. Application of i-Tree Eco in the U.S., Canada and UK allow for the inclusion of grass and shrubs within the model, and eventually this may be the case for other EU countries, but until then i-Tree will be limited in its ability to measure the full range of NBS types in urban areas.
- The results of i-Tree Eco in the Netherlands should be validated either through direct observations or in comparison with other assessment tools. Tools such as ANK and TEEB Stad, developed exclusively for the Netherlands, are well-suited to such comparisons for Dutch case studies, although the ES covered may not overlap entirely with those measured by i-Tree Eco.
- Capturing the full range of urban ES requires either the expansion of the capabilities of i-Tree Eco or its integration with other tools as means of ‘filling in the gaps’. Very recently, Roebeling (2019) at UNaLab has developed a framework for integrating several models and tools for scenario assessments. i-Tree Eco is listed as one of the tools to be included in this new framework, though its use is limited to ecosystem structure and biodiversity.
- GIS software was used to collect, organise and transform data for use in i-Tree (Figure 9). However i-Tree Eco itself does not produce maps or other spatial outputs that would be useful for presenting and interpreting results. Adding such features, which could involve closer integration with GIS software, strengthen the position of i-Tree Eco vis-à-vis other tools that are GIS-based.

5.4 Additional ecosystem services assessment

Cooling effect

The UHI effect that is observed in urban areas occurs due to the higher absorption of sunlight radiation by darker materials such as asphalt and concrete, a slower release of this heat by these materials, and less natural evaporation because of soil sealing (Remme et al., 2017). NBS are well placed to positively affect the cooling capacity of urban areas since vegetation and water bodies can increase the evaporation capacity of an area while tree canopy provides shading to reduce the local UHI effect (Baró, Haase, Gómez-Baggethun, & Frantzeskaki, 2015).

The local cooling effect of trees is the most relevant urban ES that was missing from i-Tree Eco’s capabilities. The growing concern over climate change, heat waves and associated health problems has elevated the prioritisation of this ES to the point where any urban NBS assessment cannot afford to ignore it (Geneletti & Zardo, 2016). For this reason the cooling effect of Park Frankendael’s vegetation and water on the UHI effect was estimated using the ANK model developed by RIVM (Remme et al., 2017). While exact quantities are not provided, Figure 12 illustrates the average effect that the park has within the city and provides an initial estimate of its magnitude (which varies across the different elements of the park).

Cultural ES

Through surveys, interviews, personal observations and event calendars, it’s evident that Park Frankendael is an important source of cultural ES that are simply not captured within i-Tree Eco. Some of these cultural ES can be monetised through economic valuation methods while others are expressed in qualitative terms only. The value transfer method used for quantifying the recreation, aesthetic and spiritual ES of Park Frankendael is a crude approximation that fails to account local the biophysical and socioeconomic conditions that would affect the final valuation. However, the large number and diversity of reference studies used by Brenner et al. (2010) in their own analysis meant that these same value estimates, tailored to biophysical regions in Western Europe, could also be reasonably justified for use in a context such as Amsterdam as long as the limitations of the value transfer were explicitly acknowledged.

Space for educational activities and traffic-free mobility are additional cultural ES often associated with urban parks (Kaplan, 1984; Santos et al., 2016). While quantitative analyses for these ES was not possible a part of the current study, their inclusion in the value case for Park Frankendael is still relevant for creating a more complete picture of the benefits of the park while incorporating non-financial dimensions of value (Figure 17).

5.5 Valuing urban nature-based solutions

The value case of benefits for Park Frankendael is the final output of the current study. This value case should be viewed as a snapshot baseline assessment of the value of the park according to select urban ES. The goal of the presented value case is to identify, highlight and quantify (where possible) the many biophysical and socioeconomic benefits that Park Frankendael provides to the city of Amsterdam and its residents. These can be expressed as the total economic value of annual ES flows (Table 12) or as a graphic that simply highlights the types of ES being provided (Figure 17).

Brenner et al. (2010) state that by expressing and relating these benefits to human well-being, “valuation aims to make [NBS] comparable with other sectors of the economy (e.g. built capital) for appraising investments, planning activities, developing policies, or making decisions about land and resource use.” Furthermore, the public distribution of a value case (as well the evidence and tools behind it) to a wider audience can raise awareness of the importance of urban nature and thus help shift the political discourse towards greater NBS implementation in cities.

The list of ES assessed in the current study, either through i-Tree Eco or other methods, is certainly not exhaustive. Relevant urban ES that are missing from the current value case include noise attenuation, provision of agriculture, water purification, sediment regulation, pollination, and improvements in both individual mental health and social cohesion (Gómez-Baggethun & Barton, 2013). Since there is no one tool that can capture the full range of urban ES (Annex II), the combined use of several tools, optimally integrated to complement gaps in ES measurements, could be employed within an analytical framework such as that of UNaLab (Roebeling, 2019) to create a more comprehensive assessment of urban ES across a wide range of NBS types and locations.

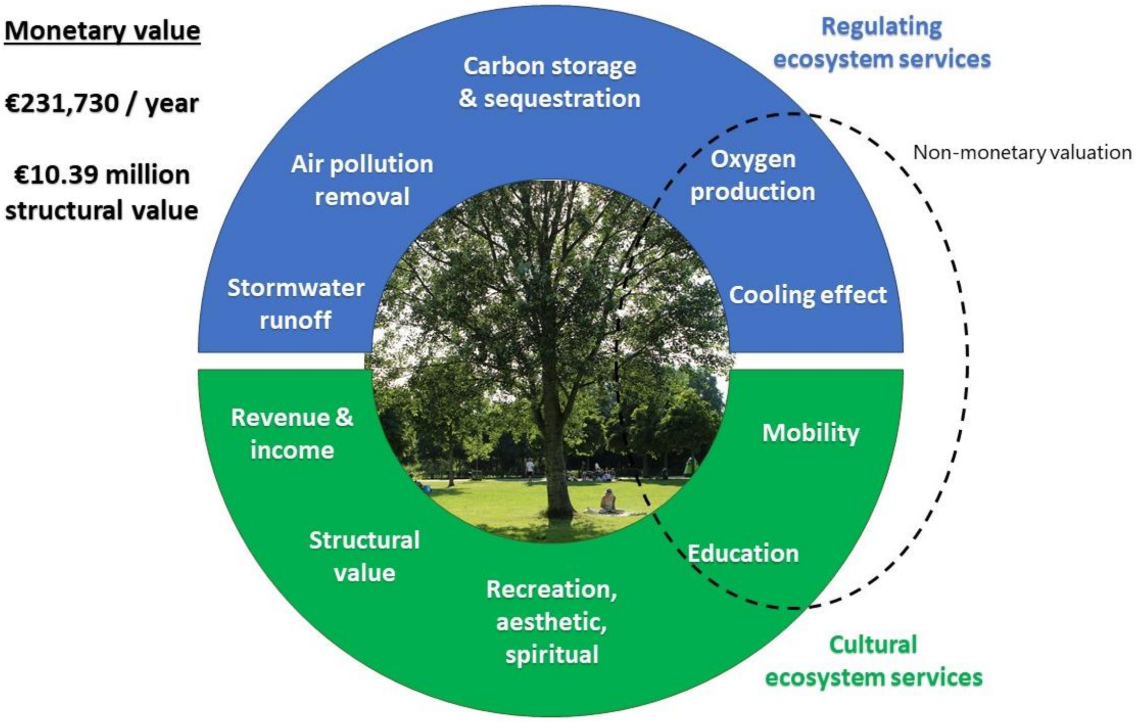


Figure 16 - Schematic diagram of the benefits delivered by Park Frankendael, divided according to regulating or cultural ES. All ES except those inside the dotted circle were quantified and monetised.

5.6 Implications for Witteveen+Bos

For W+B, the entire process of building the current value case represents a template for future urban ES assessments. Through the screening process and scoring matrix, an ‘off the shelf’ tool can be appropriately selected with chosen criteria that reflect the company’s needs and local conditions. Subsequent applications of i-Tree Eco or another tool on urban case studies can pave the way for integrating ES assessments into future W+B projects where empirical evidence is required to justify the inclusion of NBS in proposed designs or strategies.

The following steps are required for effectively incorporating urban ES assessments into the service offerings of W+B:

1. Identify which current W+B projects would benefit from the inclusion of i-Tree Eco or other forms of ES assessments, as a means of testing tool performance and feasibility while transferring knowledge to colleagues;
2. Classify which urban ES are considered to be high priority for current (and future) W+B clients, beyond those recognised in the literature;
3. Include the identification of relevant ES, and possible tools that can be applied, as part of the NBS rapid assessment platform that was recently developed by W+B;
4. For specific projects, build the ideal combination of ES assessment tools that captures all relevant ES from a NBS and integrate the results into a single value case of monetised and non-monetised benefits.

6 CONCLUSION

"And into the forest I go, to lose my mind and find my soul" - Danu (2014)

The current study aimed to *identify the most effective assessment tool for measuring the multiple benefits from nature-based solutions (NBS) in cities* and to illustrate *how the empirical evidence from such a tool could be captured and presented for an urban case study in a relevant way to local stakeholders*.

Based on specific screening and evaluation criteria, *i-Tree Eco* obtained the highest score across a selection of six tools, and thus was deemed to be the *most effective tool* for application to the urban case study of Park Frankendael in Amsterdam. The screening process and *scoring matrix* developed and used by this study highlighted the *main strengths and weaknesses of each of the six tools* and allowed for a direct comparison between them in terms of scientific validity and feasibility.

This study sets up a useful methodology that can be used by a variety of urban stakeholders for selecting, comparing and ranking ecosystem services assessment tools. This approach can therefore facilitate the greater use of such tools in urban decision-making and spatial planning by narrowing down options and scoring them according to specific project needs expressed through chosen criteria.

Overall, the *performance of i-Tree Eco was positive* in capturing the ecosystem services provided by Park Frankendael. While there are some practical limitations that affect the scope and ease-of-use of i-Tree Eco in the Netherlands, the tool outputs reflect sound scientific knowledge and future application of i-Tree Eco in additional Dutch case studies is highly encouraged.

The *value case* that was developed for Park Frankendael, based on the results of i-Tree Eco and additional ecosystem services assessment methods, includes a wide range of *quantitative and qualitative benefits* to society which were assigned both *monetary and non-monetary values*. It is clear that there is sufficient and solid empirical evidence of a wide variety benefits of Park Frankendael to the city of Amsterdam and its residents. The priority now lies with using the value case for the park, and its underlying empirical evidence, as a catalyst for engaging local decision-makers and stakeholders in order to advocate for the protection of existing NBS in the city as well as greater NBS implementation in development projects across the city.

Natural ecosystems are fundamental to our existence as a species. In urban areas where environmental degradation and disconnect with nature are greatest, NBS offer a new opportunity to transform the concrete jungles we live in. By connecting human well-being with natural systems and biodiversity, cities can move beyond simply being 'sustainable' and become hubs for ecosystem regeneration at every spatial scale. Bringing nature back into our cities can restore our collective physical and mental health, improve our resiliency to meet future challenges, and actively strengthen the living ecosystems that all species depend on for survival.

7 REFERENCES

Abd-Elrahman, A. H., Thornhill, M. E., Andreu, M. G., & Escobedo, F. (2010). A community-based urban forest inventory using online mapping services and consumer-grade digital images. *International Journal of Applied Earth Observation and Geoinformation*, *12*(4), 249–260. https://doi.org/10.1016/j.jag.2010.03.003

Ashley, R. M., Digman, C. J., Horton, B., Gersonius, B., Smith, B., Shaffer, P., & Baylis, A. (2017). Evaluating the longer term benefits of sustainable drainage. *Proceedings of the Institution of Civil Engineers - Water Management*, *171*(2), 57–66. https://doi.org/10.1680/jwama.16.00118

Astell-Burt, T., & Feng, X. (2019). Association of Urban Green Space With Mental Health and General Health Among Adults in Australia. *JAMA Network Open*, *2*(7), e198209–e198209. https://doi.org/10.1001/jamanetworkopen.2019.8209

Bagstad, K. J., Semmens, D. J., Waage, S., & Winthrop, R. (2013). A comparative assessment of decision-support tools for ecosystem services quantification and valuation. *Ecosystem Services*, *5*, 27–39. https://doi.org/10.1016/j.ecoser.2013.07.004

Baró, F., Haase, D., Gómez-Baggethun, E., & Frantzeskaki, N. (2015). Mismatches between ecosystem services supply and demand in urban areas: A quantitative assessment in five European cities. *Ecological Indicators*, *55*, 146–158. https://doi.org/10.1016/j.ecolind.2015.03.013

Bastin, J.-F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., … Crowther, T. W. (2019). The global tree restoration potential. *Science*, *365*(6448), 76–79. https://doi.org/10.1126/science.aax0848

Betuel, E. (2019, May 21). Scientists Discover a Major Lasting Benefit of Growing Up Outside the City. Retrieved 2 August 2019, from Inverse website: https://www.inverse.com/article/56019-psychological-benefits-of-nature-mental-health

Bos, E., & Vogelzang, T. (2018, March). *Groei versus groen drie casestudy's over de waarde van het stadsgroen in Amsterdam*. Retrieved from https://www.wur.nl/nl/nieuws/Stadsgroen-Amsterdam-mogelijk-meer-waard-dan-woningbouw.htm

Boumans, R., Roman, J., Altman, I., & Kaufman, L. (2015). The Multiscale Integrated Model of Ecosystem Services (MIMES): Simulating the interactions of coupled human and natural systems. *Ecosystem Services*, *12*, 30–41. https://doi.org/10.1016/j.ecoser.2015.01.004

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., Vries, S. de, Flanders, J., … Daily, G. C. (2019). Nature and mental health: An ecosystem service perspective. *Science Advances*, *5*(7), eaax0903. https://doi.org/10.1126/sciadv.aax0903

Brenner, J., Jiménez, J. A., Sardá, R., & Garola, A. (2010). An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. *Ocean & Coastal Management*, *53*(1), 27–38. https://doi.org/10.1016/j.ocecoaman.2009.10.008

Brown, C., Burns, A., & Arnell, A. (2018). A Conceptual Framework for Integrated Ecosystem Assessment. *One Ecosystem*, *3*, e25482. https://doi.org/10.3897/oneeco.3.e25482

Buro Sant en Co. (2016). Park Frankendael, Amsterdam. Retrieved 10 July 2019, from Buro Sant en Co website: https://www.santenco.nl/nl/portfolio_page/park-frankendael/

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., … Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences*, *100*(14), 8086–8091. https://doi.org/10.1073/pnas.1231332100

City of Amsterdam. (2018, March). *Locatieprofielen*.

City of Amsterdam. (n.d.-a). Maps Data. Retrieved 9 July 2019, from Gemeente Amsterdam website: https://maps.amsterdam.nl/open_geodata/?LANG=en

City of Amsterdam. (n.d.-b). Vink Schooltuin. Retrieved 25 July 2019, from Gemeente Amsterdam website: https://www.amsterdam.nl/onderwijs-jeugd/basisonderwijs/natuur-milieu/vink/

Cook, B. R., & Spray, C. J. (2012). Ecosystem services and integrated water resource management: Different paths to the same end? *Journal of Environmental Management*, *109*, 93–100. https://doi.org/10.1016/j.jenvman.2012.05.016

Cord, A. F., Bartkowski, B., Beckmann, M., Dittrich, A., Hermans-Neumann, K., Kaim, A., … Volk, M. (2017). Towards systematic analyses of ecosystem service trade-offs and synergies: Main concepts, methods and the road ahead. *Ecosystem Services*, *28*, 264–272. https://doi.org/10.1016/j.ecoser.2017.07.012

Crossman, N. D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., … Maes, J. (2013). A blueprint for mapping and modelling ecosystem services. *Ecosystem Services*, *4*, 4–14. https://doi.org/10.1016/j.ecoser.2013.02.001

Czúcz, B., Arany, I., Potschin-Young, M., Bereczki, K., Kertész, M., Kiss, M., … Haines-Young, R. (2018). Where concepts meet the real world: A systematic review of ecosystem service indicators and their classification using CICES. *Ecosystem Services*, *29*, 145–157. https://doi.org/10.1016/j.ecoser.2017.11.018

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., Pejchar, L., … Shallenberger, R. (2009). Ecosystem services in decision making: Time to deliver. *Frontiers in Ecology and the Environment*, *7*(1), 21–28. https://doi.org/10.1890/080025

Dammers, E., Veerkamp, C., Ruijs, A., Hedlund, K., Olsson, P., Alsterberg, C., … Bulkeley, H. (2019). *Working paper: Set up, applicability and use of the Naturvation Index* (Working Paper No. Deliverable 3.4; p. 136). Naturvation.

Danu, M. (2014, November 8). Mariah-Danu the Druid Witch. Retrieved 25 July 2019, from Tumblr website: https://mariah-danu.tumblr.com/post/102107969350/and-into-the-forest-i-go-to-lose-my-self-and-find

Davies, C., & Lafortezza, R. (2019). Transitional path to the adoption of nature-based solutions. *Land Use Policy*, *80*, 406–409. https://doi.org/10.1016/j.landusepol.2018.09.020

de Groot, R. S., Wilson, M. A., & Boumans, R. M. J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, *41*(3), 393–408. https://doi.org/10.1016/S0921-8009(02)00089-7

de Wit, M., van Zyl, H., Crookes, D., Blignaut, J., Jayiya, T., Goiset, V., & Mahumani, B. (2012). Including the economic value of well-functioning urban ecosystems in financial decisions: Evidence from a process in Cape Town. *Ecosystem Services*, *2*, 38–44. https://doi.org/10.1016/j.ecoser.2012.08.002

Dittrich, K., & van Dijk, W. (2013). *The Value Case Methodology. A Methodology Aligning Financial and Non-Financial Values in Large Multi-Stakeholder Innovation Projects* (p. 4) [Technical Report]. Retrieved from The Netherlands Organisation of Applied Scientific Research (TNO) website: https://www.researchgate.net/publication/264944219_The_Value_Case_Methodology_A_Methodology_Aligning_Financial_and_Non-Financial_Values_in_Large_Multi-Stakeholder_Innovation_Projects

Ecosystems Knowledge Network. (n.d.). Tool Assessor—List of Tools | Ecosystems Knowledge Network. Retrieved 23 May 2019, from https://ecosystemsknowledge.net/tool-assessor-list-of-tools

Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J., … Le Roux, X. (2015). Nature-based Solutions: New Influence for Environmental Management and Research in Europe [Text]. Retrieved 18 April 2019, from https://www.ingentaconnect.com/content/oekom/gaia/2015/00000024/00000004/art00010;jsessionid=1c9eka4nfk485.x-ic-live-01

Egoh, B., Drakou, E. G., Willemen, L., Maes, J., Dunbar, M. B., European Commission, … Institute for Environment and Sustainability. (2012). *Indicators for mapping ecosystem services a review*. Luxembourg: Publications Office.

Elmhagen, B., Destouni, G., Angerbjörn, A., Borgström, S., Boyd, E., Cousins, S. A. O., … Lindborg, R. (2015). Interacting effects of change in climate, human population, land use, and water use on biodiversity and ecosystem services. *Ecology and Society*, *20*(1). Retrieved from https://www.jstor.org/stable/26269757

Escobedo, F. J., Giannico, V., Jim, C. Y., Sanesi, G., & Lafortezza, R. (2019). Urban forests, ecosystem services, green infrastructure and nature-based solutions: Nexus or evolving metaphors? *Urban Forestry & Urban Greening*, *37*, 3–12. https://doi.org/10.1016/j.ufug.2018.02.011

European Commission. (2015). *Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities: Final report of the Horizon 2020 expert group on 'Nature-based solutions and re-naturing cities'* [Website]. Retrieved from https://publications.europa.eu/en/publication-detail/-/publication/fb117980-d5aa-46df-8edc-af367cddc202

Eurostat. (2019, May 21). Electricity price statistics. Retrieved 8 August 2019, from Statistics Explained website: https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

Feld, C. K., Silva, P. M. da, Sousa, J. P., Bello, F. D., Bugter, R., Grandin, U., … Harrison, P. (2009). Indicators of biodiversity and ecosystem services: A synthesis across ecosystems and spatial scales. *Oikos*, *118*(12), 1862–1871. https://doi.org/10.1111/j.1600-0706.2009.17860.x

Frantzeskaki, N., McPhearson, T., Collier, M. J., Kendal, D., Bulkeley, H., Dumitru, A., … Pintér, L. (2019). Nature-Based Solutions for Urban Climate Change Adaptation: Linking Science, Policy, and Practice

Communities for Evidence-Based Decision-Making. *BioScience*. https://doi.org/10.1093/biosci/biz042

Geneletti, D., & Zardo, L. (2016). Ecosystem-based adaptation in cities: An analysis of European urban climate adaptation plans. *Land Use Policy*, *50*, 38–47. https://doi.org/10.1016/j.landusepol.2015.09.003

Giezen, M. (2018, August 10). Remote-sensing toont hoe groene ruimte in Amsterdam afneemt. Retrieved 9 July 2019, from Universiteit van Amsterdam website: https://www.uva.nl/shared-content/faculteiten/nl/faculteit-der-maatschappij-en-gedragswetenschappen/nieuws/2018/10/beleid-voor-een-duurzame-stad.html

Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, *86*, 235–245. https://doi.org/10.1016/j.ecolecon.2012.08.019

Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., … Elmqvist, T. (2014). A Quantitative Review of Urban Ecosystem Service Assessments: Concepts, Models, and Implementation. *AMBIO*, *43*(4), 413–433. https://doi.org/10.1007/s13280-014-0504-0

Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). Nature and Health. *Annual Review of Public Health*, *35*(1), 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443

Hassan, R., Scholes, R., & Ash, N. (Eds.). (2005). *Ecosystems and Human Well-being: Current State and Trends*. Retrieved from https://www.millenniumassessment.org/en/Global.html

Hirabayashi, S. (2013, January 30). *I-Tree Eco Precipitation Interception Model Descriptions*. Retrieved from https://www.itreetools.org/support/resources-overview/i-tree-methods-and-files/i-tree-eco-and-ufore-resources

Hirabayashi, S., Kroll, C. N., & Nowak, D. J. (2015, February 27). *I-Tree Eco Dry Deposition Model Descriptions*. Retrieved from https://www.itreetools.org/support/resources-overview/i-tree-methods-and-files/i-tree-eco-and-ufore-resources

Horton, B., Digman, C. J., Ashley, R. M., & McMullan, J. (2019). *Guidance to assess the benefits of blue and green infrastructure using B£ST*. Retrieved from https://www.susdrain.org/resources/best.html

International Union for Conservation of Nature (IUCN). (2016, September 27). Nature-based Solutions. Retrieved 21 March 2019, from IUCN website: https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions

Jax, K., Barton, D. N., Chan, K. M. A., de Groot, R., Doyle, U., Eser, U., … Wichmann, S. (2013). Ecosystem services and ethics. *Ecological Economics*, *93*, 260–268. https://doi.org/10.1016/j.ecolecon.2013.06.008

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., … Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: Perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society*, *21*(2). https://doi.org/10.5751/ES-08373-210239

Kaplan, R. (1984). Impact of urban nature: A theoretical analysis. *Urban Ecology*, *8*(3), 189–197. https://doi.org/10.1016/0304-4009(84)90034-2

Klimas, C., Williams, A., Hoff, M., Lawrence, B., Thompson, J., & Montgomery, J. (2016). Valuing Ecosystem Services and Disservices across Heterogeneous Green Spaces. *Sustainability*, *8*(9), 853. https://doi.org/10.3390/su8090853

Krauze, K., & Wagner, I. (2019). From classical water-ecosystem theories to nature-based solutions—Contextualizing nature-based solutions for sustainable city. *Science of The Total Environment*, *655*, 697–706. https://doi.org/10.1016/j.scitotenv.2018.11.187

Kwan, M.-P. (2018). The Limits of the Neighborhood Effect: Contextual Uncertainties in Geographic, Environmental Health, and Social Science Research. *Annals of the American Association of Geographers*, *108*(6), 1482–1490. https://doi.org/10.1080/24694452.2018.1453777

Landezine. (2014, January 7). Qunli National Urban Wetland by Turenscape. Retrieved 13 August 2019, from Landscape Architecture Platform website: http://www.landezine.com/index.php/2014/01/qunli-national-urban-wetland-by-turenscape/

Lele, S., Springate-Baginski, O., Lakerveld, R., Deb, D., & Dash, P. (2013). Ecosystem Services: Origins, Contributions, Pitfalls, and Alternatives. *Conservation and Society*, *11*(4), 343. https://doi.org/10.4103/0972-4923.125752

Livesley, S. J., McPherson, E. G., & Calfapietra, C. (2016). The Urban Forest and Ecosystem Services: Impacts on Urban Water, Heat, and Pollution Cycles at the Tree, Street, and City Scale. *Journal of Environmental Quality*, *45*(1), 119–124. https://doi.org/10.2134/jeq2015.11.0567

Lydon, P. M. (2018, November 11). A City, Designed by Trees. Retrieved 25 July 2019, from City as Nature website: http://cityasnature.org/post/2018/a-city-designed-by-trees/

Maes, J., Liquete, C., Teller, A., Erhard, M., Paracchini, M. L., Barredo, J. I., … Lavalle, C. (2016). An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020. *Ecosystem Services*, *17*, 14–23. https://doi.org/10.1016/j.ecoser.2015.10.023

Martínez-Harms, M. J., & Balvanera, P. (2012). Methods for mapping ecosystem service supply: A review. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *8*(1–2), 17–25. https://doi.org/10.1080/21513732.2012.663792

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* (General Technical Report No. PSW-GTR-202; p. 121). Albany, CA: U.S. Department of Agriculture, Forest Service.

MetroPolder. (n.d.). Smartroof 2.0. Retrieved 13 August 2019, from MetroPolder company website: https://metropolder.com/projecten/smartroof-2-0-2/

Millennium Ecosystem Assessment (MEA). (2005). *Ecosystems and Human Well-being: Synthesis*. Retrieved from https://www.millenniumassessment.org/en/index.html

Morales-Torres, A., Escuder-Bueno, I., Andrés-Doménech, I., & Perales-Momparler, S. (2016). Decision Support Tool for energy-efficient, sustainable and integrated urban stormwater management. *Environmental Modelling & Software*, *84*, 518–528. https://doi.org/10.1016/j.envsoft.2016.07.019

Naturvation. (n.d.). About | NATURVATION [Text]. Retrieved 22 March 2019, from NATURVATION website: https://naturvation.eu/

Nelson, E. J., & Daily, G. C. (2010). Modelling ecosystem services in terrestrial systems. *F1000 Biology Reports*, *2*. https://doi.org/10.3410/B2-53

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, Dr., … Shaw, Mr. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment*, *7*(1), 4–11. https://doi.org/10.1890/080023

Nemec, K. T., & Raudsepp-Hearne, C. (2013). The use of geographic information systems to map and assess ecosystem services. *Biodiversity and Conservation*, *22*(1), 1–15. https://doi.org/10.1007/s10531-012-0406-z

Nowak, D. J., Crane, D. E., Stevens, J. C., & Ibarra, M. (2002). *Brooklyn's urban forest* (General Technical Report No. NE-290; p. 112). Retrieved from U.S. Department of Agriculture, Forest Service website: https://www.fs.usda.gov/treesearch/pubs/3174

Nowak, D. J., Hirabayashi, S., Bodine, A., & Greenfield, E. (2014). Tree and forest effects on air quality and human health in the United States. *Environmental Pollution*, *193*, 119–129. https://doi.org/10.1016/j.envpol.2014.05.028

O'Farrell, P., Anderson, P., Le Maitre, D., & Holmes, P. (2012). Insights and Opportunities Offered by a Rapid Ecosystem Service Assessment in Promoting a Conservation Agenda in an Urban Biodiversity Hotspot. *Ecology and Society*, *17*(3). https://doi.org/10.5751/ES-04886-170327

Olander, L. P., Johnston, R. J., Tallis, H., Kagan, J., Maguire, L. A., Polasky, S., … Palmer, M. (2018). Benefit relevant indicators: Ecosystem services measures that link ecological and social outcomes. *Ecological Indicators*, *85*, 1262–1272. https://doi.org/10.1016/j.ecolind.2017.12.001

Ossa-Moreno, J., Smith, K. M., & Mijic, A. (2017). Economic analysis of wider benefits to facilitate SuDS uptake in London, UK. *Sustainable Cities and Society*, *28*, 411–419. https://doi.org/10.1016/j.scs.2016.10.002

Peh, K. S.-H., Balmford, A., Bradbury, R. B., Brown, C., Butchart, S. H. M., Hughes, F. M. R., … Birch, J. C. (2013). TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance. *Ecosystem Services*, *5*, 51–57. https://doi.org/10.1016/j.ecoser.2013.06.003

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Groffman, P. M., Band, L. E., Boone, C. G., … Wilson, M. A. (2008). Beyond Urban Legends: An Emerging Framework of Urban Ecology, as Illustrated by the Baltimore Ecosystem Study. *BioScience*, *58*(2), 139–150. https://doi.org/10.1641/B580208

Potschin-Young, M., Haines-Young, R., Görg, C., Heink, U., Jax, K., & Schleyer, C. (2018). Understanding the role of conceptual frameworks: Reading the ecosystem service cascade. *Ecosystem Services*, *29*, 428–440. https://doi.org/10.1016/j.ecoser.2017.05.015

Pure Markt. (n.d.). Park Frankendael. Retrieved 25 July 2019, from Pure Markt website: https://puremarkt.nl/locaties/park-frankendael/

Remme, R., de Nijs, T., & Paulin, M. (2017). *Natural Capital Model* (No. 2017–0040; p. 80). Retrieved from Rijksinstituut voor Volksgezondheid en Milieu (RIVM) website: www.doi.org/10.21945/RIVM-2017-0040

Remme, R. P., Edens, B., Schröter, M., & Hein, L. (2015). Monetary accounting of ecosystem services: A test case for Limburg province, the Netherlands. *Ecological Economics*, *112*, 116–128. https://doi.org/10.1016/j.ecolecon.2015.02.015

Rijksinstituut voor Volksgezondheid en Milieu (RIVM). (n.d.). Kaarten | Drupal. Retrieved 20 July 2019, from Atlas Natuurlijk Kapitaal website: https://www.atlasnatuurlijkkapitaal.nl/en/node/1761

Roebeling, P. (2019, June 26). Assessing the Multiple Impacts of Nature-based Solutions Using the Systemic Decision Support Tool. Retrieved 12 August 2019, from UNaLab website: http://unalab.eu/news/assessing-multiple-impacts-nature-based-solutions-using-systemic-decision-support-tool

Rubin, G. (2013, October 18). Feeling Blue? Consider the Beauty of Nature. Retrieved 20 July 2019, from Gretchen Rubin website: http://gretchenrubin.com/2013/10/feeling-blue-consider-the-beauty-of-nature/

Rugel, E. J., Carpiano, R. M., Henderson, S. B., & Brauer, M. (2019). Exposure to natural space, sense of community belonging, and adverse mental health outcomes across an urban region. *Environmental Research*, *171*, 365–377. https://doi.org/10.1016/j.envres.2019.01.034

Ruijgrok, E. C. M., & de Groot, R. (2006). *Kentallen Waardering Natuur, Water, Bodem en Landschap: Hulpmiddel bij MKBA's*. Rotterdam, the Netherlands: Ministerie van Landbouw, Natuur en Voedselkwaliteit.

Russo, A., Escobedo, F. J., Timilsina, N., Schmitt, A. O., Varela, S., & Zerbe, S. (2014). Assessing urban tree carbon storage and sequestration in Bolzano, Italy. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *10*(1), 54–70. https://doi.org/10.1080/21513732.2013.873822

Salmond, J. A., Tadaki, M., Vardoulakis, S., Arbuthnott, K., Coutts, A., Demuzere, M., … Wheeler, B. W. (2016). Health and climate related ecosystem services provided by street trees in the urban environment. *Environmental Health*, *15*(S1), S36. https://doi.org/10.1186/s12940-016-0103-6

Santos, T., Nogueira Mendes, R., & Vasco, A. (2016). Recreational activities in urban parks: Spatial interactions among users. *Journal of Outdoor Recreation and Tourism*, *15*, 1–9. https://doi.org/10.1016/j.jort.2016.06.001

Sharp, R., Chaplin-Kramer, R., Wood, S., Guerry, A., Tallis, H., & Ricketts, T. (2018). *InVEST User Guide*. Retrieved from http://releases.naturalcapitalproject.org/invest-userguide/latest/

Sherrouse, B.C., & Semmens, D. J. (2015). *Social values for ecosystem services, version 3.0 (SolVES 3.0)—Documentation and user manual* (Open-File Report No. 2015–1008; p. 65). Retrieved from U.S. Geological Survey website: https://www.usgs.gov/centers/gecsc/science/social-values-ecosystem-services-solves?qt-science_center_objects=0#qt-science_center_objects

Sherrouse, Benson C., Clement, J. M., & Semmens, D. J. (2011). A GIS application for assessing, mapping, and quantifying the social values of ecosystem services. *Applied Geography*, *31*(2), 748–760. https://doi.org/10.1016/j.apgeog.2010.08.002

Short, C., Clarke, L., Carnelli, F., Uttley, C., & Smith, B. (2019). Capturing the multiple benefits associated with nature-based solutions: Lessons from a natural flood management project in the Cotswolds, UK. *Land Degradation & Development*, *30*(3), 241–252. https://doi.org/10.1002/ldr.3205

Stange, E., Zulian, G., Rusch, G., Barton, D., & Nowell, M. (2017). Ecosystem services mapping for municipal policy: ESTIMAP and zoning for urban beekeeping. *One Ecosystem*, *2*, e14014. https://doi.org/10.3897/oneeco.2.e14014

Styler, T. (2009, October 20). *Trudie Styler talks Crude about Oil in Ecuador*. Retrieved from https://www.treehugger.com/culture/trudie-styler-talks-crude-about-oil-in-ecuador.html

susDrain. (n.d.). B£ST. Retrieved 8 August 2019, from The community for sustainable drainage website: https://www.susdrain.org/resources/best.html

The Nature Conservancy. (2017, June 15). Green Stormwater Infrastructure: Bioswales - Sustainable Urban Design: Educator’s Toolkit for Project-Based Learning. Retrieved 13 August 2019, from Nature Works Everywhere website: https://www.natureworkseverywhere.org/resources/sustainable-urban-design-toolkit/18/

Troy, A., & Wilson, M. A. (2006). Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. *Ecological Economics*, *60*(2), 435–449. https://doi.org/10.1016/j.ecolecon.2006.04.007

United Nations (UN). (2018, May 16). 68% of the world population projected to live in urban areas by 2050, says UN. Retrieved 8 July 2019, from UN DESA | United Nations Department of Economic and Social Affairs website: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

United States Department of Agriculture (USDA) Forest Service. (2019, July 2). *I-Tree Eco User's Manual*. Retrieved from https://www.itreetools.org/support/resources-overview/i-tree-manuals-workbooks

United States Government. (2013, May). *Technical Support Document: -Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis -Under Executive Order 12866*. Interagency Working Group on Social Cost of Carbon.

van den Bosch, M, & Ode Sang, Å. (2017). Urban natural environments as nature-based solutions for improved public health – A systematic review of reviews. *Environmental Research*, *158*, 373–384. https://doi.org/10.1016/j.envres.2017.05.040

van den Bosch, Matilda, & Nieuwenhuijsen, M. (2017). No time to lose – Green the cities now. *Environment International*, *99*, 343–350. https://doi.org/10.1016/j.envint.2016.11.025

van der Ploeg, S., & de Groot, R. S. (2010). *The TEEB Valuation Database – a searchable database of 1310 estimates of monetary values of ecosystem services*. Wageningen, the Netherlands: Foundation for Sustainable Development.

van Essen, H., Schroten, A., Otten, M., Sutter, D., Schreyer, C., Zandonella, R., … Doll, C. (2011). *External costs of transport in Europe* (Update Study No. 11.4215.50; p. 161). Retrieved from CE Delft, Infras, Fraunhofer ISI website: https://www.cedelft.eu/en/publications

van Kempen, H., & Smeets, H. (2013). *Het Grote Groenonderzoek 2013* (No. 13124; p. 112). Amsterdam: Dienst Ruimtelijke Ordening.

van Oudenhoven, A. P. E., Schröter, M., Drakou, E. G., Geijzendorffer, I. R., Jacobs, S., van Bodegom, P. M., … Albert, C. (2018). Key criteria for developing ecosystem service indicators to inform decision making. *Ecological Indicators*, *95*, 417–426. https://doi.org/10.1016/j.ecolind.2018.06.020

van Wesenbeeck, B. K., IJff, S., Jongman, B., Balog-Way, S. A. B., Kaupa, S. M., Bosche, L. V., … Meliane, I. (2017). *Implementing nature based flood protection: Principles and implementation guidance* (No. 120735; pp. 1–32). Retrieved from The World Bank website: http://documents.worldbank.org/curated/en/739421509427698706/Implementing-nature-based-flood-protection-principles-and-implementation-guidance

Veerkamp, C., Hanson, H., Almassy, D., Bockarjova, M., Botzen, W. J. W., Dammers, E., … Hedlund, K. (2018). *Working Paper on NBS assessments: Review of current methods to assess the multiple benefits and values of urban Nature-Based Solutions* (Working Paper No. Deliverable 3.3; p. 157). Naturvation.

Vigerstol, K. L., & Aukema, J. E. (2011). A comparison of tools for modeling freshwater ecosystem services. *Journal of Environmental Management*, *92*(10), 2403–2409. https://doi.org/10.1016/j.jenvman.2011.06.040

Villa, F., Bagstad, K. J., Voigt, B., Johnson, G. W., Portela, R., Honzák, M., & Batker, D. (2014). A Methodology for Adaptable and Robust Ecosystem Services Assessment. *PLOS ONE*, *9*(3). https://doi.org/10.1371/journal.pone.0091001

Villa, F., Ceroni, M., Bagstad, K., Johnson, G., & Krivov, S. (2009). *ARIES (ARtificial Intelligence for Ecosystem Services): A new tool for ecosystem services assessment, planning, and valuation.* 10. Venice, Italy.

Vitale, J. D., Moore, J. T., Graves, C. E., & Kelsch, M. (2009). Hydrometeorological aspects of the Kansas turnpike flash flood of 30-31 August 2003. *National Weather Digest*, *33*(2), 16.

Wang, J., Endreny, T. A., & Nowak, D. J. (2008). Mechanistic Simulation of Tree Effects in an Urban Water Balance Model1. *JAWRA Journal of the American Water Resources Association*, *44*(1), 75–85. https://doi.org/10.1111/j.1752-1688.2007.00139.x

Witteveen+Bos (W+B). (2018, February 27). Working together towards the Sustainable Development Goals. Retrieved 8 July 2019, from https://www.witteveenbos.com/news/ant/

Witteveen+Bos (W+B). (n.d.). Sustainable design. Retrieved 8 July 2019, from Witteveen+Bos website: https://www.witteveenbos.com/about-us/how-we-work/sustainable-design-principles/

XE.com. (n.d.). XE - The World's Trusted Currency Authority: Money Transfers & Free Exchange Rate Tools. Retrieved 7 August 2019, from https://www.xe.com/

Zardo, L., Geneletti, D., Pérez-Soba, M., & Van Eupen, M. (2017). Estimating the cooling capacity of green infrastructures to support urban planning. *Ecosystem Services*, *26*, 225–235. https://doi.org/10.1016/j.ecoser.2017.06.016

Zulian, G., Polce, C., & Maes, J. (2014). ESTIMAP: A GIS-BASED MODEL TO MAP ECOSYSTEM SERVICES IN THE EUROPEAN UNION. *Annali Di Botanica*, *4*(0). https://doi.org/10.4462/annbotrm-11807

Zulian, Grazia, Paracchini, M. L., Maes, J., & Liquete, C. (2013). *ESTIMAP: Ecosystem services mapping at European scale* (Technical Report No. JRC 87585; p. 58). Retrieved from European Commission Joint Research Centre website: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/estimap-ecosystem-services-mapping-european-scale

Zulian, Grazia, Stange, E., Woods, H., Carvalho, L., Dick, J., Andrews, C., … Viinikka, A. (2018). Practical application of spatial ecosystem service models to aid decision support. *Ecosystem Services*, *29*, 465–480. https://doi.org/10.1016/j.ecoser.2017.11.005

8

ANNEXES

8.1 Annex I - Common examples of urban nature-based solutions

Figure 17 - Clockwise from top left: Bioswale alongside a neighbourhood street (The Nature Conservancy, 2017); Green roof atop a building (MetroPolder, n.d.); Entrance to Park Frankendael in Amsterdam, the Netherlands; Urban wetland (Landezine, 2014)

8.2 Annex II - Urban ecosystem services checklist

Table 14 - Checklist for measuring ES completeness of each tool

Category	Urban ecosystem service	Description	InVEST	ARIES	SolVES	B£ST	ESTIMAP	i-Tree
Provisioning	Food supply	Vegetables, fruit and herbs	1	1	1		1	
	Fresh water supply		1	1		1		
	Raw materials	Timber, firewood, fuel			1			
Regulating	Temperature regulation	Local cooling effects						
		Building energy use				1		1
	Air purification	Removal and fixation of pollutants					1	1
	Carbon sequestration	Carbon capture and storage	1	1		1		1
	Water flow regulation	Infiltration	1	1		1	1	1
	Sediment regulation	Avoided soil erosion		1				
	Waste treatment	Water quality	1	1		1		
		Soil quality						
	Stability	Coastal protection	1	1			1	
	Pollination	Pollinators	1	1			1	
	Noise	Attenuation				1		
Cultural	Recreation	Leisure	1	1	1	1	1	
	Mobility	Travel routes				1		
	Aesthetic	Attractiveness	1	1	1		1	
	Mental health	Stress, anxiety, depression, mood			1			
	Physical health	Adiposity, disease, mortality, activity				1		1
	Child development	Birth outcomes, cognitive function						
	Spiritual	Meditation, inspiration			1			
	Social cohesion	Sense of community						
	Education	Outdoor learning			1	1		
	Economic	Jobs / productivity				1		
		Property prices						1
		Tourism			1	1	1	
		Heritage			1			
		Bequest			1			
Total ES included (max = 28)			**9**	**10**	**10**	**12**	**8**	**6**

8.3 Annex III - Additional information for attended events

URIP-bijeenkomst Groen als verbindend element in het Utrecht Science Park – verslag

Botanische Tuinen Utrecht Science Park, 6 februari 2019

NATURVATION
cities – nature – innovation
Gemeente Utrecht
Utrecht University
Planbureau voor de Leefomgeving

Figure 18 - Cover page of official report from Naturvation Urban-Regional Innovation Partnership Workshop held in Utrecht, the Netherlands on February 6, 2019

4-5 April 2019

Paris Forum on NBS

Addressing major societal challenges: climate change adaptation-mitigation, risk management and resilience

Photo © Sophie Robichon

platform.think-nature.eu/paris-forum

PARIS

CSTB
le futur en construction

thinknature

Figure 19 - Official poster of the ThinkNature Paris Forum on NBS held in Paris, France on April 4-5, 2019

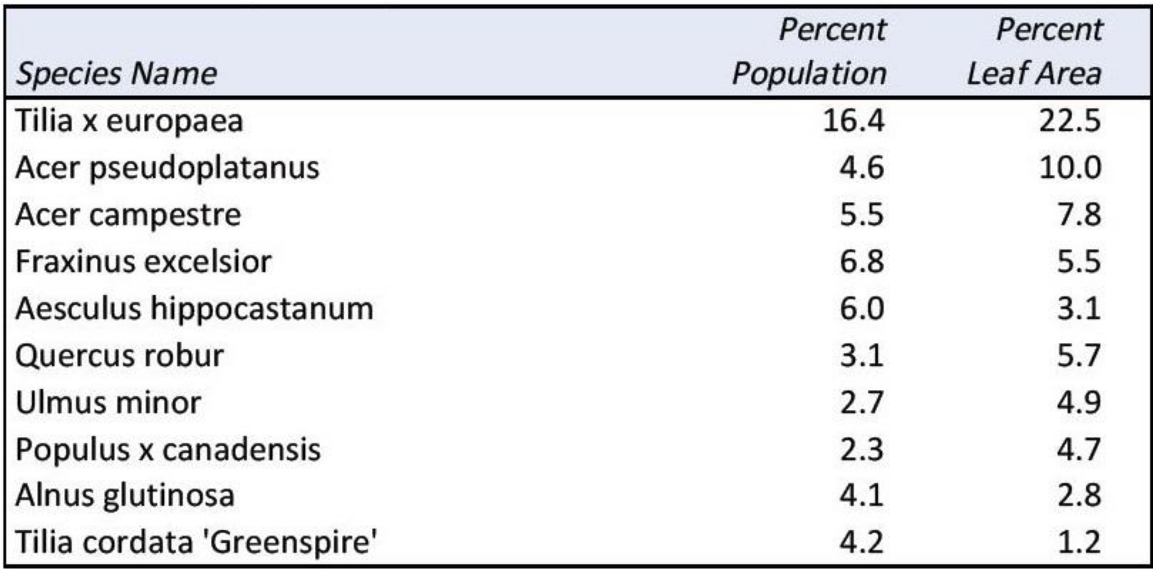
8.4 Annex IV - Sample tree data

Table 15 - Sample tree data from Park Frankendael for i-Tree Eco

Tree Number	Species Scientific Name	DBH (cm)	Tree Height (m)	Land Use	Longitude	Latitude	Street Tree?	Public?	Direction to building (azimuth degrees)	Distance to building (m)
451582	Abies concolor	69.0	12.9	Park	4.931849	52.351658	FALSE	TRUE		
480763	Abies grandis	19.4	10.5	Agriculture	4.929978	52.348656	FALSE	FALSE		
480981	Abies grandis	9.9	6.0	Agriculture	4.929818	52.348656	FALSE	FALSE		
450042	Acer campestre	98.0	14.3	Park	4.931233	52.348909	FALSE	TRUE		
450993	Acer pseudoplatanus	60.0	10.6	Commercial/Industrial	4.930272	52.352785	FALSE	TRUE	344	17.5
451000	Acer pseudoplatanus	85.0	15.7	Commercial/Industrial	4.930529	52.352975	FALSE	TRUE	297	13
451001	Acer pseudoplatanus	85.0	15.7	Commercial/Industrial	4.930532	52.353006	FALSE	TRUE	283	12
451570	Aesculus pavia	25.0	7.1	Park	4.93237	52.351577	FALSE	TRUE		
451633	Ailanthus altissima	127.0	17.0	Park	4.931046	52.35111	FALSE	TRUE		
451656	Alnus cordata	77.0	13.0	Park	4.928063	52.351706	FALSE	TRUE		
451657	Alnus cordata	104.0	16.3	Park	4.927652	52.351469	FALSE	TRUE		
454415	Betula pendula	51.0	15.9	Commercial/Industrial	4.932976	52.350678	FALSE	TRUE		
475116	Betula pendula	45.0	11.3	Park	4.929107	52.350975	FALSE	TRUE	131	6.9
475117	Betula pendula	45.0	11.3	Park	4.929074	52.350948	FALSE	FALSE	103	7.7
475118	Betula pendula	27.0	8.5	Park	4.929143	52.350929	FALSE	FALSE	82	2.7
451498	Fraxinus excelsior	203.0	22.9	Water/wetland	4.934184	52.350832	FALSE	TRUE		
449534	Fraxinus excelsior	139.0	32.2	Transportation	4.926709	52.34918	TRUE	TRUE		
453982	Fraxinus excelsior	11.0	5.3	Park	4.930617	52.349602	FALSE	TRUE		
451632	Ginkgo biloba	68.0	12.1	Park	4.931307	52.351108	FALSE	TRUE		
453983	Magnolia soulangeana	61.0	10.4	Park	4.930504	52.34958	FALSE	TRUE		
451441	Magnolia stellata	111.0	9.6	Park	4.932626	52.351513	FALSE	TRUE		
451435	Salix alba	13.0	4.8	Park	4.932612	52.351702	FALSE	TRUE		
451436	Salix alba	9.6	6.0	Park	4.932659	52.351671	FALSE	TRUE		
454354	Salix alba	44.0	13.7	Park	4.928965	52.350992	FALSE	TRUE	114	16.6
450314	Tilia x europaea	66.0	12.5	Park	4.93112	52.348764	TRUE	TRUE		

8.5 Annex V - Tree population characteristics in Park Frankendael

Table 16 - The ten most predominant species in Park Frankendael with corresponding leaf area percentages



Species Name	*Percent Population*	*Percent Leaf Area*
Tilia x europaea	16.4	22.5
Acer pseudoplatanus	4.6	10.0
Acer campestre	5.5	7.8
Fraxinus excelsior	6.8	5.5
Aesculus hippocastanum	6.0	3.1
Quercus robur	3.1	5.7
Ulmus minor	2.7	4.9
Populus x canadensis	2.3	4.7
Alnus glutinosa	4.1	2.8
Tilia cordata 'Greenspire'	4.2	1.2

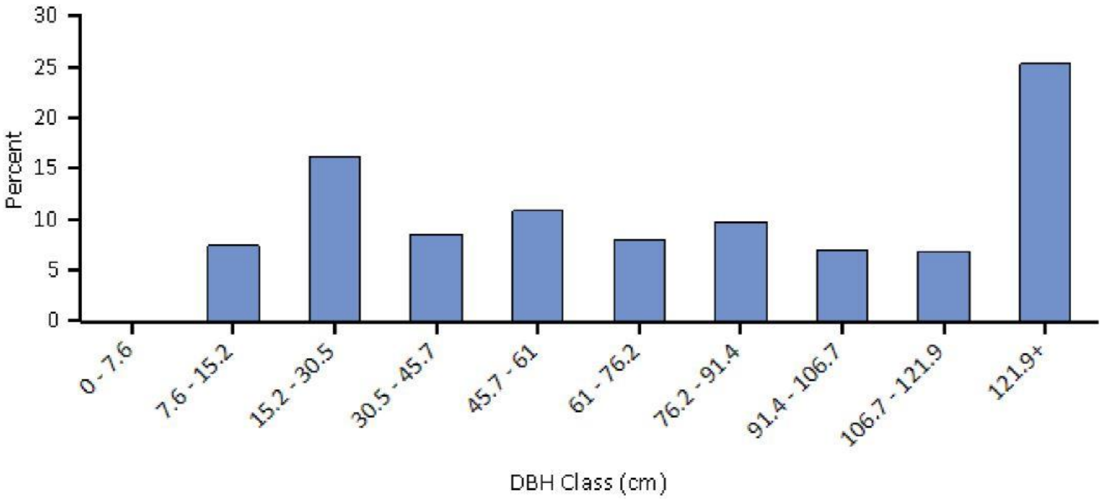


Figure 20 - Distribution of tree population according to DBH (diameter at breast height)

8.6 Annex VI - Scoring matrix sources

Table 17 - Scientific papers, grey literature and primary tool documents used in scoring matrix

Source	**Tool**					
	InVEST	**ARIES**	**SolVES**	**B£ST**	**ESTIMAP**	**i-Tree**
Peer-reviewed scientific papers that independently reviewed or applied a tool						
Abd-Elrahman et al., 2010						√
Vigerstol & Aukema, 2011	√	√				
Bagstad et al., 2013	√	√	√			
Nemec and Raudsepp-Hearne, 2013	√	√	√			
Peh et al., 2013	√	√				
Russo et al., 2014						√
Baró et al., 2015						√
Morales-Torres et al., 2016				√		
Ossa-Moreno et al., 2017				√		
Stange et al., 2017					√	
Zulian et al., 2018					√	
Third party grey literature that provide summaries and descriptions for a tool						
Ecosystems Knowledge Network, n.d.	√	√		√		√
Peer-reviewed scientific papers authored by a tool's own developers						
Sherrouse et al., 2011			√			
Zulian et al.,, 2014					√	
Ashley et al., 2017				√		
Primary technical documents per tool						
Zulian et al., 2013					√	
Villa et al., 2014		√				
Sherrouse & Semmens, 2015			√			
Sharp et al., 2018	√					
(Horton et al., 2019)				√		
USDA Forest Service, 2019						√

8.7 Annex VII - Descriptions of scores in scoring matrix

Table 18 - Explanation behind each score in the scoring matrix (Table 10)

Criteria	InVEST		ARIES		SolVES		B£ST		ESTIMAP		i-Tree	
Ecosystem health *Structure*	3	Habitat quality and conservation metrics included	2	Assessment of ES depends on ecosystem quality	1	Landscape metrics don't include status, condition, health or biodiversity of ecosystem	1	Only measures changes in the size and type of green and blue space	3	Yes	3	Tree species, sizes and crown health as inputs
Ecosystem health *Integrity*	3	Environmental condition is measured	1	Basic measurements of change over time	1		1		3	Yes	2	Tree crown health and risk of pest included
Ecosystem services *Completeness*	See Annex II for checklist of number of ES covered by each tool											
Ecosystem services *Uncertainty*	0	No explicit handling of uncertainty	3	Allows for a calculation of uncertainty through Bayesian and Monte Carlo approaches	0	No explicit handling of uncertainty	3	Uses sensitivity analysis with user-defined estimates of confidence (0-100) for quantities and valuation	0	The method does not address uncertainty explicitly	2	Sources of uncertainty are highlighted but not quantified within the tool
Ecosystem services *Economic analysis*	3	Final map result can be expressed in economic terms	3	Outputs have the potential to be monetised	0	Non-monetary preferences of relative values	3	Outputs can be monetised	0	No monetary valuation	3	Outputs are automatically monetised
Feasibility *Capacity*	1	GIS software and skills required (and expertise to parametrise model)	1	GIS and modelling training required	2	Moderate GIS software and skills	3	Basic Excel skills only	1	Medium GIS expertise	3	Basic Excel skills and no prior knowledge of software needed

Feasibility *Data*	1	Can be very data intensive	2	Contains global datasets when data are scarce	2	Spatial data and personal surveys required	1	Wide range of data required	2	Land cover classes easily available	1	Tree measurements not always commonly available
Feasibility *Scalability*	2	Local and landscape scales	2	Local and landscape scales	1	Landscape scale only	2	Site and local scales	2	Scaled down from 1ha to 10m (local and landscape scales)	3	Site, local and landscape scales
Feasibility *Adaptability*	3	Room for input of direct observations	3	Can supplement or replace default values with local data	3	Preference values and spatial data can be updated	3	Can incorporate site-specific, locally derived values, including surveys	3	Not limited to type of local data that can be added	3	Can incorporate site-specific, locally derived values

Description of methodology for scoring matrix

Score breakdown	Types of sources (in descending order of validity)
3 = Desirable (excellent)	Peer-reviewed scientific papers that independently reviewed or applied a tool
2 = Acceptable (fair)	Third party grey literature that provide summaries and descriptions for a tool
1 = Undesirable (poor)	Peer-reviewed scientific papers authored by a tool’s own developers
0 = Absent (not applicable)	Expert judgement based on a review of primary documents for a tool

8.8 Annex VIII - Supplemental scoring matrix with alternative criteria

Table 19 - Scoring matrix with additional criteria that could be used in future scoring exercises

Criteria		InVEST	ARIES	SolVES	B£ST	ESTIMAP	i-Tree
Credibility Does the tool allow for evidence and arguments that are perceived as scientifically adequate?	*Urban suitability*	**1**	**2**	**3**	**3**	**2**	**3**
	Peer-reviewed scientific backing	**2**	**2**	**2**	**1**	**2**	**3**
	Practical support	**2**	**2**	**3**	**2**	**1**	**3**
Salience Is the tool relevant to the dynamic nature of NBS all over the world?	*Flexibility for range of NBS*	**3**	**3**	**3**	**3**	**3**	**1**
	Time requirements	**1**	**1**	**1**	**1**	**1**	**2**
	Transferable to other locations	**3**	**2**	**3**	**1**	**2**	**2**
	Temporal analysis	**1**	**3**	**1**	**3**	**1**	**2**
	Synergies and trade-offs	**2**	**3**	**3**	**1**	**3**	**1**
Legitimacy Does the generation of information identify relevant beneficiaries of ES?	*Beneficiaries (demand for ES)*	**0**	**3**	**3**	**2**	**1**	**0**
Total score (max = 27)		**15**	**21**	**22**	**17**	**16**	**17**

Criteria adapted from the work of Cash et al. (2003) and van Oudenhoven et al. (2018)

Description of methodology for scoring matrix

Score breakdown	Types of sources (in descending order of validity)
3 = Desirable (excellent)	Peer-reviewed scientific papers that independently reviewed or applied a tool
2 = Acceptable (fair)	Third party grey literature that provide summaries and descriptions for a tool
1 = Undesirable (poor)	Peer-reviewed scientific papers authored by a tool's own developers
0 = Absent (not applicable)	Expert judgement based on a review of primary documents for a tool