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Urban Nature's Health Effects and Monetary Valuation: A Systematic Review

Xianwen Chen

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Norwegian Institute for Nature Research

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Urban Nature's Health Effects and Monetary Valuation: A Systematic Review

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Ramparts of Akershus Castle used for recreation. Photo: Erik Framstad

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Abstract

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Extensive research has demonstrated that urban nature has positive effects to human health. Urban nature has been found to restore cognitive fatigue and to help with a direction of focus. Positive effects of urban nature have been found on mental disorders such as ADHD, dementia, and depression. Therapeutic effects of horticulture have also been discovered and validated. Furthermore, research has demonstrated that urban nature reduces the incidence of cardiovascular disease, respiratory disease, mortality, and other negative health problems. Crime reduction has also been found to be associated with greener surroundings in cities. However, the monetary values of these health effects have largely not been studied.

Through a systematic literature search, I reviewed publications that estimate monetary values of urban nature's health effects. The literature search resulted in ten articles, of which four are peer-reviewed journal articles, one is a book chapter, whilst five are in the grey literature.

In the reviewed literature, large economic values have been estimated from urban nature's health effects. Lee et al. (2008) find that respondents in Busan, South Korea are willing to pay US$ 170 per month for a horticultural therapy site per person. Wolf et al. (2015) estimate an annual monetary value between US$ 2.7 and 6.8 billion (2012 US$), when accounting for urban nature's health benefits to newborns, ADHD, high school performance, crime reduction, cardiovascular disease, and Alzheimer's disease. Nowak et al. (2014) estimate that urban trees in the contiguous US generate a monetary value of US$ 6.8 billion through its removal of air pollutants and the associated health effects, which ranges from the minimum estimate of US$ 0.99 billion and the maximum estimate of US$ 8.96 billion.

Monetary estimates of urban nature's health effects may be useful as a further argument for urban planners promoting investment in urban green infrastructure. In order to carry out economic valuation of green infrastructure measures for health purposes several lines of research need strengthening. Firstly, more studies are required to estimate the monetary value of other health effects from urban nature, for example, on depression and obesity. Secondly, case studies outside of the US, the UK, and South Korea are needed to provide more representative results, as well as contributing to global estimates of urban nature's health effects. Finally, more innovative research is required to identify the causal links between (lack of) urban nature and its health (illness) effects.

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Sammendrag

Chen, X. 2016. Urban naturs helseeffekter og monetær verdsetting: en systematisk litteraturgjennomgang. – NINA Rapport 1278. 28 s.

Omfattende forskning har vist at urban natur har positive effekter på menneskers helse. Urban natur er funnet å gjenopprette kognitiv tretthet og hjelpe med å opprettholde fokus. Positive effekter av urban natur er funnet på psykiske lidelser som ADHD, demens og depresjon. Terapeutiske effekter av hagebruk er også påvist. Videre har forskning vist at urban natur reduserer forekomst av hjerte- og karsykdommer, luftveissykdommer, dødelighet og andre helseproblemer. Redusert kriminalitet er også funnet å være assosiert med grønnere omgivelser i byer. Men de økonomiske verdiene av disse helseeffektene har ikke vært mye studert.

Gjennom et systematisk litteratursøk, har jeg gjennomgått litteraturen som anslår helseeffekter av urban natur i pengeverdi. Litteratursøket resulterte i ti artikler, hvorav fire er fagfellevurderte tidsskriftartikler, en er et bokkapittel, mens de øvrige fem er rapporter (grå litteratur).

I den gjennomgåtte litteraturen er store økonomiske verdier anslått for helseeffekter ved urban natur. Lee et al. (2008) finner at respondentene i Busan, Sør-Korea, er villige til å betale US$ 170 per måned og person for å ha tilgang til et sted for hagebruksterapi. Wolf et al. (2015) anslår en årlig pengeverdi av mellom US$ 2,7 og 6,8 milliarder (2012 US$), når man summerer verdien av urban naturs helsemessige fordeler for nyfødte, ADHD-behandling, ytelser i videregående skole, redusert kriminalitet, hjerte- og karsykdommer, og Alzheimers sykdom. Nowak et al. (2014) anslår at urbane trær i det kontinentale US genererer en pengeverdi på US$ 6,8 milliarder gjennom fjerning av luftforurensninger og tilhørende helseeffekter, noe som gir et minimums- og maksimumsanslag på US$ 0,99-8,96 milliarder.

Stor videre forskningsinnsats er nødvendig. For det først trengs mer forskning for å beregne pengeverdier av andre helseeffekter fra urban natur, for eksempel på depresjon og på fedme. For det andre er det nødvendig med case-studier utenfor USA, Storbritannia og Sør-Korea for å få mer representative resultater, samt å bidra til globale økonomiske estimater av helseeffektene av urban natur. For det tredje trengs mer innovativ forskning, spesielt for å identifisere årsakssammenhenger mellom urban natur og dens helseeffekter.

De gunstige helsemessige effektene av urban natur og deres økonomiske verdier bør vurderes sammen med andre goder av urban natur, inkludert konvensjonelle ikke markedsmessige pengeverdier av urban natur. Det endelige målet bør være å gi en omfattende og helhetlig verdsetting av urban natur.

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Contents

Foreword

This report is the result of an initiative by the Oslo Centre for Interdisciplinary Environmental and Social Research (CIENS) to identify and summarize research results on key areas of significance for urban sustainability. The Norwegian Ministry of Climate and Environment provided funding and helped identify thematic areas of interest for systematic reviews of current research within the wider theme of urban sustainability. A small CIENS committee assessed several proposals for such reviews from CIENS researchers and decided to provide basic funding for three proposals, one of which was the review presented here.

It is increasingly recognized that urban nature is important for the health and well-being of urban citizens. However, in densely populated urban areas, the competition for space is intense and it is not obvious that areas of urban nature will receive sufficient priority in urban development. By quantifying the importance of urban nature for human health and well-being in monetary terms, the importance of such nature areas may be formulated in the same 'currency' as many of the other interests in urban development. Hence, it is important to assess the research results that are available on the monetary value of urban nature for human health and well-being.

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Oslo, July, 2016

Xianwen Chen

1 Introduction

The study of urban green infrastructure and its role in public health is of vital importance. Europe is among the worlds most urbanized regions, with approximately 73% of Europeans living in urban areas (United Nations, 2014). In Norway, 81% of the total population live in urban and densely built up areas. Norway's capital city Oslo has one of the highest percentage growth rates of large cities in Europe, with almost half the growth from immigration (Human Rights Service, 2015).

The world's populations are plagued by lifestyle-related illnesses (Popkin et al., 2006; Flegal et al., 2010). Ogden et al. (2015) report that 34.9% of American adults are obese as of 2011-2012. In both developed and developing countries obesity is continuing on the rise (Flegal et al., 2002; Prentice, 2006). Lifestyle-related illnesses are costly both in terms of public health impacts and medical treatment costs (Withrow & Alter, 2011) The Department of Health of the UK estimates that physical inactivity in England costs UK £8.2 billion, not accounting an additional £2.5 billion cost for obesity due to inactivity (Department of Health, 2004).

A number of studies have sought to study the effects of urban nature on public health (e.g., Frumkin, 2005; Keniger et al., 2013; Hartig et al., 2014; Wolf & Robbins, 2015). Being in the nature itself produces beneficial effects including relaxation, reducing stress, and restoration. Wilson (1984) refers to these effects as the Biophilia effect. The University of Washington has summarized research outputs on urban nature's effects on life quality, including health and well-being (University of Washington, 2014). In Norway, a similar list is managed by the Norwegian University of Life Sciences (2016). For a recent review, see Hartig et al. (2014).

It can be useful for policy makers to evaluate urban nature in the benefit-cost framework. In the trade-off between conservation and development of unbuilt land, commercial development of the land into residential complexes, manufacturing, commercial or office buildings is often prioritized on economic grounds. The economic benefits of property development, job creation, and business development are usually visible in monetary terms, while urban nature's benefits seldom find support in quantitative, much less monetary, arguments. The economic values of commercial interests represent the opportunity cost of conserving land for urban nature. Evaluating urban ecosystem services in monetary terms may support policy-making by providing arguments in the same language as investment decisions. The costs of providing and improving urban nature include (i) investment to extend and improve urban green space, and (ii) investment in facilitation of access and use. Willis & Crabtree (2011, p. 375–376) provide such perspective in the context of urban tree planting. Benefit-cost analysis has been widely applied in research and in policy-making (Carson, 2005).

Traditionally, when estimating urban nature's monetary values, health effects, are typically not accounted for. In urban areas, the provision services of urban nature is usually rather limited, given the limited sizes of the green area (Hartig et al., 2014). However, nature's health effects are likely much larger in urban area than in rural area, because urban nature is much more used than rural nature (Hartig et al., 2014).

Although a number of studies have been conducted on the linkages between urban nature and public health, research on the economic valuation of such linkages remain scarce (Wolf & Robbins, 2015). In this report, I first conduct a systematic search (Alliance for Useful Evidence, 2013) on literature that estimate monetary values of urban nature's health effects. Then I review all the discovered literature and summarize their key findings. Following the summary, I discuss future research needs and challenges. Finally, I conclude. To the best of our knowledge, this is the first systematic review on the monetary values of urban nature's health effects.

2 Systematic Literature Search

The search criteria are fourfold. First, I focus on the positive health effects from urban nature. Second, the article has to be on the monetary valuation of such positive health effects. Third, we excluded all articles that are not written in the English language. Fourth, the article needs to be available, either on-line or through libraries, at latest by May 15, 2016.

First, a literature search was conducted on Web of Science. The search tries all possible combinations of four types of specified keywords in article topics: (1) keywords on monetary valuation, (2) keywords on urban, (3) keywords on nature, and (4) keywords on health, as shown in **table 1**. The first search was conducted on March 6, 2016. The search was later repeated to (a) include a new keyword that was thought of or discovered from previous literature search, and (b) to include the latest publications. The last search was conducted on April 25, 2016, which returned 5,061 unique articles.

Table 1: *List of keywords.*

Monetary Valuation	Urban	Nature	Health
Value	Urban	Nature	Health
Valuation	City	Green	Sickness
Willingness to pay	Town	Blue	Illness
Willingness to accept	Downtown	Park	Restoration
WTP	Metropolitan	Woods	Restorative
WTA		Forest	Rehabilitation
		Path	Therapy
		Grass	Intervention
		Tree	Mortality
		Pasture	Disability
			Well-being
			Emotion
			Fitness
			Treatment
			Trial
			Clinical
			Medicine
			Care
			Mental
			Dementia
			Depression
			Psychology
			Psychological
			Physical
			Physiology
			Attention

Because reading through the full texts of the 5,061 articles requires more human resources (or time) than available, in the second step, I only went through article titles, and in some cases also abstracts, to determine whether an article was potentially related to the topic. I was concerned that an article might contain monetary value estimates of urban nature's benefits, but not stressed in the title nor in the abstract. Because of this concern, I included some articles that do not contain monetary value estimates in the title or abstract per se, but might have done so in

the full text. These articles included (1) articles that are on monetary valuation of urban nature, urban environment, or urban ecology, and (2) articles that are on urban nature's health effects. By the end of the second step, I had selected 144 articles[1].

In the third step, I went through the abstracts of the 114 articles, and the main texts whenever needed to determine whether an article should be included in the review. During this step and all previous steps, literature review articles were included so that I could trace all relevant literature on the topic. However, I did not include the literature review articles in the final list of the literature research result, because these articles, by their nature, do not contain original estimates of monetary values. By the end of the third step, 17 articles had been selected.

In the final step, I read through the full texts of the 17 articles to determine whether they have estimated monetary values of health effects from urban nature. Moreover, for each article I applied the snowballing technique (Alliance for Useful Evidence, 2013). Using backward snowballing, I went over all the cited articles in the article, and checked if these contained monetary value estimates of urban nature's health effects. Using forward snowballing[2], I went over all the literature that has cited the article, which is done on Google Scholar, to see if it contains monetary value estimates of urban nature's health effects. For all relevant articles discovered through snowballing, I conducted the same backward and forward snowballing techniques on them. By the end of the final step, 10 publications were selected for the systematic review. These include 4 peer-reviewed journal articles, 1 book chapter, and 5 publications in the grey literature (i.e., non-peer-reviewed reports etc).

[1] I also set aside 76 articles that are not on monetary valuation, but are relevant for urban nature and public health, so that they may be used in later discussion.

[2] The forward snowballing technique is not commonly used in systematic literature search. However, I use this method to trace the latest research on the topic, which has proven to be helpful.

3 Summary of the Reviewed Literature

I list the publications that I have discovered through the systematic literature search in **table 2**. The publications are listed with peer reviewed journal articles in the top in the table, then book chapters, and finally the gray publications including various types of reports. Among the discovered publications, there are slightly more grey publications than peer-reviewed articles, which is consistent with an earlier non-systematic literature review article by Wolf & Robbins (2015).

Table 2: *List of publications from the systematic search.*

Publication	Type	Area	Key findings
Wolf et al. (2015)	Journal article	US	• Potential monetary benefit of US$ 5.3 million, from potential cost reduction with increased medical costs in the first year of infants' life care, due to correlation between birth weight and urban nature. • Monetary benefit between US$ 383.5 million and 1.9 billion from 5% to 25% medication replacement costs for attention deficit hyperactivity disorder (ADHD), due to urban nature's effect of reducing ADHD symptoms. • A conservative estimate of monetary benefit of US$ 1.3 billion per year in terms of increased income from higher secondary school performance, due to urban nature's effect on students' performance and capacity to direct attention. • Monetary benefit between US$ 340.6 and 899.4 million from reduction in health care costs from reduction in several types of crimes, due to urban nature's effects. • Monetary benefit of US$ 1.2 billion from reduced cardiovascular mortality costs, due to positive effects from urban nature. • Monetary benefit ranging from US$ 725 million to 1.5 billion from reduced medical costs of Alzheimer's disease, due to positive effects from urban nature.
Nowak et al. (2014)	Journal article	US	• Mean monetary benefits of US$ 6.8 billion, with a range between the minimum estimate of US$ 0.99 billion and the maximum estimate of US$ 8.96 billion, from urban trees and forests' service of pollution removal.
Nowak et al. (2013)	Journal article	US	• Estimated monetary values of reduced numbers of twelve different types of negative health incidences due to $PM_{2.5}$ reduction from trees in urban nature in ten US cities. • Annual values range from US$ 1.1 million in Syracuse to US$ 60.1 million in New York City. • Most of the value come from the effects of reducing human mortality.
Lee et al. (2008)	Journal article	Busan, South Korea	• Individuals are on average willing to pay around US$ 170 per month for a horticulture therapy site.

Publication	Type	Area	Key findings
Willis & Crabtree (2011)	Book chapter	UK	• Same as CJC Consulting (2005)
Green Infrastructure Northwest (2011)	Grey publication	England and Scotland, UK	• Monetary value of £ 184.24 per extra cyclist encouraged by green asset scheme due to reduced mortality. • Major investment in public space in Erith Marshes and Belvedere, including new access opportunities, will create the walking benefits of £ 1.4 million and cycling benefits of £ 0.6 million, in terms of net present value calculated over 5 years.
McPherson (2010)	Grey publication	Philadelphia,US	• Same as Harnik & Welle (2008)
Harnik & Welle (2009)	Grey publication	Sacramento, US	• Monetary value of health care savings of physically active users of all the parks in Sacramento were US$ 19,871,863 in 2007.
Harnik & Welle (2008)	Grey publication	Philadelphia,US	• Monetary value of US$ 69,419,000 for the health benefits generated by users being active in the park system of Philadelphia.
CJC Consulting (2005)	Grey publication	UK	• The economic value of the health benefits of reduced air pollution due to woodland greater than two ha: £ 900,000 per year. • The economic value of health benefits of 1% reduction in the sedentary population: £ 1.44 billion per year, which is equivalent to a mean of £ 2,423 per additional active person per year.

One common approach to estimate monetary benefits of urban nature's health effects is to estimate avoided medical costs. Researchers then need to include both the effects of urban nature on health and the medical costs of the treatments. In the following subsection, I list monetary benefits of urban nature in terms of reduced medical costs.

3.1 Cardiovascular Disease

Cardiovascular disease is a primary cause of death worldwide. CDC (2015) estimates that one in four deaths in the US are caused by cardiovascular disease, whilst Scarborough et al. (2011) suggest that the corresponding figure for the UK is 30%.

Research has established a connection between urban nature and cardiovascular disease. Mitchell & Popham (2008) find that health inequalities related to income deprivation in mortalities, which include all causes and circulatory disease, are lower in populations living in the greenest area. Richardson & Mitchell (2010) find that men living in areas with 25% or more green cover, have 5% lower cardiovascular disease mortality. Donovan et al. (2013) find that tree losses in the US due to the emerald ash borer, which is a green jewel beetle that is highly destructive to ash trees in Northwest Europe and North America, is associated with an additional 6113 deaths related to illness of the lower respiratory system and 15,080 additional deaths because of cardiovascular disease.

Consequently, increased cardiovascular disease due to lacking access to green spaces is a major source of healthcare costs. Luengo-Fernandez et al. (2006) estimate that cardiovascular disease costed the UK £ 29.1 billion in 2004, of which £ 492.7 and 179.85 million is due to mortality costs in terms of lost productivity for males and females, respectively.

Wolf et al. (2015) estimate that there is a monetary benefit of US$ 1.2 billion (2012 US$) from reduced cardiovascular mortality costs of American males, due to positive effects from urban nature. Their estimates combine the cost estimates from Luengo-Fernandez et al. (2006) and the nature effect estimates from Richardson & Mitchell (2010), assuming that green cover increases to 25% or more in and around homes and neighbourhoods of male residents. Nowak et al. (2014) estimate that, in the conterminous US, urban trees' removal of $PM_{2.5}$ pollutants from the air reduces cardiovascular hospital admission by 49 cases, which generates US$ 1,876,000 in terms of saved medical costs in the US per year.

3.2 Physical Activity and Mortality

Physical activities reduce the chances of illnesses and mortality due to physical inactivity. Regular physical activities help reduce the risk of cardiovascular disease, non-insulin dependent diabetes mellitus, osteoarthritis, some forms of cancer, and obesity (Green Infrastructure Northwest, 2011). However, despite these benefits, for many countries only less than half of the population are physically active. For example, in England, 39% of men and 29% of women do at least 30 minutes of moderately intensive physical activity for five days per week, suggesting that 23 million people in England are not active enough for the health benefits (Green Infrastructure Northwest, 2011).

Urban nature facilitates physical activity (Giles-Corti et al., 2005; Cohen et al., 2006; Maas et al., 2008). Cohen et al. (2007) find that living within one mile of the park facilitates park use for citizens of Los Angeles. Branas et al. (2011) find that greening of vacant urban land is associated with more self-reported exercises among residents of Philadelphia, Pennsylvania. A few studies have estimated urban nature's effects on physical activity, reduced mortality, and the associated monetary benefits. Harnik & Welle (2009) estimate that physically active users of all the parks in Sacramento, US, saved health care costs of US$ 20 million in 2007. Harnik & Welle (2008) and McPherson (2010) estimate that the annual monetary value of the health effects from the Philadelphia park system for the parks' users, is US$ 69 million[3].

There are three studies from the UK as well. Under the assumption that urban nature reduces 1% of the sedentary population in the UK, CJC Consulting (2005) and Willis & Crabtree (2011) estimate that annual values due to health benefits in terms of reduced mortality and morbidity is £ 1.44 billion[4]. Green Infrastructure Northwest (2011) estimates that for every extra cyclist encouraged by the green asset scheme relative to the no intervention case, there is a monetary value of £184.24 due to reduced mortality. Applying this estimate to Erith Marshes and Belvedere, two areas in London, Green Infrastructure Northwest (2011) estimates that major investment in public space, including new access opportunities, will create benefits for walkers and cyclists of, respectively, £ 1.4 million and £ 0.6 million, in terms of net present value calculated over 5 years.

[3] The estimates in McPherson (2010) seem to be from Harnik & Welle (2008). However, it is also possible that McPherson (2010) replicated the analysis of Harnik & Welle (2008).
[4] Willis & Crabtree (2011) is a book chapter that seems to be based on CJC Consulting (2005), which is a report. They have the same estimates.

3.3 Alzheimer's Disease

Prince et al. (2015) estimate that over 46 million people live with dementia worldwide and project an increase to 135 million in 2050. Hurd et al. (2013) estimate that 14.7% of the Americans older than 70 years old had dementia in 2010. Between 30% and 50% of later stage patients of dementia can exhibit agitated and aggressive behaviours. They are usually treated with psychotropics and/or physical restraints (Whall et al., 1997) However, Detweiler et al. (2009) note that one side effect of the dementia medications is an elevated risk of falls.

Alzheimer's disease is costly for patients and for the society. Using data from the 2010 US National Health and Retirement Study, Hurd et al. (2013) find that annual monetary cost per person due to dementia was US$ 56,290 or US$42,746, depending on the method used to value informal care in 2010. The total estimated cost of dementia worldwide is US$ 818 billion (Prince et al., 2015).

Research has found positive effects of nature on dementia patients. Whall et al. (1997) find that natural elements, including sounds of nature and pictures, reduce agitation and aggressive behaviours among late-stage dementia patients. Mather et al. (1997) find positive effects of garden use to Alzheimer patients, but not to their disruptive behaviours. Murphy et al. (2010) find that wander gardens, which are outdoor confined spaces that permit unrestrained activities, prevent agitation of the dementia patients. They also find that the effect is differentiated depending on whether the patient can walk unassisted. Detweiler et al. (2009) find that the high use group of the dementia patients, which is defined as those who visited the garden more than the median, had a significant reduction in high-dose antipsychotics. However, there was relatively no change in antidepressant, hypnotic, and anxiolytic use among the high use group. Furthermore, they required fewer scheduled medications and had less falls and lower fall morbidity than those who used the wander garden less frequently. Moreover, using nature for horticultural therapy does not have negative side-effects such as increased risk of falls.

Based on the estimated wander-garden effects to dementia patients from Detweiler et al. (2009), Wolf et al. (2015) assume that horticultural therapy can replace between 5% and 10% of medication for Alzheimer's disease patients. Consequently, they estimate that the monetary value from the reduced medication costs range between US$ 724.6 million and 1.45 billion.

3.4 Air Pollution Removal and Related Health Benefit

Air pollution negatively affects human health (Seaton et al., 1995; Pope III et al., 2002; Pope III and Dockery, 2006). Common air pollutants include carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), lead (Pb), sulphur dioxide (SO_2), and particulate matter (PM), which includes particulate matter less than 10 microns (PM_{10}) and particulate matter less than 2.5 microns ($PM_{2.5}$) (Nowak et al., 2014). Air pollution negatively affects human health through pulmonary, cardiac, vascular, and neurological systems (Pope III et al., 2002; Pope III & Dockery, 2006)[5]. Approximately 130,000 and 4700 deaths in the US in 2005 are attributed to $PM_{2.5}$ pollutants and O_3 pollutants, respectively (Fann et al., 2012).

Air pollution causes negative health incidences, including (1) acute bronchitis, (2) acute myocardial infarction, (3) acute respiratory symptoms, (4) asthma exacerbation, (5) chronic bronchitis, (6) emergency room visits, (7) hospital admissions related to cardiovascular symptoms, (8) hospital admissions related to respiratory symptoms, (9) lower respiratory symptoms, (10) mortality, (11) upper respiratory symptoms, and (12) work loss days (Nowak et al., 2014). For literature references to these health incidences, see table 1 in Nowak et al. (2014, pp. 122–123).

[5] Although in previous text I have separated out for example cardiovascular disease, all air pollution related illnesses are discussed in this subsection, mainly because the reviewed research articles on this topic tend to investigate these illnesses together.

Urban nature, particularly trees, reduce air pollution. Trees remove some gaseous air pollution by the plant surface and some by uptake via leaf stomata (Nowak et al., 2014). Leaf stomata remove most of the pollution of O_3, SO_2, and NO_2. Nowak et al. (2006) estimate that urban trees in the US remove 711,000 tonnes of air pollutants. Nowak et al. (2014) estimate that urban trees in the conterminous US remove 68,000, 523,000, 27,000, and 33,000 tonnes of NO_2, O_3, $PM_{2.5}$, and SO_2, respectively. Consequently, urban nature reduces the incidence of illnesses caused by airborne pollutants (Cavanagh & Clemons, 2006; Nowak et al., 2014). The US EPA Environmental Benefits Mapping and Analysis Program (BenMAP) model (US Environmental Protection Agency, 2016) is the most widely used tool for estimating the monetary benefits from urban trees' health impacts due to air pollution removal (Nowak et al., 2014).

To date, Nowak et al. (2014) is the most up-to-date, comprehensive, and detailed research on urban trees' health effects and their monetary values. They have estimated the monetary values from reduced adverse health effects due to removal of specific air pollutants, including NO_2, O_3, $PM_{2.5}$, and SO_2. I report these values in **table 3**, which is taken from table 4 in Nowak et al. (2014, p. 126). In total, Nowak et al. (2014) estimate that urban trees in the conterminous US generate a monetary value of US$ 6.8 billion per year through their removal of air pollutants and the associated health effects, ranging from a minimum estimate of US$ 0.99 billion to a maximum of US$ 8,96 billion.

Table 3: *Estimated monetary values from reduced adverse health effects due to urban trees' pollutant reduction effects by Nowak et al. (2014).*

Pollutant	Adverse Health Effects	Estimated Monetary Value (US$)
NO_2	Asthma Exacerbation	17,178,000
	Hospital Admissions	11,823,000
	Acute Respiratory Symptoms	455,000
	Emergency Room Visits	78,000
	Total	**29,534,000**
O_3	Mortality	1,439,586,000
	Acute Respiratory Symptoms	29,543,000
	Hospital Admissions	13,852,000
	School Loss Days	14,428,000
	Emergency Room Visits	70,000
	Total	**1,497,479,000**
$PM_{2.5}$	Mortality	3,062,289,000
	Chronic Bronchitis	29,720,000
	Acute Respiratory Symptoms	12,006,000
	Acute Myocardial Infarction	7,629,000
	Asthma Exacerbation	8,005,000
	Work Loss Days	3,602,000
	Hospital Admissions, Cardiovascular	1,876,000
	Hospital Admissions, Respiratory	1,246,000
	Lower Respiratory Symptoms	146,000
	Upper Respiratory Symptoms	103,000
	Emergency Room Visits	62,000
	Acute Bronchitis	20,000
	Total	**3,126,703,000**
SO_2	Acute Respiratory Symptoms	64,000
	Asthma Exacerbation	1,393,000
	Emergency Room Visits	34,000
	Hospital Admissions	3,432,000
	Total	**4,923,000**

Nowak et al. (2013) have estimated health effects and their monetary values from the removal of $PM_{2.5}$ particles by urban trees in ten US cities. They find that the majority of the monetary values arise from the reduced human mortality, which is typically around one person per city per year. The estimated reduced human mortality in New York City is the highest, which is 7.6 persons per year. The annual monetary values of the health effects vary from US$ 1.1 million in Syracuse to US$ 60.1 million in New York City. **Table 4** lists the removal of $PM_{2.5}$ by urban trees and the estimated monetary values from the associated health effects in the ten US cities, produced from table 5 of Nowak et al. (2013, p. 398).

Table 4: *Estimated removal of $PM_{2.5}$ by urban trees and estimated monetary values from the associated health effects by Nowak et al. (2013)*

City, State	Removal of $PM_{2.5}$ (tonnes per year)	Estimated Monetary Value (US$ per year)
Atlanta, GA	64.5	9,170,000
Baltimore, MD	14.0	7,780,000
Boston, MA	12,7	9,360,000
Chicago, IL	27.7	25,860,000
Los Angeles, CA	32.2	23,650,000
Minneapolis, MN	12.0	2,610,000
New York, NY	37.4	60,130,000
Philadelphia, PA	12.3	9,880,000
San Francisco, CA	5.5	4,720,000
Syracuse, NY	4.7	1,100,000

In the UK, Powe & Willis (2004) estimate that all the woodlands that are greater than 2 ha, reduce the number of deaths by five to seven per year and hospital admissions by four to six, through air pollution absorption. Based on Powe & Willis (2004)'s estimates, CJC Consulting (2005) and Willis & Crabtree (2011) estimate that UK woodlands greater than 2 ha have health benefits from air pollution absorption of £ 0.9 million per year. Neither Powe & Willis (2004), CJC Consulting (2005), nor Willis & Crabtree (2011) have studied woodlands that are smaller than 2 ha, although both argue that these woodlands likely produce larger benefits, because they are closer to urban populations and to sources of pollution.

3.5 Birth Weight

Birth weight is an important indicator for newborn health and long-term childhood health and development (Paneth, 1995; Horbar et al., 2002). In the short-term, newborns with low birth weight often require additional care (Almond et al., 2005; Russell et al., 2007). In the long-term, Black et al. (2007) and Johnson & Schoeni (2011) find that birth weight has implications for adult disease outcomes, height, IQ, and income.

A number of studies have found correlations between higher birth weight and greater tree canopy. Studying singleton newborns in Portland, Oregon, Donovan et al. (2011) find a correlation between greater tree canopy and reduced risk of having low birth weight. A 10% increase in tree canopy within 50 meters of the mother's home is correlated with a reduction in the risk of *small for gestational age* (SGA), which is the medical term describing a newborn with a body weight that is below the 10th percentile, by 1.42 in 1000 (Donovan et al., 2011). Dadvand et al. (2012), Markevych et al. (2014), Laurent et al. (2013), and Hystad et al. (2014) find similar positive associations between nature and higher birth weight in Spain, Germany, US, and Canada, respectively. The causal link between nature and higher birth weight is, however, not yet identified.

Wolf et al. (2015) have estimated the potential cost savings in annual incremental hospital charges for low birth weight infants across the US. They combine the estimates of nature's effect

on birth weight from Donovan et al. (2011) and the cost estimates from Russell et al. (2007) to estimate the cost saving due to urban nature's effect on newborns' birth weight. Using the annual birth numbers from the CDC and the estimates of SGA percentages from Ananth et al. (2004), Wolf et al. (2015) estimate that urban nature has a potential cost saving of US$ 5.3 million (2012 US$) in the first year of infants' health care. They have not estimated the monetary benefits of higher birth weight's effects to infants' later life stages, because of data limitation.

3.6 Attention Deficit Hyperactivity Disorder (ADHD)

Recent research demonstrates that interacting with nature leads to reduced symptoms of ADHD (Taylor et al., 2001; Taylor & Kuo, 2009, 2011; van den Berg & van den Berg, 2011). ADHD is a common brain disorder that affects large segments of the population (Polanczyk et al., 2007). For example, in a US study, Taylor & Kuo (2009) find that a 20 minutes' walk in a city park is roughly equivalent to the peak effect of an extended release stimulant medication methylphenidate, which is the most common ADHD medication. In a Dutch study, van den Berg & van den Berg (2011) find that a natural environment reduces ADHD symptoms.

Treating ADHD is costly. Visser (2013) reports that 66.3% of the American children that were diagnosed with ADHD, were taking medication during 2007–2008. Bloom et al. (2012) estimate that 3.47 million American children take ADHD medication in 2011. Pelham et al. (2007) estimate that the treatment cost and other health care costs for each child and adolescent with ADHD is US$ 14,756 (2012 US$) per person per year. Consumers Union (2013) lists common medications that are used for treating ADHD, of which the average drug cost per month is US$ 184.

Because ADHD medication can be replaced, at least partially, by interacting with urban nature, urban nature produces monetary benefits from the medical cost savings. Based on urban nature's health effect on ADHD from Taylor & Kuo (2009) and the average drug cost from Consumers Union (2013), Wolf et al. (2015) estimate the cost saving from urban nature to ADHD treatment ranging from US$ 383.5 million to US$ 1.9 billion per year, corresponding to assumptions of 5% medication replacement and 25% medication replacement effects of urban nature, respectively.

3.7 Attention Restoration and School Performance

Viewing nature is relaxing and restores attention (Kaplan, 1995; Berman et al., 2008). Studying 72 college students living in dormitories, Tennessen & Cimprich (1995) find that students with window views of nature have better performances on attentional measures. Shibata & Suzuki (2001) suggest that in-classroom plants may influence restoration of mental fatigue among students. In a recent study by Felsten (2009), college students state that direct exposure to nature, window view of nature, and viewing images of nature are restorative for attention, when the students are cognitively fatigued.

Part of nature's effects on attention restoration is reflected in school performances of students (Matsuoka, 2010; Shibata & Suzuki, 2001). Studying public high school students in several counties in Michigan, Matsuoka (2010) finds that views of nature from cafeteria and classroom windows are positively correlated with higher standardized test scores, graduation rates, and percentage of students planning to attend a four-year college, and negatively correlated with occurrences of future criminal behaviour. Shibata & Suzuki (2001) find that, using undergraduate college students in Japan, student performance is positively affected by the presence of indoor plants.

Improved school performances have economic consequences for students themselves and to the society. Higher education is typically associated with higher income (Houthakker, 1959; Griliches, 1977)[6]. Based on the estimates from Matsuoka (2010), Wolf et al. (2015) estimate that urban nature has potential effects of increasing 114,813 additional high school graduates per year, which will generate US$ 1.3 billion in average total income due to higher education. They have not estimated how more high school graduates will affect the macroeconomy of the US.

3.8 Horticultural Therapy

Horticulture is associated with various health benefits (Detweiler et al., 2009). Horticulture is found to reduce the medication intake of certain drugs for dementia patients (Detweiler et al., 2009). Gonzalez et al. (2011) find that horticultural activities reduce depression severity among the participants. Reviewing 16 studies, Gonzalez & Kirkevold (2014) conclude that sensory gardens and horticultural activities may improve patients' well-being and reduce the occurrence of disruptive behaviour, reduce the use of psychotropic medication, reduce serious falls, and improve sleep and sleep patterns. Therefore, as an alternative therapy method, horticulture brings health benefits to patients and generates monetary values.

Lee et al. (2008) use the contingent valuation method to study residents' willingness to pay for a horticultural therapy site. The study took place in Busan, South Korea. They find a mean willingness-to-pay of around US$ 170 per month, which is economically significant. The standard deviation is around US$ 60 for the mean willingness-to-pay per month, suggesting that 68% of the respondents are willing to pay between US$ 110 to 230 per month. Among all the reviewed studies, Lee et al. (2008) is the only study that use the stated-preference method.

3.9 Crimes

A number of studies have discovered associations between urban nature and crime rates (Kuo & Sullivan, 2001; Branas et al., 2011; Wolfe & Mennis, 2012; Troy et al., 2012; Donovan & Prestemon, 2012). The correlation tends to be negative, i.e. greener surroundings are associated with lower crime rates. Using responses from residents who were randomly assigned to 98 different public apartment buildings, which were architecturally identical but with varying levels of vegetation, Kuo & Sullivan (2001) find that more residents living in buildings with more trees and grass perceived a safe living environment than otherwise. Kuo & Sullivan (2001) also find less reported property crimes and violent crimes in the apartment buildings with greener surroundings. Troy et al. (2012) find that 10% increase in tree canopy is correlated with around 12% decrease in crime. Using data between 1999 and 2008 from Philadelphia, Pennsylvania, Branas et al. (2011) find that greening of vacant urban land is associated to a reduction in gun robberies, vandalism, and criminal mischief.

Part of crimes' negative impacts are on human health. Crimes affect psychological well-being of victims (McCann & Pearlman, 1990). Violent crimes, by their nature, hurt victims' physical health. In the worst case, a crime leads to death of individuals. Miller et al. (1996) estimate that the average cost of rape is US$ 87,000, when considering the crime's effect on the victim's quality of life. Miller et al. (1996) estimate that the costs of robberies, assault, and theft range from US$ 558 for theft to US$ 24,000 for assault (2012 US$). Estimates from Heaton (2010) are higher, ranging from US$ 2,369 for theft to 96,600 for assault (2012 US$).

If urban nature reduces crimes then it may be reasonable to estimate the resulting health benefits and their monetary values. Based on urban nature's effects from Troy et al. (2012) and Branas

[6] Higher education may also contribute to firms' productivity and, in aggregation, a nation's economy (Ng & Feldman, 2009). However, Murphy (1993) argues that over-expansion of higher education does not produce adequate benefits to the society that are comparable to the educational costs.

et al. (2011) and the cost estimates from Miller et al. (1996), Wolf et al. (2015) estimate that urban nature of US cities that have populations greater than 500,000, potentially provide total monetary benefits between US$ 340.6 and 899.4 million in cost saving from reduced crimes in 2012, when considering robbery, aggravated assault, burglary, and theft. Among the four types of crimes, aggravated assault is the most detrimental to health. Wolf et al. (2015) estimate that the monetary benefits of reduced costs from reduced aggravated assault crimes range between US$ 340.6 to 502.4 million in 2012.

4 Future Research Needs and Challenges

In this section I discuss future research needs on monetary valuation of urban nature's health effects. Potential challenges and strategies to overcome them are discussed as well.

4.1 Research Needs

The mere fact that the systematic literature search only found ten studies, of which only four are peer-reviewed journal articles, points out that there is great need for future research. Current lack of research efforts on monetary valuation of urban nature's health effects presents low hanging fruits for researchers. Numerous studies have investigated nature's health effects (e.g., Hartig et al., 2014; Gascon et al., 2015). Researchers, particularly economists, need to take these estimates and combine them with economic costs and benefits of various health effects, to estimate the monetary values of urban nature's health effects. A great number of studies have also used various economic tools to value the benefits of nature (Mitchell & Carson, 1989; Carson, 2005; Champ et al., 2012). Researchers, particularly public health researchers, need to explore the linkages of urban nature and health effects, to bridge the current gap in the literature.

Currently among the literature written in English language, researchers have only investigated monetary benefits of urban nature's health effects in the US, the UK, and South Korea. Most of the results on urban nature's health effects are likely to be valid in other countries as well (e.g., Gascon et al., 2015). Still, it is important to expand such studies to other countries. It is possible to use existing research results and estimate monetary values of urban nature's health benefits for other regions. For example, we may calibrate the i-Tree software, which is developed by USDA Forest Service (McPherson, 2010), to estimate monetary values in areas and countries outside of the US, for example, Norway. In the light of the current limited number of studies and value estimates, it is also important to replicate the studies, both within sample and out of sample. In that way, the robustness of these research findings can be verified, validated, or falsified.

Obesity is an increasing lifestyle-related health problem worldwide. Urban nature has been found to facilitate physical exercise. However, currently the majority of monetary benefits are calculated based on reduced mortality from physical exercise. More research is required on how much urban nature contributes to health benefits and the associated monetary values from effects on obesity through increased physical exercise.

Research dating back to the 1980s show that green space shortens patients' recovery time and therefore reduces costs associated with hospital stays (Ulrich, 1984). Green Infrastructure Northwest (2011) suggests that future research is required to quantify the monetary values generated from the reduced costs of in-patient hospital stays. Nowak et al. (2013) is the only study that has investigated the reduction of in-patient stays from the health effects of reduced air pollution due to urban trees' pollution removal effects. Urban nature's other health effects to reduce in-patient stays and the associated monetary values need to be investigated. For example, one straightforward estimate would be to calculate reduced in-hospital stays due to having direct exposure to nature in the room, direct exposure to nature in the hospital, nature view from a window, nature view from pictures, hearing of nature sounds, and other types of sensory stimuli.

Existing research findings suggest that urban nature helps people restore their mental capacities from cognitive fatigue (Kaplan, 1995; Berman et al., 2008). However, none of the existing research has investigated the monetary worth of such effects. A straightforward next step is to find the costs of alternative ways to restore cognitive abilities after fatigue. These costs would represent the lower bound estimate for urban nature's health effects on mental restoration.

Urban nature has positive effects to mental disorders such as ADHD, Alzheimer's disease, and depression. Branas et al. (2011) find that greening of vacant urban land is associated with less

self-reported stress among residents of Philadelphia, Pennsylvania. So far none of the studies have conducted monetary valuation of urban nature's mental health effects other than ADHD and Alzheimer's disease. This gap in the literature calls for more research efforts.

Exhaustively summarizing urban nature's health effects itself is challenging. For example, Willis & Crabtree (2011, pp. 376–377) summarize that increased exercise reduces the incidence of coronary heart disease (CHD), cerebrovascular illness (stroke), and certain types of cancer. There are other benefits that are associated with increased physical exercise, which need to be accounted for. Similarly, discovering and quantifying urban nature's every health effect will be challenging.

There are also increased costs associated with increased urban nature, which need to be considered. Increased physical activities are associated with probable increases in injuries (Willis & Crabtree, 2011). However, Willis & Crabtree (2011) argue that because increased physical activities are mostly walking, the increased costs due to increased injuries are expected to be minor.

So far, the most comprehensive account of urban nature's total monetary value from health effects is by Wolf et al. (2015). Accounting for urban nature's health benefits to newborns, ADHD, high school performance, crime reduction, cardiovascular disease, and Alzheimer's disease, Wolf et al. (2015) estimate an annual monetary value between US$ 2.7 and 6.8 billion (2012 US$). This figure is conservative, because is does not account for other health effects of urban nature, nor the costs. Because of the lack of monetary value estimates of many of urban nature's health effects, it is not possible yet to summarize an overall monetary value in a comprehensive way. More thorough research is required to identify and estimate individual health effects, before an encompassing estimate of total health benefits can be estimated.

Moreover, the total economic value of urban nature's health effects is likely to vary. First, it depends on the health effects that a study includes. Second, it is subject to the area, scale, time, and method that a study employs.

4.2 Conceptual Challenges

There are conceptual challenges, too. I find that applying the ecosystem services framework to urban nature's health effect is not as straightforward as one would imagine. Under the ecosystem services framework, nature's services can be categorized into provisioning services, regulating services, supporting services, and cultural services. Take nature's relaxation effect as an example. The relaxation effect is likely to have a component from nature's cultural ecosystem services, which by definition includes activities such as having a break in the park. However, it may also have a component from nature's regulatory ecosystem services, because one may feel relaxed because of the microclimate regulatory function of the park (Bolund & Hunhammar, 1999).

4.3 Methodological Challenges

There are methodological challenges as well. The economic benefits of urban nature's health effects can be evaluated in different ways (Drummond et al., 2015; Wolf & Robbins, 2015). Comparison of methods is an important line of research.

Disentangling urban nature's health effects from other factors can be challenging. Anecdotal evidence suggests that part of the health benefits from being in urban nature comes from the social and psychological benefits of increased social contacts (Maas et al., 2008). Therefore, the monetary values that we have estimated may contain values of elements other than direct health effects of urban nature.

Most of the reviewed literature relied on health effect evidence from correlation studies. As such, the causal links between urban nature and health effects are not yet well understood. For example, one challenge arises in the identification of the causality between green space and increased physical exercise, and the causality between increased physical exercise and improved health. (Willis & Crabtree 2011). A similar challenge exists for other health effects, too.

To address the challenge, innovation in research methods is necessary. First, we can design experiments as randomized controlled trials to investigate the effects (e.g., Lorig et al., 1999). Second, we can look for naturally occurring experiments (e.g., Donovan et al., 2013). Third, we can construct quasi-experiment using statistical methods (e.g., Ng, 2000).

Caution needs to be taken when designing studies and choosing methods. For example, the researcher needs to take care when interpreting positive intervention results, because it could be due to the Hawthorne effect (McCarney et al., 2007). This again warrants identification of causal effects and application of novel methods.

5 Conclusions

From the review of the ten papers that were found through a systematic literature search, I find that urban nature's health effects have, both statistically and economically, significant monetary values. However, great efforts are required to investigate other types of urban nature's health effects and their associated monetary values, as well as such effects and values in different regions, countries, and nature type settings.

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