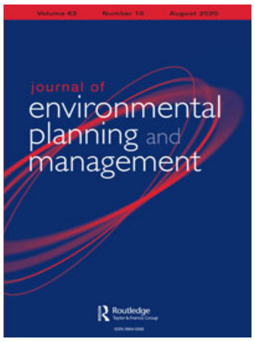

Journal of Environmental Planning and Management

ISSN: 0964-0568 (Print) 1360-0559 (Online) Journal homepage: https://www.tandfonline.com/loi/cjep20

Monetary valuation of urban nature's health effects: a systematic review

Xianwen Chen

To cite this article: Xianwen Chen (2020) Monetary valuation of urban nature's health effects: a systematic review, Journal of Environmental Planning and Management, 63:10, 1716-1737, DOI: 10.1080/09640568.2019.1689107

To link to this article: https://doi.org/10.1080/09640568.2019.1689107

Journal of Environmental Planning and Management, 2020
Vol. 63, No. 10, 1716–1737, https://doi.org/10.1080/09640568.2019.1689107

Routledge
Taylor & Francis Group

REVIEW ARTICLE

Check for updates

Monetary valuation of urban nature's health effects: a systematic review

Xianwen Chen[a,b]*

[a]*Department of Landscape Ecology, Norwegian Institute for Nature Research, Oslo, Norway;* [b]*Faculty of Business, Languages and Social Sciences, Østfold University College, Halden, Norway*

(*Received 13 June 2018; final version received 21 October 2019*)

Allocation of public budgets requires deliberate analyses of the costs and benefits of alternative budget usages, which must be made using the same metric. The use of monetary term is the standard metric in government budgeting and is ideal for cost-benefit analysis. This paper systematically searched and reviewed literature on monetary valuation of urban nature's health effects. Although extensive research has demonstrated urban nature's positive health effects for humans, the review only found ten items in the literature, including four peer-reviewed journal articles, one book chapter, and five reports. Large monetary values were found. These estimates are useful as an argument for urban planners promoting investment in urban green infrastructure. The small number of studies calls for more research. Specifically, more research is required to investigate the monetary values of urban nature's other health effects, including the impact on depression and obesity. Case studies covering larger geographical areas are needed to account for heterogeneities across countries.

Keywords: urban environment; urban nature; health effect; monetary valuation; systematic review

JEL: I18 (Government Policy • Regulation • Public Health); Q51 (Valuation of Environmental Effects); Q57 (Ecological Economics: Ecosystem Services • Biodiversity Conservation • Bioeconomics • Industrial Ecology)

1. Introduction

The study of urban green infrastructure and its role in public health is of vital importance. Europe is among the world's most urbanized regions, with approximately 73% of Europeans living in urban areas (United Nations 2014).[1] In the US, 81% of the population live in urban areas according to the 2010 Census by the US Census Bureau.

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 to increase (Flegal *et al.* 2002; Prentice 2006). Lifestyle-related illnesses are costly both in terms of public health impacts and medical treatment costs (Withrow and Alter 2011). The Department of Health in the UK estimates that physical inactivity

*Email: xianwen.chen@gmail.com

in England costs UK £8.2 billion, not including 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 and Robbins 2015). Being within nature itself produces beneficial effects, including relaxation and reducing stress. 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 using 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 and Crabtree (2011, 375–376) provide such a perspective in the context of urban tree planting. Benefit-cost analysis has been widely applied in research and in policy-making (Carson 2011).

Traditionally, when estimating urban nature's monetary values,[2] health effects are typically not accounted for. In urban areas, the provision of services by urban nature is usually rather limited, given the limited size of the green areas (Hartig *et al.* 2014). However, nature's health effects are likely much larger in urban areas than in rural areas, because urban nature is much more frequently used than rural nature[3] (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 remains scarce (Wolf and Robbins 2015; Bowen and Lynch 2017). In this study, I first conduct a systematic search (Alliance for Useful Evidence 2013) on literature that estimates the monetary values of urban nature's health effects. Then I review all the literature discovered and summarize the key findings. Following the summary, I discuss future research needs and challenges. Finally, I conclude. To the best of my knowledge, this is the first systematic review on the monetary values of urban nature's health effects.

2. Systematic literature search and literature review

A systematic literature search was conducted on March 6, 2016. The search was later repeated to (a) include a new keyword that was identified or discovered from a previous literature search, and (b) to include the latest publications. The last time that a literature search was conducted was September 30, 2019. The details of the literature searches can be found in Appendix 1 (online supplemental data).

I list the publications that I have discovered through the systematic literature search in Table 1. The publications are listed with peer reviewed journal articles at the top of the table, then book chapters, and finally the grey 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 and Robbins (2015).

Including grey literature is important in this study, to supplement the lack of peer-reviewed publications. McAuley *et al.* (2000) found out that 33% of the randomly-selected 135 meta-analyses included grey literature, ranging from 4.5% to 75% of the studies surveyed in these meta-analyses. They found that peer-reviewed articles had 15% larger intervention effects than intervention effects found in the grey literature. This suggests that there is a selection bias in terms of what authors and journals choose to publish, which is well known in the profession as non-significant result bias. Usually it is much more difficult to publish a study that has a non-significant result than a study that has a significant result. By including grey literature in my review, less significant results may be included as a direct consequence, which is not an issue because this review intends to present the entire picture of the academic studies on this topic so far, not just those studies with significant results that have been published in peer-reviewed journals. Because grey literature has not gone through a peer-review process, it is important to bear in mind that it may be of lower quality than literature in peer-reviewed journals.

One common approach to estimate the 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. To a much less degree are other conventional valuation methods in health economics literature used on this topic, particularly stated-preference methods such as contingent valuation (Carson 2011) and choice experiment (de Bekker-Grob, Ryan, and Gerard 2012; Clark *et al.* 2014).

2.1. 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 and 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 areas. Richardson and 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 6,113 deaths related to illness of the lower respiratory tract and 15,080 additional deaths because of cardiovascular disease.

Consequently, increased cardiovascular disease due to lack of access to green spaces is a major source of healthcare costs. Luengo-Fernandez *et al.* (2006) estimate that cardiovascular disease cost the UK £29.1 billion in 2004, of which £492.7 and

Table 1. 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 reductions in medical costs in the first year of infants' life care, due to correlation between tree canopy coverage of mother's home and increase in birth weight of singleton newborns • Monetary benefit between US$ 383.5 million and 1.9 billion from 5% to 25% medication replacement possibilities 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$ 4.7 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 reduction in 12 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 comes 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

(*Continued*)

Table 1. (*Continued*).

Publication	Type	Area	Key findings
Willis and 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 the 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 and Welle (2008)
Harnik and Welle (2009)	Grey publication	Sacramento, US	• Monetary value of health care savings of physically active users of all the parks in Sacramento were US$ 1,98,71,863 in 2007
Harnik and Welle (2008)	Grey publication	Philadelphia, US	• Monetary value of US$ 6,94,19,000 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: £ 9,00,000 per year • The economic value of health benefits of 1% reduction in the sedentary population: £ 1.44 billion per year (equivalent of a mean of £ 2,423 per additional active person per year)

179.85 million was 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 for 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 and Mitchell (2010), assuming that green cover increases to 25% or more in and around the 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 admissions by 49 cases, which generates US$18,76,000 in terms of saved medical costs in the US per annum.

2.2. *Physical activity and mortality*

Physical activities reduce the chance of illness and mortality due to physical inactivity. Regular physical activities help to reduce the risk of cardiovascular disease, non-insulin dependent diabetes mellitus, osteoarthritis, some forms of cancer, and obesity (Green Infrastructure Northwest 2011; The GBD 2015 Obesity Collaborators 2017). However, despite these benefits, for many countries 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 to gain the health benefits (Green Infrastructure Northwest 2011).

Being physically active generates economic benefits through savings in medical costs. Wang and Brown (2004) found that, in 1987, Americans who were physically active had $354[4] less in medical expenditure than those who were not physically active. They found that 6.1% of medical expenditure was associated with physical inactivity. Pratt, Macera, and Wang (2000) and Wang *et al.* (2005) estimated that in the US, in 1987, physically active people spent $564[5] less on medical expenditure than physically inactive people.

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 a 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 exercise 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 and 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 and 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.[6]

There are also three studies from the UK. Under the assumption that urban nature reduces 1% of the sedentary population in the UK, CJC Consulting (2005) and Willis and Crabtree (2011) estimate that annual values due to health benefits in terms of reduced mortality and morbidity is £1.44 billion.[7] 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.

2.3. 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 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 dementia medications is an elevated risk of falls.

Alzheimer's disease is costly for patients and for 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, Nemecek, and Oliver (1997) find positive effects of garden use for Alzheimers 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 in dementia patients. They also find that the effect is differentiated depending on whether the patient can walk unassisted. Detweiler *et al.* (2009) find that a high-use group of 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 on 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 ranges between US$724.6 million and 1.45 billion.

2.4. 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), sulfur 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 and Dockery 2006).[8] Approximately 130,000 and 4,700 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, 122–123).

Urban nature, particularly trees, reduce air pollution. Trees remove some gaseous air pollution through the plant's surface and some by uptake via leaf stomata (Nowak *et al.* 2014). Leaf stomata remove most of the pollution by O_3, SO_2, and NO_2. Nowak, Crane, and Stevens (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 and 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, the study by Nowak *et al.* (2014) is, among all of the reviewed literature, the most up-to-date 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 2, which is taken from Table 4 in Nowak *et al.* (2014, 126). In total, Nowak *et al.* (2014) estimate that urban trees in the conterminous US generate a monetary value of US$4.7 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.

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 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 people 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 3 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, reproduced from Table 5 in Nowak *et al.* (2013, 398).

In the UK, Powe and 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 and Willis's (2004) estimates, CJC Consulting (2005) and Willis and 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 and Willis (2004), CJC Consulting (2005), nor Willis and 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.

Table 2. 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**

Table 3. 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

2.5. *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 medical care (Almond, Chay, and Lee 2005; Russell *et al.* 2007). In the long-term, Black, Devereux, and Salvanes (2007) and Johnson and 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, the 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 effects on infants' later life stages, because of data limitations.

2.6. Attention deficit hyperactivity disorder (ADHD)

Recent research demonstrates that interacting with nature leads to reduced symptoms of ADHD (Taylor, Kuo, and Sullivan 2001; Taylor and Kuo 2009, 2011; van den Berg and 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 and Kuo (2009) find that a 20 minute 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 and van den Berg (2011) find that a natural environment reduces ADHD symptoms.

Treating ADHD is costly. Visser *et al.* (2013) reports that 66.3% of American children who were diagnosed with ADHD, were taking medication during 2007–2008. Bloom, Cohen, and Freeman (2012) estimate that 3.47 million American children took ADHD medication in 2011. Pelham, Foster, and Robb (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 and 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.

2.7. Attention restoration and school performance

Viewing nature is relaxing and restores attention (Kaplan 1995; Berman, Jonides, and Kaplan 2008). Studying 72 college students living in dormitories, Tennessen and Cimprich (1995) find that students with window views of nature have better performance on attentional measures. Shibata and 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, a 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 performance of students (Matsuoka 2010; Shibata and 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 course, and negatively correlated with occurrences of future criminal behaviour. Shibata and Suzuki (2001) find that, using undergraduate college students in Japan, student performance is positively affected by the presence of indoor plants.

Improved school performance has economic consequences for students themselves and for society. Higher education is typically associated with higher income (Houthakker 1959; Griliches 1977).[9] 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 high school graduates will affect the macroeconomy of the US.

2.8. 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 reduced depression severity among the participants. Reviewing 16 studies, Gonzalez and 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 for 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 uses the stated-preference method.

2.9. Crimes

A number of studies have discovered associations between urban nature and crime rates (Kuo and Sullivan 2001; Branas *et al.* 2011; Wolfe and Mennis 2012; Troy, Morgan Grove, and O'Neil-Dunne 2012; Donovan and 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 and Sullivan (2001) found that more residents living in buildings with more trees and grass perceived a safe living environment than otherwise. Kuo and Sullivan (2001) also find less reported property crimes and violent crimes in the apartment buildings with greener surroundings. Troy, Morgan Grove, and O'Neil-Dunne (2012) find that a 10% increase in tree canopy is correlated with around a 12% reduction in crime. Using data between 1999 and 2008 from Philadelphia, Pennsylvania, Branas *et al.* (2011) find that greening of vacant urban land is associated with a reduction in gun robberies, vandalism, and criminal mischief.

Part of crimes' negative impacts are on human health. Crimes affect the psychological well-being of victims (McCann and Pearlman 1990). Violent crimes, by their nature, hurt victims' physical health. In the worst case, a crime can lead to the death of individuals. Miller, Cohen, and Wiersema (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, Cohen, and Wiersema (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 crime, then it may be reasonable to estimate the resulting health benefits and their monetary values. Based on urban nature's effects from Troy, Morgan Grove, and O'Neil-Dunne (2012) and Branas *et al.* (2011) and the cost estimates from Miller, Cohen, and Wiersema (1996), Wolf *et al.* (2015) estimate that urban nature in US cities that have populations greater than 500,000, potentially provide total monetary benefits between US$340.6 and 899.4 million in cost savings 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.

3. Discussion: future research needs and challenges

The mere fact that the systematic literature search only found ten studies, of which only four are peer-reviewed journal articles, points to the great need for future research. Current lack of research efforts on monetary valuation of urban nature's health effects is calling for more research efforts into the complex and challenging studies of translating health outcomes and effect sizes. 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 and Carson 1989; Carson 2011; Champ, Boyle, and Brown 2012). Researchers, particularly public health researchers, need to explore the linkages between urban nature and health effects, to bridge the current gap in the literature.

Currently among the literature written in the 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 also likely to be valid in other countries (e.g., Gascon *et al.* 2015). Still, it is important to examine whether results from existing studies hold in other countries. It is possible to use existing research results and estimate monetary values for urban nature's health benefits for other regions. For example, one may calibrate the i-Tree software, which is developed by the USDA Forest Service (McPherson 2010), to estimate monetary values in areas and countries outside 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.

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, estimated monetary values may contain values of elements other than the direct health effects of urban nature.

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. Obesity is a condition that spans a distribution of bodyweight, from BMI of 30.0 and onwards if we follow the BMI cut-off point from the CDC, this varies from person to person (depends on e.g. the height of the person). Obesity itself does not incur medical costs. However, there are health conditions that may develop as a result of obesity, which will require medical attention and cost the patient and society. To quantify the costs of obesity and the consequent benefits of healthy body weight, a researcher will need to specifically target individual health conditions that are associated with obesity and analyse the costs (and benefits) of (not having) the condition. Bodyweight reduction varies depending on the amount of exercise, calorie intake, and, in this context, the amount of exposure to urban nature. Therefore, the benefits, medical and monetary, will depend on exposure to urban nature, which adds another layer of complexity.

Research dating back to the 1980s shows that green space shortens patients' recovery time and therefore reduces the 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-patient stays due to direct exposure to nature in the room, direct exposure to nature in the hospital, nature views from a window, nature views 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, Jonides, and Kaplan 2008). However, none of the existing research has investigated the monetary value 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. Providing precise estimates, however, will be challenging. Just as in the case of obesity, stress itself does not incur costs, but the resulting medical conditions, such as anxiety attacks and depression, cost patients and society. Just as in the case of obesity, the amount and types of exposure to nature affect how much reduction in anxiety there can be. Therefore, estimation of health benefits will have to be medical condition-specific and depend on exposure quantity and pathway.

Urban nature has positive effects on 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 a monetary valuation of urban nature's mental health effects other than for ADHD and Alzheimer's disease. This gap in the literature calls for more research efforts to study urban nature's effects on other types of mental disorders.

Exhaustively summarizing urban nature's health effects is challenging. Willis and Crabtree (2011, 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. The nature and health literature has broadly studied mental health, cognitive function, immune system, and stress reduction etc. between urban trees and public health. The economic valuation literature has so far not taken these pathways in the analyses.

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 and Crabtree 2011). The types of injuries and their severity will vary and depend on the types and duration of exposure to urban nature. The costs will be injury specific, too. However, notice that Willis and 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 it does not account for other health effects of urban nature. Because of the lack of monetary value estimates of many of urban nature's health effects, it is not yet possible 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. The economic benefits of urban nature's health effects can be evaluated in different ways (Drummond *et al.* 2015; Wolf and Robbins 2015). Comparison of methods will be an important line of research.

3.1. Methodological challenges

There are also methodological challenges. The economic benefits of urban nature's health effects can be evaluated in different ways (Drummond *et al.* 2015; Wolf and 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 the 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 and Crabtree 2011). A similar challenge also exists for other health effects.

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 a 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 the application of novel methods. Hartig *et al.* (2014), Frumkin *et al.* (2017), and Chen *et al.* (2019) are recent publications that discuss in depth the research challenges and agenda.

Except for Lee *et al.* (2008), all other existing literature translated health benefits into monetary values. Methodological innovations are needed to, for example, design outcome research to directly generate monetization outcomes. One possibility is to employ subjective valuation methods.

Compared with translating actual cost reductions that are generated by the health benefits of contacting urban nature, researchers could investigate further with subjective valuation of the health benefits. A person, who benefits from, say, mental relaxation while enjoying urban nature, could be willing to pay more or less than the actual cost reduction from the medical expenses from mental relaxation. Commonly used methods such as contingent valuation (Carson 2011) and choice experiment (de Bekker-Grob, Ryan, and Gerard 2012; Clark *et al.* 2014) could be applied in such a context.

Finally, when more studies on the monetary valuation of urban nature's health benefits are available, new studies could then use the existing results and use benefit transfer (Hanley, Ryan, and Wright 2003) to estimate values in new contexts.

3.2. Replication

Monetary valuation studies provide important numbers to policy makers, which in turn impact whether a country's government implements, for example, an intervention. Therefore, it is vital that the numbers are robust and trustworthy.

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.

The robustness lies in three dimensions. First, the robustness of how urban nature impacts human health needs to be established, to generalize the health outcomes from urban nature. This is largely on the shoulders of environmental health researchers. Second, the translation between health effect and monetary valuation needs to be robust so that trustworthy numbers are estimated and provided. Third, valuation methods are tested for their consistency and eventually guidelines for choosing and using valuation methods are developed for practitioners.

4. 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.

Acknowledgements

The Ministry of Climate and Environment of Norway provided financial support for this research. The author is grateful for the beneficial discussions with Erik Framstad and David N. Barton. The author wishes to thank the audience of CIENS Breakfast Seminar "Natur i byen – viktig for helse og velvre" for their comments. The comments from an anonymous reviewer have helped improve this article. All remaining errors are the author's.

Supplemental data

Supplemental data for this article can be accessed here

Notes

1. For example, 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).
2. In this study, I interchangeably use the terms "monetary value" and "economic value".
3. Considering that urban areas are more populated than rural areas, although smaller in size, urban nature is more frequently used by city dwellers than rural nature by rural dwellers.
4. The estimate is in terms of 2003 US dollars.
5. The estimate is in terms of 1998 US dollars.
6. The estimates in McPherson (2010) seem to be from Harnik and Welle (2008). However, it is also possible that McPherson (2010) replicated the analysis of Harnik and Welle (2008).
7. Willis and Crabtree (2011) is a book chapter that seems to be based on CJC Consulting (2005), which is a report. They have the same estimates.
8. 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.
9. Higher education may also contribute to firms' productivity and, in aggregation, a nation's economy (Ng and 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.
10. The forward snowballing technique is not commonly used in systematic literature search. However, I used this method to trace the latest research on the topic, which has proven to be helpful.
11. It was not possible to specify publication month in the search. Therefore, the entire year of 2016 had to be included.

ORCID

Xianwen Chen http://orcid.org/0000-0001-9262-2568

References

Alliance for Useful Evidence. 2013. Learning From Research: Systematic Reviews for Informing Policy Decisions: A Quick Guide. Technical Report. London: Alliance for Useful Evidence. http://www.alliance4usefulevidence.org/assets/Alliance-final-report-08141.pdf.

Almond, D., K. Y. Chay, and D. S. Lee. 2005. "The Costs of Low Birth Weight." The Quarterly Journal of Economics 120 (3): 1031–1083. doi:10.1093/qje/120.3.1031.

Ananth, C. V., B. Balasubramanian, K. Demissie, and W. L. Kinzler. 2004. "Small-For-Gestational-Age Births in the United States: An Age-Period-Cohort Analysis." *Epidemiology* 15 (1): 28–35. doi:10.1097/01.ede.0000100288.37475.19.

Berman, M. G., J. Jonides, and S. Kaplan. 2008. "The Cognitive Benefits of Interacting With Nature." *Psychological Science* 19 (12): 1207–1212. doi:10.1111/j.1467-9280.2008.02225.x.

Black, S. E., P. J. Devereux, and K. G. Salvanes. 2007. "From the Cradle to the Labor Market? The Effect of Birth Weight on Adult Outcomes." *The Quarterly Journal of Economics* 122 (1): 409–439. doi:10.1162/qjec.122.1.409.

Bloom, B., R. A. Cohen, and G. Freeman. 2012. Hyattsville, Maryland: National Center for Health Statistics, Vital and Health Statistics. http://www.cdc.gov/nchs/data/series/sr_10/sr10_254.pdf.

Bowen, K. J., and Y. Lynch. 2017. "The Public Health Benefits of Green Infrastructure: The Potential of Economic Framing for Enhanced Decision-Making." *Current Opinion in Environmental Sustainability* 25: 90–95. doi:10.1016/j.cosust.2017.08.003.

Branas, C. C., R. A. Cheney, J. M. MacDonald, V. W. Tam, T. D. Jackson, and T. R. Ten Have. 2011. "A Difference-In-Differences Analysis of Health, Safety, and Greening Vacant Urban Space." *American Journal of Epidemiology* 174 (11): 1296–1306. doi:10.1093/aje/kwr273.

Carson, R. T. 2011. *Contingent Valuation: A Comprehensive Bibliography and History*. Gloucestershire, UK: Edward Elgar Publishing.

Cavanagh, J.-A E., and J. Clemons. 2006. "Do Urban Forests Enhance Air Quality?" *Australasian Journal of Environmental Management* 13 (2): 120–130. doi:10.1080/14486563.2006.9725122.

CDC. 2015. "Heart Disease Facts." http://www.cdc.gov/heartdisease/facts.htm.

Champ, P. A., K. J. Boyle, and T. C. Brown. 2012. *A Primer on Nonmarket Valuation*. Vol. 3. New York: Springer Science and Business Media.

Chen, X. S. De Vries, T. Assmuth, J. Dick, T. Hermans, O. Hertel, A. Jensen, L. Jones, S. Kabisch, T. Lanki., et al. 2019. "Research Challenges for Cultural Ecosystem Services and Public Health in (peri-)Urban Environments." *Science of the Total Environment* 651: 2118–2129. doi:10.1016/j.scitotenv.2018.09.030

CJC Consulting. 2005. "Economic Benefits of Accessible Green Spaces for Physical and Mental Health: Scoping Study." https://forestry.gov.scot/publications/sustainable-forestry/economic-research/600-economic-benefits-of-accessible-green-spaces-for-physical-and-mental-health-scoping-study.

Clark, M. D., D. Determann, S. Petrou, D. Moro, and E. W. de Bekker-Grob. 2014. "Discrete Choice Experiments in Health Economics: A Review of the Literature." *Pharmacoeconomics* 32 (9): 883–902. doi:10.1007/s40273-014-0170-x.

Cohen, D. A., J. S. Ashwood, M. M. Scott, A. Overton, K. R. Evenson, L. K. Staten, D. Porter, T. L. McKenzie, and D. Catellier. 2006. "Public Parks and Physical Activity Among Adolescent Girls." *Pediatrics* 118 (5): e1381–e1389. doi:10.1542/peds.2006-1226.

Cohen, D. A., T. L. McKenzie, A. Sehgal, S. Williamson, D. Golinelli, and N. Lurie. 2007. "Contribution of Public Parks to Physical Activity." *American Journal of Public Health* 97 (3): 509–514. doi:10.2105/AJPH.2005.072447.

Consumers Union. 2013. *Evaluating Prescription Drugs Used to Treat: Attention Deficit Hyperactivity Disorder (ADHD). Comparing Effectiveness, Safety, and Price. Technical Report.* Consumers Union. http://www.consumerreports.org/health/resources/pdf/best-buy-drugs/ADHDFinal.pdf.

Dadvand, P., J. Sunyer, X. Basagana, F. Ballester, A. Lertxundi, A. Fernandez-Somoano, M. Estarlich, R. Garcia-Esteban, M. A. Mendez, and M. J. Nieuwenhuijsen. 2012. "Surrounding Greenness and Pregnancy Outcomes in Four Spanish Birth Cohorts." *Environmental Health Perspectives* 120 (10): 1481. doi:10.1289/ehp.1205244.

de Bekker-Grob, E. W., Ryan, M., and K. Gerard. 2012. "Discrete Choice Experiments in Health Economics: A Review of the Literature." *Health Economics* 21 (2): 145–172. doi:10.1002/hec.1697.

Department of Health. 2004. *At Least Five a Week: Evidence on the Impact of Physical Activity and Its Relationship to Health: A Report From the Chief Medical Officer*. London: Department of Health. http://www.bhfactive.org.uk/sites/Exercise-Referral-Toolkit/downloads/resources/cmos-report-at-least-five-a-week.pdf.

Detweiler, M. B., P. F. Murphy, K. Y. Kim, L. C. Myers, and A. Ashai. 2009. "Scheduled Medications and Falls in Dementia Patients Utilizing a Wander Garden." *American Journal of Alzheimer's Disease and Other Dementias* 24 (4): 322–332. doi:10.1177/1533317509334036.

Donovan, G. H., D. T. Butry, Y. L. Michael, J. P. Prestemon, A. M. Liebhold, D. Gatziolis, and M. Y. Mao. 2013. "The Relationship Between Trees and Human Health: Evidence From the Spread of the Emerald Ash Borer." *American Journal of Preventive Medicine* 44 (2): 139–145. doi:10.1016/j.amepre.2012.09.066.

Donovan, G. H., Y. L. Michael, D. T. Butry, A. D. Sullivan, and J. M. Chase. 2011. "Urban Trees and the Risk of Poor Birth Outcomes." *Health and Place* 17 (1): 390–393. doi:10.1016/j.healthplace.2010.11.004.

Donovan, G. H., and J. P. Prestemon. 2012. "The Effect of Trees on Crime in Portland, Oregon." *Environment and Behavior* 44 (1): 3–30. doi:10.1177/0013916510383238.

Drummond, M. F., M. J. Sculpher, K. Claxton, G. L. Stoddart, and G. W. Torrance. 2015. *Methods for the Economic Evaluation of Health Care Programmes*. 4th ed. New York: Oxford University Press.

Fann, N., A. D. Lamson, S. C. Anenberg, K. Wesson, D. Risley, and B. J. Hub-Bell. 2012. "Estimating the National Public Health Burden Associated With Exposure to Ambient $PM_{2.5}$ and Ozone." *Risk Analysis* 32 (1): 81–95. doi:10.1111/j.1539-6924.2011.01630.x.

Felsten, G. 2009. "Where to Take a Study Break on the College Campus: An Attention Restoration Theory Perspective." *Journal of Environmental Psychology* 29 (1): 160–167. doi:10.1016/j.jenvp.2008.11.006.

Flegal, K. M., M. D. Carroll, C. L. Ogden, and L. R. Curtin. 2010. "Prevalence and Trends in Obesity Among US Adults, 1999–2008." *Jama* 303 (3): 235–241. doi:10.1001/jama.2009.2014.

Flegal, K. M., M. D. Carroll, C. L. Ogden, and C. L. Johnson. 2002. "Prevalence and Trends in Obesity Among US Adults, 1999–2000." *Jama* 288 (14): 1723–1727. doi:10.1001/jama.288.14.1723.

Frumkin, H. 2005. "Health, Equity, and the Built Environment." *Environmental Health Perspectives* 113 (5): A290–A291. doi:10.1289/ehp.113-a290.

Frumkin, H., G. N. Bratman, S. J. Breslow, B. Cochran, P. H. Kahn Jr, J. J. Lawler, P. S. Levin, P. S. Tandon, U. Varanasi, K. L. Wolf., et al. 2017. "Nature Contact and Human Health: A Research Agenda." *Environmental Health Perspectives* 125 (7): 075001. doi:10.1289/EHP1663.

Gascon, M., M. Triguero-Mas, D. Martínez, P. Dadvand, J. Forns, A. Plasència, and M. J. Nieuwenhuijsen. 2015. "Mental Health Benefits of Long-Term Exposure to Residential Green and Blue Spaces: A Systematic Review." *International Journal of Environmental Research and Public Health* 12 (4): 4354–4379. doi:10.3390/ijerph120404354.

Giles-Corti, B., M. H. Broomhall, M. Knuiman, C. Collins, K. Douglas, K. Ng, A. Lange, and R. J. Donovan. 2005. "Increasing Walking: How Important Is Distance to, Attractiveness, and Size of Public Open Space?" *American Journal of Preventive Medicine* 28 (2 Suppl 2): 169–176. doi:10.1016/j.amepre.2004.10.018.

Gonzalez, M. T., and M. Kirkevold. 2014. "Benefits of Sensory Garden and Horticultural Activities in Dementia Care: A Modified Scoping Review." *Journal of Clinical Nursing* 23 (19-20): 2698–2715. doi:10.1111/jocn.12388.

Gonzalez, M. T., T. Hartig, G. G. Patil, E. W. Martinsen, and M. Kirkevold. 2011. "A Prospective Study of Existential Issues in Therapeutic Horticulture for Clinical Depression." *Issues in Mental Health Nursing* 32 (1): 73–81. doi:10.3109/01612840.2010.528168.

Green Infrastructure Northwest. 2011. *Building Natural Value for Sustainable Economic Development: The Green Infrastructure Valuation Toolkit User Guide*. *Technical Report*, Green Infrastructure Northwest. http://www.greeninfrastructurenw.co.uk/resources/Green_Infrastructure_Valuation_Toolkit_UserGuide.pdf.

Griliches, Z. 1977. “Estimating the Returns to Schooling: Some Econometric Problems.” *Econometrica* 45 (1): 1–22. doi:10.2307/1913285.
Hanley, N., M. Ryan, and R. Wright. 2003. “Estimating the Monetary Value of Health Care: Lessons From Environmental Economics.” *Health Economics* 12 (1): 3–16. doi:10.1002/hec.763.
Harnik, P., and B. Welle. 2008. *How Much Value Does the City of Philadelphia Receive From its Park and Recreation System? Technical Report*. The Trust for Public Land. http://cloud.tpl.org/pubs/ccpe_PhilaParkValueReport.pdf.
Harnik, P., and B. Welle. 2009. *Measuring the Economic Value of a City Park System. Technical Report.* The Trust for Public Land. http://cloud.tpl.org/pubs/ccpe-econvalueparks-rpt.pdf.
Hartig, T., R. Mitchell, S. de Vries, and H. Frumkin. 2014. “Nature and Health.” *Annual Review of Public Health* 35 (1): 207. doi:10.1146/annurev-publhealth-032013-182443.
Heaton, P. 2010. *Hidden in Plain Sight: What Cost-of-Crime Research Can Tell Us About Investing in Police*. *Technical Report*. Santa Monica, CA: Rand Corporation.
Horbar, J. D., G. J. Badger, J. H. Carpenter, A. A. Fanaroff, S. K. Ilpatrick, M. LaCorte, R. Phibbs, and R. F. Soll. 2002. “Trends in Mortality and Morbidity for Very Low Birth Weight Infants.” *Pediatrics* 110 (1): 143–151. doi:10.1542/peds.110.1.143.
Houthakker, H. S. 1959. “Education and Income.” The Review of Economics and Statistics 41 (1): 24–28. doi:10.2307/1925454.
Human Rights Service. 2015. *Befolkningsutvikling i Oslo og noen kritiske utfordringer. Technical Report.* Human Rights Services. http://www.rights.no/wp-content/uploads/2015/06/HRS-N-1-2015-Befolkningsutvikling-og-noen-kristiske-utfordringer1.pdf.
Hurd, M. D., P. Martorell, A. Delavande, K. J. Mullen, and K. M. Langa. 2013. “Monetary Costs of Dementia in the United States.” *New England Journal of Medicine* 368 (14): 1326–1334. doi:10.1056/NEJMsa1204629.
Hystad, P., H. W. Davies, L. Frank, J. Van Loon, U. Gehring, L. Tamburic, and M. Brauer. 2014. “Residential Greenness and Birth Outcomes: Evaluating the Influence of Spatially Correlated Built-Environment Factors.” *Environmental Health Perspectives* 122 (10): 1095–1102. doi:10.1289/ehp.1308049.
Johnson, R. C., and R. F. Schoeni. 2011. “Early-Life Origins of Adult Disease: National Longitudinal Population-Based Study of the United States.” *American Journal of Public Health* 101 (12): 2317–2324. doi:10.2105/AJPH.2011.300252.
Kaplan, S. 1995. “The Restorative Benefits of Nature: Toward an Integrative Framework.” *Journal of Environmental Psychology* 15 (3): 169–182. doi:10.1016/0272-4944(95)90001-2.
Keniger, L. E., K. J. Gaston, K. N. Irvine, and R. A. Fuller. 2013. “What Are the Benefits of Interacting With Nature?” *International Journal of Environmental Research and Public Health* 10 (3): 913–935. doi:10.3390/ijerph10030913.
Kuo, F. E., and W. C. Sullivan. 2001. “Environment and Crime in the Inner City: Does Vegetation Reduce Crime?” *Environment and Behavior* 33 (3): 343–367. doi:10.1177/00139160121973025.
Laurent, O., J. Wu, L. Li, and C. Milesi. 2013. “Green Spaces and Pregnancy Outcomes in Southern California.” *Health and Place* 24: 190–195. doi:10.1016/j.healthplace.2013.09.016.
Lee, C.-K., S.-A. Park, J. W. Mjelde, T.-K. Kim, and J.-H. Cho. 2008. “Measuring the Willingness-to-Pay for a Horticulture Therapy Site Using a Contingent Valuation Method.” *HortScience* 43 (6): 1802–1806. doi:10.21273/HORTSCI.43.6.1802.
Lorig, K. R., D. S. Sobel, A. L. Stewart, B. W. Brown, Jr., A. Bandura, P. Ritter, V. M. Gonzalez, D. D. Laurent, and H. R. Holman. 1999. “Evidence Suggesting That a Chronic Disease Self-Management Program Can Improve Health Status While Reducing Hospitalization: A Randomized Trial.” *Medical Care* 37 (1): 5–14. doi:10.1097/00005650-199901000-00003.
Luengo-Fernandez, R., J. Leal, A. Gray, P. Sophie, and R. Mike. 2006. “Cost of Cardiovascular Diseases in the United Kingdom.” *Heart* 92 (10): 1384–1389. doi:10.1136/hrt.2005.072173.
Maas, J., R. A. Verheij, P. Spreeuwenberg, and P. P. Groenewegen. 2008. “Physical Activity as a Possible Mechanism Behind the Relationship Between Green Space and Health: A Multilevel Analysis.” *BMC Public Health* 8: 206. doi:10.1186/1471-2458-8-206.
Markevych, I., E. Fuertes, C. M. T. Tiesler, M. Birk, C.-P. Bauer, S. Koletz-Ko, A. von Berg, D. Berdel, and J. Heinrich. 2014. “Surrounding Greenness and Birth Weight: Results From

the GINIplus and LISAplus Birth Cohorts in Munich." *Health and Place* 26: 39–46. doi:10.1016/j.healthplace.2013.12.001.

Mather, J. A., D. Nemecek, and K. Oliver. 1997. "The Effect of a Walled Garden on Behavior of Individuals With Alzheimer's." *American Journal of Alzheimer's Disease* 12 (6): 252–257. doi:10.1177/153331759701200603.

Matsuoka, R. H. 2010. "Student Performance and High School Landscapes: Examining the Links." *Landscape and Urban Planning* 97 (4): 273–282. doi:10.1016/j.landurbplan.2010.06.011.

McAuley, L., B. Pham, P. Tugwell, and D. Moher. 2000. "Does the Inclusion of Grey Literature Influence Estimates of Intervention Effectiveness Reported in Meta-Analyses?" The Lancet 356 (9237): 1228–1231. doi:10.1016/S0140-6736(00)02786-0.

McCann, I. L., and L. A. Pearlman. 1990. "Vicarious Traumatization: A Framework for Understanding the Psychological Effects of Working With Victims." *Journal of Traumatic Stress* 3 (1): 131–149. doi:10.1007/BF00975140.

McCarney, R., J. Warner, S. Iliffe, R. Van Haselen, M. Griffin, and P. Fisher. 2007. "The Hawthorne Effect: A Randomised, Controlled Trial." *BMC Medical Research Methodology* 7: 30. https://bmcmedresmethodol.biomedcentral.com/articles/10.1186/1471-2288-7-30

McPherson, E. G. 2010. "Tools for Valuing Tree and Park Services." *Western Arborist* 2010: 58–63.

Miller, T. R., M. A. Cohen, and B. Wiersema. 1996. *Victim Costs and Consequences: A New Look. Technical Report.* Washington, DC: US Department of Justice, Office of Justice Programs, National Institute of Justice. https://www.ncjrs.gov/pdffiles/victcost.pdf.

Mitchell, R., and F. Popham. 2008. "Effect of Exposure to Natural Environment on Health Inequalities: An Observational Population Study." *The Lancet* 372 (9650): 1655–1660. doi:10.1016/S0140-6736(08)61689-X.

Mitchell, R. C., and R. T. Carson. 1989. *Using Surveys to Value Public Goods: The Contingent Valuation Method*. New York: Resources for the Future.

Murphy, J. 1993. "A Degree of Waste: The Economic Benefits of Educational Expansion." *Oxford Review of Education* 19 (1): 9–31. doi:10.1080/0305498930190102.

Murphy, P., Y. Miyazaki, M. B. Detweiler, and K. Y. Kim. 2010. "Longitudinal Analysis of Differential Effects on Agitation of a Therapeutic Wander Garden for Dementia Patients Based on Ambulation Ability." *Dementia* 9 (3): 355–373. doi:10.1177/1471301210375336.

Ng, C. F. 2000. "Effects of Building Construction Noise on Residents: A Quasi-Experiment." *Journal of Environmental Psychology* 20 (4): 375–385. doi:10.1006/jevp.2000.0177.

Ng, T. W. H., and D. C. Feldman. 2009. "How Broadly Does Education Contribute to Job Performance?" *Personnel Psychology* 62 (1): 89–134. doi:10.1111/j.1744-6570.2008.01130.x.

Norwegian University of Life Sciences. 2016. "Portal for Nature and Human Health Research." https://www.nmbu.no/en/nature-and-health.

Nowak, D. J., D. E. Crane, and J. C. Stevens. 2006. "Air Pollution Removal by Urban Trees and Shrubs in the United States." *Urban Forestry and Urban Greening* 4 (3): 115–123. doi:10.1016/j.ufug.2006.01.007.

Nowak, D. J., S. Hirabayashi, A. Bodine, and E. Greenfield. 2014. "Tree and Forest Effects on Air Quality and Human Health in the United States." *Environmental Pollution* 193: 119–129. doi:10.1016/j.envpol.2014.05.028.

Nowak, D. J., S. Hirabayashi, A. Bodine, and R. Hoehn. 2013. "Modeled $PM_{2.5}$ Removal by Trees in Ten US Cities and Associated Health Effects." *Environmental Pollution* 178: 395–402. doi:10.1016/j.envpol.2013.03.050.

Ogden, C. L., M. D. Carroll, C. D. Fryar, and K. M. Flegal. 2015. "Prevalence of Obesity Among Adults and Youth: United States, 2011–2014." *NCHS Data Brief* 219: 1–8.

Paneth, N. S. 1995. "The Problem of Low Birth Weight." *The Future of Children* 5 (1): 19–34. doi:10.2307/1602505.

Pelham, W. E., E. M. Foster, and J. A. Robb. 2007. "The Economic Impact of Attention-Deficit/Hyperactivity Disorder in Children and Adolescents." *Ambulatory Pediatrics* 7 (1): 121–131. doi:10.1016/j.ambp.2006.08.002.

Polanczyk, G., Mı́ S. de Lima, B. L. Horta, J. Biederman, and L. A. Rohde. 2007. "The Worldwide Prevalence of ADHD: A Systematic Review and Metaregression Analysis." *American Journal of Psychiatry* 164 (6): 942–948. doi:10.1176/ajp.2007.164.6.942.

Pope III, C. A., R. T. Burnett, M. J. Thun, E. E. Calle, D. Krewski, K. Ito, and G. D. Thurston. 2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution." *Jama* 287 (9): 1132–1141. doi:10.1001/jama.287.9.1132.

Pope III, C. A., and D. W. Dockery. 2006. "Health Effects of Fine Particulate Air Pollution: Lines That Connect." *Journal of the Air and Waste Management Association* 56 (6): 709–742. doi:10.1080/10473289.2006.10464485.

Popkin, B. M., S. Kim, E. R. Rusev, S. Du, and C. Zizza. 2006. "Measuring the Full Economic Costs of Diet, Physical Activity and Obesity-Related Chronic Diseases." *Obesity Reviews* 7 (3): 271–293. doi:10.1111/j.1467-789X.2006.00230.x.

Powe, N. A., and K. G. Willis. 2004. "Mortality and Morbidity Benefits of Air Pollution (SO_2 and PM_{10}) Absorption Attributable to Woodland in Britain." *Journal of Environmental Management* 70 (2): 119–128. http://www.sciencedirect.com/science/article/pii/S0301479703002007. doi:10.1016/j.jenvman.2003.11.003.

Pratt, M., C. A. Macera, and G. Wang. 2000. "Higher Direct Medical Costs Associated With Physical Inactivity." *The Physician and Sportsmedicine* 28 (10): 63–70. doi:10.3810/psm.2000.10.1237.

Prentice, A. M. 2006. "The Emerging Epidemic of Obesity in Developing Countries." *International Journal of Epidemiology* 35 (1): 93–99. doi:10.1093/ije/dyi272.

Prince, M., A. Wimo, M. Guerchet, G.-C. Ali, Y.-T. Wu, and M. Prina. 2015. *World Alzheimer Report 2015: The Global Impact of Dementia. An Analysis of Prevalence, Incidence, Cost and Trends*. *Technical Report*. Alzheimer's Disease International. https://www.alz.co.uk/research/WorldAlzheimerReport2015.pdf.

Richardson, E. A., and R. Mitchell. 2010. "Gender Differences in Relationships Between Urban Green Space and Health in the United Kingdom." *Social Science and Medicine* 71 (3): 568–575. doi:10.1016/j.socscimed.2010.04.015.

Russell, R. B., N. S. Green, C. A. Steiner, S. Meikle, J. L. Howse, K. Poschman, T. Dias, et al. 2007. "Cost of Hospitalization for Preterm and Low Birth Weight Infants in the United States." *Pediatrics* 120 (1): e1–e9. doi:10.1542/peds.2006-2386.

Scarborough, P., K., Wickramasinghe, P. Bhatnagar, and M. Rayner. 2011. *Trends in Coronary Heart Disease, 1961–2011*. London: British Heart Foundation. https://www.bhf.org.uk/~/media/files/research/heart-statistics/bhf-trends-in-coronary-heart-disease.pdf.

Seaton, A., D. Godden, W. MacNee, and K. Donaldson. 1995. "Particulate Air Pollution and Acute Health Effects." The Lancet 345 (8943): 176–178. doi:10.1016/S0140-6736(95)90173-6.

Shibata, S., and N. Suzuki. 2001. "Effects of Indoor Foliage Plants on Subjects' Recovery From Mental Fatigue." *North American Journal of Psychology* 3 (3): 385–395.

Taylor, A. F., and F. E. Kuo. 2009. "Children With Attention Deficits Concentrate Better After Walk in the Park." *Journal of Attention Disorders* 12 (5): 402–409. doi:10.1177/1087054708323000.

Taylor, A. F., F. E. Kuo, and W. C. Sullivan. 2001. "Coping With ADD the Surprising Connection to Green Play Settings." *Environment and Behavior* 33 (1): 54–77. doi:10.1177/00139160121972864.

Taylor, A. F., and F. E. M. Kuo. 2011. "Could Exposure to Everyday Green Spaces Help Treat ADHD? Evidence From Children's Play Settings." *Applied Psychology: Health and Well-Being* 3 (3): 281–303. doi:10.1111/j.1758-0854.2011.01052.x.

Tennessen, C. M., and B. Cimprich. 1995. "Views to Nature: Effects on Attention." *Journal of Environmental Psychology* 15 (1): 77–85. doi:10.1016/0272-4944(95)90016-0.

The GBD 2015 Obesity Collaborators. 2017. "Health Effects of Overweight and Obesity in 195 Countries over 25 Years." *New England Journal of Medicine* 377: 13–27.

Troy, A., J. Morgan Grove, and J. O'Neil-Dunne. 2012. "The Relationship Between Tree Canopy and Crime Rates Across an Urban–Rural Gradient in the Greater Baltimore Region." *Landscape and Urban Planning* 106 (3): 262–270. doi:10.1016/j.landurbplan.2012.03.010.

Ulrich, R. 1984. "View Through a Window May Influence Recovery." *Science* 224 (4647): 420–421. doi:10.1126/science.6143402.

United Nations. 2014. *World Urbanization Prospects: The 2014 Revision. Technical Report.* Population Division, United Nations. http://esa.un.org/unpd/wup/Publications/Files/WUP2014-Highlights.pdf.

University of Washington. 2014. "Green Cities: Good Health." http://depts.washington.edu/hhwb/.

US Environmental Protection Agency. 2016. "Environmental Benefits Mapping and Analysis Program Community Edition (BenMAP-CE)." https://www.epa.gov/benmap.
van den Berg, A. E., and C. G. van den Berg. 2011. "A Comparison of Children With ADHD in a Natural and Built Setting" *Child: Care, Health and Development* 37 (3): 430–439. doi: 10.1111/j.1365-2214.2010.01172.x.
Visser, S. N., S. J. Blumberg, M. L. Danielson, R. H. Bitsko, and M. D. Kogan. 2013. "State-Based and Demographic Variation in Parent Reported Medication Rates for Attention-Deficit/Hyperactivity Disorder, 2007–2008." *Preventing Chronic Disease* 10. doi:10.5888/pcd9.120073.
Wang, G., and D. R. Brown. 2004. "Impact of Physical Activity on Medical Expenditures Among Adults Downhearted and Blue." *American Journal of Health Behavior* 28 (3): 208–217. doi:10.5993/AJHB.28.3.2.
Wang, G., C. A. Macera, B. Scudder-Soucie, T. Schmid, M. Pratt, and D. Buchner. 2005. "A Cost-Benefit Analysis of Physical Activity Using Bike/Pedestrian Trails." *Health Promotion Practice* 6 (2): 174–179. doi:10.1177/1524839903260687.
Whall, A. L., M. E. Black, C. J. Groh, D. J. Yankou, B. J. Kupferschmid, and N. L. Foster. 1997. "The Effect of Natural Environments Upon Agitation and Aggression in Late Stage Dementia Patients." *American Journal of Alzheimer's Disease* 12 (5): 216–220. doi:10.1177/153331759701200506.
Willis, K., and B. Crabtree. 2011. "Measuring Health Benefits of Green Space in Economic Terms." In *Forests, Trees and Human Health*, edited by K. Nilsson, M. Sangster, C. Gallos, T. Hartig, S. de Vries, K. Seeland and J. Schipperijn, 375–402. Dordrecht: Springer.
Wilson, E. O. 1984. *Biophilia*. Cambridge, MA: Harvard University Press.
Withrow, D., and D. A. Alter. 2011. "The Economic Burden of Obesity Worldwide: A Systematic Review of the Direct Costs of Obesity." *Obesity Reviews* 12 (2): 131–141. doi: 10.1111/j.1467-789X.2009.00712.x.
Wolf, K. L., M. K. Measells, S. C. Grado, and A. S. T. Robbins. 2015. "Economic Values of Metro Nature Health Benefits: A Life Course Approach." *Urban Forestry and Urban Greening* 14 (3): 694–701. doi:10.1016/j.ufug.2015.06.009.
Wolf, K. L., and A. S. T. Robbins. 2015. "Metro Nature, Environmental Health, and Economic Value." *Environmental Health Perspectives* 123 (5): 390–398. doi:10.1289/ehp.1408216.
Wolfe, M. K., and J. Mennis. 2012. "Does Vegetation Encourage or Suppress Urban Crime? Evidence From Philadelphia, PA." *Landscape and Urban Planning* 108 (2–4): 112–122. doi: 10.1016/j.landurbplan.2012.08.006.