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Green Infrastructure and Health

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Abstract

The health benefits of green space are well known, but the health effects of green infrastructure less so. Green infrastructure goes well beyond the presence of green space and refers more to a strategically planned network of natural and seminatural areas, with other environmental features designed and managed to deliver a wide range of ecosystem services and possibly to improve human health. In this narrative review, we found that small green infrastructure, such as green roofs and walls, has the potential to mitigate urban flooding, attenuate indoor temperatures and heat islands, improve air quality, and muffle noise, among other benefits, but these effects have not been linked directly to health. Larger green infrastructure has been associated with reduced temperatures, air pollution, and crimes and violence, but less so with health, although there some evidence suggests that it may be beneficial for health (e.g., good health, decreased mortality). Finally, parks and street trees show many health benefits, but it is not clear if they can always be considered green infrastructure.



INTRODUCTION

Green Space

Exposure to green spaces has been associated with, among others, improved perceived general health, better pregnancy outcomes (e.g., birth weight), enhanced brain development in children, better cognitive function in adults, improved mental health, lower risk of a number of chronic diseases (e.g., diabetes and cardiovascular conditions), and reduced premature mortality (15, 17, 29, 33, 35, 37, 48). The mechanisms underlying the health effects of green spaces are yet to be fully established, but reducing stress/restoring cognition; mitigating exposure to air pollution, noise, and heat; enhancing social cohesion/interactions; increasing physical activity; and enriching micro- and macrobiodiversity and environmental microbial input are suggested by-products (29, 33).

The US Environmental Protection Agency (EPA) has defined green spaces as the “land that is partly or completely covered with grass, trees, shrubs, or other vegetation,” which includes “parks, community gardens, and cemeteries” (40). The availability of green spaces in urban areas could be a function of several factors in which the climate and urban planning play key roles. For example, a survey of 386 European cities revealed that while there was a general north–south decreasing gradient in the percentage of green space coverage within these cities, there were still greener cities in the south and less green cities in the north (13). The amount of green space available to people in cities around the world also varies considerably from, for example, 1.9 m² per person in Buenos Aires, Argentina, to 52.0 m² in Curitiba, Brazil.

Green Infrastructure

The focus of this review is on green infrastructure, which is more than just a green space. However, the definitions of what a green infrastructure is vary considerably. A widely cited definition of green infrastructure is “an interconnected network of greenspace that conserves natural ecosystem values and functions and provides associated benefits to human populations” (3). But neighborhood and national parks, parkways, forests, community gardens, and the myriad other forms of conserved private and public components of natural landscape (green spaces), taken together and considered as a system, could also be regarded as green infrastructure (8). In urban environments, this infrastructure can include not only landscape patches and corridors but also other representations of nature (e.g., green roofs, street trees) that provide health-supporting ecosystem services without requiring the same level of consumption of finite urban land.

The European Environment Agency states that green infrastructure comprises a wide range of environmental features that operate at different scales and form part of an interconnected ecological network (11). At the same time, these features must be multifunctional; they must be more than simply a green space. For example, a single tree in the middle of a city or an isolated patch of uniform grass is unlikely to qualify as green infrastructure unless it also contributes to key local environmental values. Nevertheless, these spatial features may operate at different scales, from small linear features to entire functional ecosystems, and may contribute to green infrastructure in urban, peri-urban, and rural areas and both inside and outside protected areas (11).

The European Union (12) states that green infrastructure is a strategically planned network of natural and seminatural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation, and climate mitigation and adaptation. This network of green (land) and blue (water) spaces can improve environmental conditions and therefore citizens' health and quality of life (12).

The US EPA (41) appears to have a more limited definition and refers to green infrastructure as a cost-effective, resilient approach to managing wet weather impacts that provides many

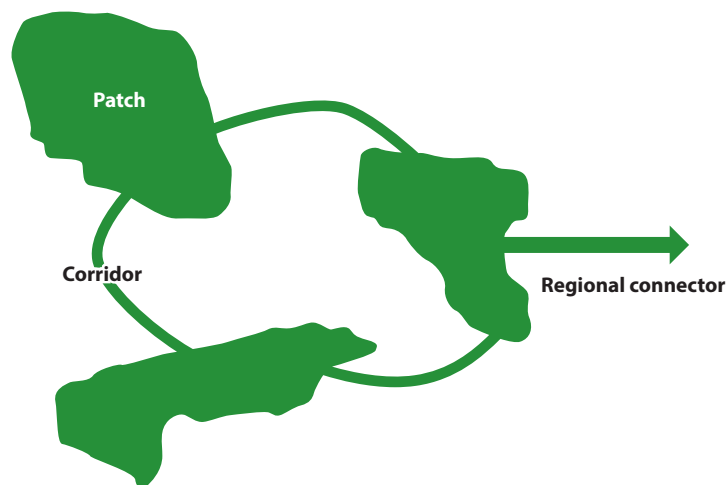


Figure 1

A drawing of green infrastructure. Figure adapted with permission from Coutts & Hahn (8).

community benefits. While single-purpose gray stormwater infrastructure—conventional piped drainage and water treatment systems—is designed to move urban stormwater away from the built environment, green infrastructure reduces and treats stormwater at its source while delivering environmental, social, and economic benefits (41).

Green Infrastructure and Health

A number of reviews have been written on citywide or large green infrastructure and health. Coutts & Hahn (8) published a review on green infrastructure, ecosystem services, and human health, with a particular focus on ecosystems, and they have also provided a figure of what a green infrastructure can look like (**Figure 1**). Venkataramanan et al. (44) conducted a multidisciplinary systematic review of peer-reviewed and gray literature on the effects of green infrastructure for storm water and flood management on individuals', households', and communities' (a) physical health, (b) mental health, (c) economic well-being, and (d) flood resilience and social acceptance of green infrastructure. They found that no studies connected green infrastructure for storm water and flood management to mental or physical health outcomes (**Figure 2**). Suppakittpaisarn et al. (38) reviewed familiar types of green infrastructure, such as trees and green spaces, and found that they were beneficial for health and behavior. They suggested that for some of the specific categories of green infrastructure, such as trees, considerable evidence exists on the impacts on human health. For other categories, such as rain gardens, green roofs, or biodiverse plantings, however, there was scant evidence of a health impact. However, it was unclear if they were addressing green space or green infrastructure. Green roofs and walls are considered green infrastructure but are more local.

The aim of this article is to provide a review of the studies on green infrastructure and health. One of the challenges in such a review is in defining green infrastructure, as this term goes beyond the simple presence of green space. Because it is difficult to tell from the papers whether a green space is (part of) a green infrastructure, we restrict ourselves primarily to papers that use the term green infrastructure, with some additional studies on trees, and address the limitations of doing so in the discussion.

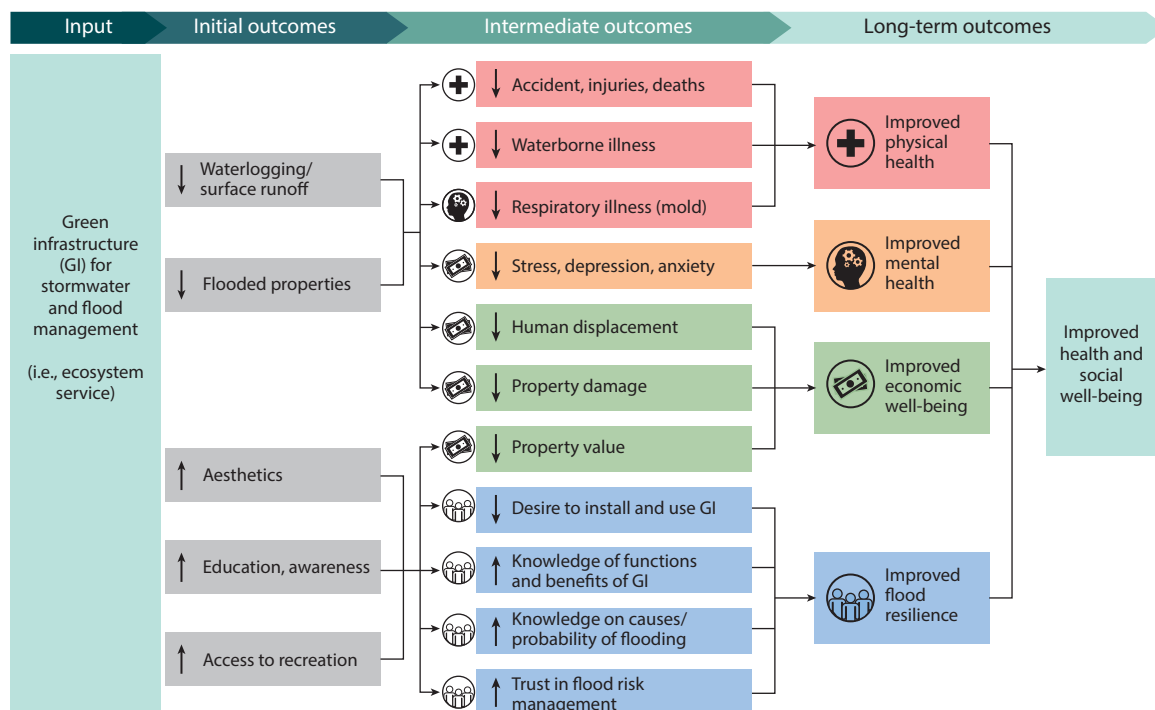


Figure 2

Hypothesized causal pathways between green infrastructure (GI) projects and their initial, intermediate, and long-term outcomes for human health and social well-being. Figure adapted with permission from Venkataramanan et al. (44).

REVIEWING THE LITERATURE

We conducted a review of the existing reviews of green infrastructure and health and searched in PubMed and Google scholar for the keyword “green infrastructure OR Green space infrastructure OR greenspace infrastructure” AND health. After the initial review, we added “street trees” and “parks” to the search because they did not come up much in the initial search but could be considered green infrastructure if they form part of a network. The review is not systematic, but rather narrative, including much of the relevant literature but also outlining the particular issues of the research topic. We included studies that used the term green infrastructure or what has been referred to by others as green infrastructure (e.g., green walls and roofs).

RESULTS

Green Roofs and Walls

A number of studies have evaluated the effects of green roofs and walls, but these studies measured mostly perceptions and risk factors for health and not health as such (18, 23, 24, 47). Green roofs and walls have the potential to mitigate urban flooding, attenuate indoor temperatures and heat islands, improve air quality, and muffle noise, among other benefits, but the evidence is not clear cut (7). Wong & Jim (51) suggested that green roofs harbor fewer mosquitoes and therefore reduce the transmission of vector-borne disease by mosquitoes.

Green Infrastructure

Hewitt et al. (16) suggested in their review that the introduction of green infrastructure is seen as a win-win solution to urban air pollution, reducing ground-level concentrations without imposing restrictions on traffic and other polluting activities. Air pollution is an important risk factor for health. The impact of green infrastructure on air quality is highly context dependent; models suggest that green infrastructure can improve urban air quality in some situations but may be ineffective or even detrimental in others. Hewitt et al. set out a novel conceptual framework to explain how and where green infrastructure can improve air quality and offered six specific policy interventions, underpinned by research, that will always allow green infrastructure to improve air quality.

Dennis et al. (10) employed a green infrastructure approach combining a high-resolution spatial data set of land cover and function with area-level demographic, socioeconomic data and chronic morbidity. Green infrastructure attributes showed associations with health in all sociodemographic contexts, even where associations between health and overall green cover were non-significant. Associations varied by urban sociodemographic group. Quality of green infrastructure was a significant predictor of good health in areas of low income and low green infrastructure cover. Proximity of publicly accessible green infrastructure was also significant. Dennis et al. concluded that the influence of urban green infrastructure on population health is mediated by green-space form, quantity, accessibility, and vegetation health. People in urban neighborhoods that are characterized by lower-income and older-age populations were disproportionately healthy if their neighborhoods contained accessible, good-quality public green space.

Venter et al. (45) hypothesized that heat-related diagnoses for heat-sensitive citizens (age 75+) in Oslo were correlated with monthly air temperatures and that green infrastructure such as tree canopy cover reduced extreme land surface temperatures and thus reduced health risk from heat exposure. Land surface temperatures were negatively correlated with tree canopy cover ($R^2 = 0.45$) and vegetation greenness ($R^2 = 0.41$). The authors found that monthly air temperatures were significantly correlated with the number of skin-related diagnoses at the city level, but temperatures were unrelated to diagnoses under circulatory, nervous system, or general categories. In a scenario in which each city tree was replaced by the most common nontree cover in its neighborhood, this study suggested that the area of Oslo exceeding a 30°C health risk threshold during the summer would increase from 23% to 29%. Combining modeling results with populations at risk at the census tract level, Venter et al. estimated that each tree in the city mitigated the additional heat exposure of one heat-sensitive person by one day.

Branas et al. (5) conducted a decade-long difference-in-differences analysis of the impact of a vacant lot greening program in Philadelphia, Pennsylvania, on health and safety outcomes. Before and after outcome differences among treated vacant lots were compared with matched groups of control vacant lots that were eligible but did not receive treatment. Across 4 sections of Philadelphia, 4,436 vacant lots totaling more than 7.8 million square feet (about 725,000 m²) were greened from 1999 to 2008. The authors showed that vacant lot greening was associated with consistent reductions in gun assaults across all 4 sections of the city ($P < 0.001$) and consistent reductions in vandalism in 1 section of the city ($P < 0.001$). They also showed that vacant lot greening was associated with residents' reporting less stress and more exercise in select sections of the city ($P < 0.01$).

Kondo et al. (20) investigated the health and safety effects of urban green storm water infrastructure installments. The authors conducted a difference-in-differences analysis of the effects of green storm water infrastructure installments on health (e.g., blood pressure, cholesterol and stress levels) and safety (e.g., felonies, nuisance and property crimes, narcotics crimes) outcomes from



2000 to 2012 in Philadelphia, Pennsylvania. They used mixed-effects regression models to compare differences in pre- and post-treatment measures of outcomes for treatment sites ($n = 52$) and randomly chosen matched control sites ($n = 186$) within multiple geographic extents surrounding green storm water infrastructure sites. They showed consistent and statistically significant reductions in narcotics possession (18–27% less) within sixteenth-mile, quarter-mile, half-mile ($P < 0.001$), and eighth-mile ($P < 0.01$) distances from treatment sites and at the census tract level ($P < 0.01$). Narcotics manufacture and burglaries were also significantly reduced at multiple scales. Nonsignificant reductions in homicides, assaults, thefts, public drunkenness, and narcotics sales were associated with green infrastructure installation in at least 1 geographic extent.

Kondo et al. (21) conducted a study of the Lots of Green program to reuse vacant land in 2010 and its association with crime. After adjustment for various sociodemographic factors, the authors demonstrated statistically significant reductions in all crime classes for at least one lot treatment type. They found the most consistent significant reductions in burglaries around stabilization lots and reductions in assaults around community reuse lots. Spillover crime reduction effects were found in contiguous areas around newly treated lots. Significant increases in motor vehicle thefts around both types of lots were also found after they had been greened. They suggested that community-initiated vacant lot greening may have a greater impact on reducing more serious, violent crimes.

Burley (6) studied to what extent Portland's green infrastructure initiative reduced neighborhood violence by increasing the availability of new trees to residents of underserved communities as a modality for green infrastructure intervention. They determined whether an increase in new street trees resulted in reduced violent crime counts in the years following the planting of the trees. Results indicated that there was a strong negative correlation between the number of trees planted and violent crimes in the years following the planting of trees, net of neighborhood covariates. This effect was especially pronounced in neighborhoods with lower median household income. These findings suggest that the inclusion of new street trees in underserved neighborhoods may be one solution to the endemic of violence in such neighborhoods.

URBAN TREES

A couple of recent reviews suggest that urban trees can deliver multiple environmental, economic, social, and health services and functions in cities, including a reduction in air pollution, ultraviolet radiation, and heat exposure, and can improve attention restoration, mental health, stress reduction, birth outcomes, immune response, active living, weight status, and cardiovascular disease and function (36, 49). The question though is whether the trees were green infrastructure, i.e., they form part of a larger system; this determination was generally not clear in the studies, which makes them more difficult to interpret.

Street Trees and Health

A number of studies were conducted around street trees and health in New York, United States. Lovasi et al. (27) found that an increase in tree density of 1 standard deviation [(SD) 343 trees per km²] was associated with a lower prevalence of asthma [relative risk (RR), 0.71 per SD of tree density; 95% confidence interval (CI) (0.64–0.79)] but not with hospitalizations for asthma [RR = 0.89 per SD of tree density; 95% CI (0.75–1.06)] in children in New York. But children living in areas with more street trees were more physically active, and those living in areas with more park access had smaller skinfolds (26). A higher density of street trees (at the 75th versus 25th percentile) was associated with a 12% lower prevalence of obesity [95% CI for the prevalence ratio (PR):

0.79–0.99] (28). Abelt & McLafferty (1) found a significant inverse association between nearby street trees and the odds of preterm birth for all women. Reid et al. (34) found higher reporting of “very good” or “excellent” health for respondents with the highest, compared with the lowest, quartiles of trees [RR = 1.23, 95% CI (1.06–1.44)] in adults. Findings imply that higher exposure to vegetation, particularly trees outside of parks, may be associated with better health.

In Toronto, Canada, Kardan et al. (19) found that having 10 more trees in a city block, on average, improved health perception in ways comparable to an increase in annual personal income of \$10,000 and moving to a neighborhood with a \$10,000 higher median income or being 7 years younger. They also found that having 11 more trees in a city block, on average, decreased cardiometabolic conditions in ways comparable to an increase in annual personal income of \$20,000 and moving to a neighborhood with a \$20,000 higher median income or being 1.4 years younger. Tsai et al. (39) found that street tree cover was consistently protective for healthy weight status. Every 10% increase in street tree cover within 2,000 m was associated with 18% lower odds of being overweight or obese [adjusted odds ratio (AOR) = 0.82, 95% CI (0.81–0.84) in Phoenix; 0.82, 95% CI (0.81–0.83) in Portland]. When compared with residents with less than 10% street tree cover within 2,000 m, those with greater than 10% tree cover had at least 13% [AOR = 0.87 for Portland, 95% CI (0.81–0.92)] lower odds of being overweight or obese.

In São Paulo, Brazil, Moreira et al. (31) found that the number of street trees in the regional governments (OR = 0.937) and the number of parks within 1 km (OR = 0.876) were inversely associated with a diagnosis of hypertension. Wang et al. (46) found that trees were positively associated with psychological well-being in Guangzhou, China.

Parks and Health

Dadvand et al. (9) found that residential proximity to forests was associated with 39% and 25% lower relative prevalence of excessive screen time and overweight/obesity, respectively, but was not associated with current asthma in children in Sabadell, Spain. In contrast, living close to parks was associated with a 60% higher relative prevalence of current asthma but had only weak negative associations with obesity/overweight or excessive screen time. Andrusaityte et al. (2) found that every additional hour of time spent in parks was associated with decreased sedentary behavior and a lower risk of poor health, and less time spent in a park was associated with poorer general and mental health among 4–6-year-old children in Kaunas, Lithuania.

A number of studies have been conducted around park visits and mental health. Bojorquez & Ojeda-Revah (4) found that public parks improved mental health and suggest that this effect could be more important at some stages in the life course for women. Urban public park coverage in the 400-m buffer had an inverse association with depression score that was moderated by age (significant only for younger participants), with no evidence of mediation. Park coverage in the 800-m buffer also had an inverse association with depression score, moderated by age and occupation (significant for younger participants and homemakers), and a mediated association was observed. Wood et al. (50) found that positive mental health was associated not only with parks with a nature focus but also with green spaces characterized by recreational and sporting activity, whereas Min et al. (30) reported that those living in regions with the lowest number of parks and green areas (fourth quartile) had 16–27% greater odds for depression and suicidal indicators. Yigitcanlar et al. (52) showed that the frequency of park visits was negatively associated with downward emotional state and positively associated with contentedness with life. Grilli et al. (14) showed that higher levels of visitation to green spaces were related to better health. Moreover, the attribute preference exploration suggested that number of visits were likely to increase with the provision of specific green space attributes, particularly visitor facilities.



Kondo et al. (22) conducted a green space health impact assessment with adult residents to estimate the annual premature mortality burden associated with projected changes in tree canopy cover in Philadelphia between 2014 and 2025. Using up-to-date exposure–response functions, the authors calculated the number of preventable annual premature deaths citywide, and for areas of lower versus higher socioeconomic status, for each of three tree canopy scenarios: low, moderate, and ambitious. The ambitious scenario reflected the city’s goal of 30% tree canopy cover in each of the city’s neighborhoods, and low and moderate scenarios were based on the varying levels of plantable space across neighborhoods. They estimated that 403 [95% CI (298–618)] premature deaths overall, including 244 [95% CI (180–373)] premature deaths in areas of lower socioeconomic status, could be prevented annually in Philadelphia if the city were able to meet its goal of increasing tree canopy cover to 30%.

DISCUSSION

Green space has many health benefits, but the health effects of green infrastructure are still largely unknown owing to a lack of studies. Green infrastructure such as green roofs and walls have the potential to mitigate urban flooding, attenuate indoor temperatures and heat islands, improve air quality, and muffle noise, among other benefits, but it has not been linked to health. Larger green infrastructure has been associated with reduced temperatures, air pollution, and crimes and violence, but less so with health, although some data suggest that it may be beneficial for health (e.g., good health, mortality). Furthermore, urban trees can provide a reduction in air pollution, ultraviolet radiation, and heat exposure and can improve attention restoration, mental health, stress reduction, birth outcomes, immune response, active living, weight status, and cardiovascular disease and function. Overall, what counts as a green space and as a green infrastructure is unclear, which limits the interpretation of studies.

In this review, we were guided by the authors of the primary literature in their terminology for green space and green infrastructure because it is almost impossible to determine whether something is a large green space or a green infrastructure in the epidemiological papers. Trees are often considered as the main green infrastructure in a city, but it is often unclear if we are talking about a few trees together on a network or green infrastructure that includes trees. The definition given to green infrastructure by, for example, the European Environment Agency (11) and European Union (12) refers to networks and infrastructure that is strategically planned. The greening of vacant lots or the increase in tree cover in cities such as Philadelphia can be regarded as strategically planned green infrastructure, in part if they are studied as such. But for many other health studies, it is unclear whether investigators studied just some green space or a network that may count as a green infrastructure.

For smaller green infrastructures such as green roofs and walls, this designation is easier to determine because they are distinct; however, studies on health effects are lacking. Rain gardens, green roofs, green walls, and bioswales have various looks, sizes, plant species, and arrangements, which are not always well described. In addition, to study the health benefits of these various types of green infrastructure, their components must be recognized as independent variables, which is a challenging process. Furthermore, it is often relatively small, affecting relatively few people, and therefore health effects are difficult to measure.

What is clear from our literature review is a sheer lack of studies on the health effects of green infrastructure. Even with less strict criteria for inclusion, there will not be a large evidence base. Therefore, increasing the evidence base on green infrastructures and health, including the provision of useful definitions for what is included in green infrastructure as well as a good description in the studies, is urgently needed. Future studies should investigate the health effects of quality,



type, dose, frequency, and duration of exposure to green infrastructure. It is likely that, as is the case for green space, green infrastructure has many health benefits (15, 17, 29, 33, 35, 37, 48). Of particular interest are well-conducted studies that evaluate the introduction of new green infrastructures, so-called intervention or quasi-experimental studies.

For example, many cities are now greening and are introducing networks of green space that add to biodiversity in those areas and connect various parts of the city. They are often included under nature-based solutions initiatives. Whether this network approach has additional health benefits compared with patches of green space or tree-lined streets around the city is unclear. The introduction of these new green networks provides a useful opportunity for study, particularly if they also account for inequalities that exist in cities (22). However, this approach requires very large studies and significant resources.

These new innovative urban policies, interventions, and actions can also improve sustainability, livability, and public health. Cities need land-use changes and greening as well as vision, citizen involvement, collaboration, leadership and investment, and systemic multidisciplinary approaches (32). Systemic multidisciplinary approaches are essential to bring together a range of different disciplines, including urban planners, environmentalists, ecologists and ecosystem professionals, epidemiologists, psychologists, statisticians, and economists. More sustainable (i.e., carbon neutral and biodiversity rich) and livable cities will create many benefits for both human health and the planet. Adding some patches of green space are not sufficient; we need proper networks of green infrastructure to realize these benefits.

However, green and blue infrastructures also have the potential to create unexpected, undesirable, side effects for health, as reported by Löhmus & Balbus (25). Efforts to increase the green infrastructure in urban environments may promote the introduction and survival of vector or host organisms for infectious pathogens, with a resulting spread of a variety of diseases. In addition, more green connectivity in urban areas may potentiate the role of rats and ticks in the spread of infectious diseases. Bodies of water and wetlands may provide habitats for mosquitoes and toxic algal blooms. Increasing urban green space may also adversely affect citizens who are allergic to pollen. Incorporating public health awareness and interventions into urban planning at the earliest stages can help insure that green and blue infrastructures achieve their full potential for health promotion (25).

Green infrastructures are essential and should be implemented where possible. Many tools are available to help. Van Oijstaeijen et al. (43) reviewed the evaluation tools to support investment decisions on urban green infrastructure, and they found that most tools were not designed for the peculiarities of the urban context. Several elements contributed to hampering the uptake of green infrastructure valuation tools. The authors found that the limited effort in the economic case for green infrastructure remains a burden. Few tools have taken into consideration the peculiarities of cities: urban ecosystem (dis)services, multi-scalability, life span assessments of cobenefits, and the importance of social benefits. The authors suggested that resources be developed by the scientific community in partnership with local authorities in order to create tool kits that are specific to the needs identified during the urban planning process.

Finally, green investments and solutions are often insufficiently applied because of potential obstacles, such as cognitive bias, poor translation of science into policy, academic traditions, and economic constraints (42). Van den Bosch & Nieuwenhuijsen (42) concluded that the probability of natural spaces producing net benefits to both health and urban ecosystems is high and that increased efforts are required to translate this knowledge into policy and practice, especially in developing parts of the world.

In conclusion, green space has many health benefits, but the health effects of green infrastructure are still largely unknown owing to a lack of studies. Further studies are urgently needed to



study the (additional) health benefits of green infrastructure on health. Systemic multidisciplinary approaches are essential to get the best benefits.

DISCLOSURE STATEMENT

The author is not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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